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Innovation and imitation in a vertically differentiated model—R&D costs as a prerequisite to patentability

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Abstract: By incorporating an increasing R&D cost function into a vertically differentiated model, we investigate the optimal behaviors of an innovator and an imitator as well as the effectiveness of patent protections with varied R&D costs. The results show that the imitator enjoys the second-mover advantage and the high-quality advantage in a free market. The effect on social welfare from implementing patent protection depends on the magnitude of the R&D costs. In the case of low R&D costs, patent protection should not be granted, since competition could enhance social welfare. In the case of a high R&D cost, patent protection will be unable to induce innovation, making it invalid for raising social welfare. Only in the case of moderate R&D costs could patent protection provide adequate incentive to the innovator, and thus improve social welfare. As a policy solicitation, we suggest that R&D costs could be a good measure of non-obviousness and should be included as a prerequisite to patentability.

Keywords: Vertical Differentiation, Second-Mover Advantage, High-Quality Advantage, R&D Costs, Prerequisite To Patentability

1. Introduction

The interaction between innovators and imitators not only influences their profits significantly, but also is also closely related to social welfare, as well as the implementation effect of related policies. This study analyzes the interactive relationship between innovators and imitators on product quality and price in a vertically differentiated market, so as to probe into the effects of implementing patent protection on firm behavior and social welfare.

The main viewpoint of literatures on innovative and imitative behaviors is that imitative behavior will exploit the profits of the innovator, which then weakens the motive for innovation. In addition, when the imitator selects the level of product quality, he will face a trade-off relationship, as the more similar the product is to the innovator's, the lower the R&D cost will be, but the competition will be more severe. Most of the literatures related to quality competition have concluded that innovators produce high quality goods and gain larger profits, i.e., have the high quality advantage and first mover advantage. Examples include research by Gabszewicz and Thisse [5], and Shaked and Sutton [19], and more recently by Choi and Shin [4], Lipmann and Wamer [13], and Lehmann-Grube [11].

However, the empirical research findings show that the first mover advantage is not the golden rule of market competition, because examples of second mover advantage can be found easily. Schnaars [18] listed the market of 28 novelties, and indicated that the imitators have pick-up advantage, which causes them to exceed the innovators and become the market leader1. In addition, Golder and Tellis [7] studied the brand competition among 50 product types, and found that the pioneer firms in the product market have only a 53% survival rate, and that the average market share is as low as 10%. On the contrary, the imitators have a 92% survival rate and an average of 28% of the market share2.

Therefore, in order to rebuild the scenario of imitative behavior eroding the economic returns of innovative behavior, and to reflect the empirical truth that the imitation cost

[1] For example, in the PC industry, the later IBM exceeded MITS and became the industry leader.
[2] In addition, Tellis and Golder [22] provided more examples of second mover advantage.

is much lower than the R&D cost, this paper modifies the model of Pepall [15], and finds that the imitator may gain higher profit than the innovator in some circumstances.

In comparison to the setting of R&D costs being unrelated to the product quality of innovators indicated by Pepall [15], this paper assumes that the R&D cost is positively correlated with the quality, i.e., the R&D cost increases with the product quality of the innovator. The imitation cost of the imitator is directly proportional to the R&D cost of the innovator, and this ratio is related to the product differentiation between the two firms. In this cost structure, whether the imitator chooses quality is higher or lower than that of the innovator, the cost must be lower than the R&D cost of the innovator. In addition, for the innovator, an R&D that increases with the quality highlights the load of innovative R&D. Under the effect of these two factors, it is found that in equilibrium, the imitator produces high quality products and has higher market share and profits; namely, the imitator has high quality advantage and second mover advantage simultaneously.

There are numerous theoretical models in literature studying the causes for the second mover advantage from different angles. Hoppe [8] suggested that as new technology is adopted, the profit of the innovator will be uncertain; therefore the imitator can learn from the experience of the innovator in order to prevent mistakes. The externality of the information causes the imitation cost of the imitator to produce the new product to be much lower than the R&D cost of the innovator. Smirnov and Wait [21] proposed that if the investment has a hold-up, the later investment firm might exceed the pioneer firm due to having the aforesaid information externality. Dutta, Lach and Rustichini [3] indicated that the faster the technology changes, the more likely it will be for the imitator to win. Hoppe and Lehmann-Grube [9] argued that the second mover advantage is an unavoidable result when the quality improvement cost is very high, and that when the quality improvement cost approximates infinitely great, the second mover advantage will be equivalent to the high quality advantage found by Aoki and Prusa [1], and Lehmann-Grube [11]. However, this paper shows the R&D cost of the innovator does not need to be infinitely great to generate second mover advantage. As long as the R&D cost is higher than the imitation cost of the imitator, the latter will have second mover advantage and high quality advantage at the same time.

Secondly, this paper discusses how the R&D cost influences the effect of implementing a patent system from the angles of consumer surplus and social welfare. This paper assumes the patent to be a strict patent protection, namely, the granting of a patent makes the innovator the exclusive firm. It is found when the R&D cost is very low, although granting the innovator a patent can increase its profit, the patent restricts the market output, which then reduces the consumers' surplus and social welfare. When the R&D cost is very high, even if the innovator is granted a patent, it cannot gain a profit; therefore, the patent does not help in the development of new products or new technology. When the R&D cost is moderate, the existence of a patent gives the innovator a positive profit, and then increases the consumers' surplus and social welfare.

The findings of this study are consistent with a number of empirical research results. For example, Mansfield, Schwartz and Wagner [14] researched 34 imitated new product markets in the northeast region of the U.S. and found that even if the imitation cost is much lower than the innovation cost, the innovators will retain access to the markets as long as there are profits. However, on one hand, Sakakibara and Branstetter [17] found that in Japan in 1998, when the new patent law was implemented and the patent scope was expanded, industrial R&D costs and innovation achievements did not increase accordingly. This leads to the thought that the implementation of a patent should stimulus innovation behavior on certain conditions. On the other hand, Jaffe and Lerner [10] argued that under current patent system, the innovation game is one of lawyers but not of innovators. Consequently, many grated patents do not enhance consumers' surplus and social welfare.

In related theoretical studies, Arrow [2] indicated that if the imitation cost is much lower than the R&D cost, the potential threat from the imitator will make the innovator become unwilling to develop new products. Levin, Klevorick, Nelson and Winter [12] suggested that increasing the imitation cost through the use of patents is helpful to the development of new markets. Pepall and Richards [16] further indicated that the higher the imitation cost is in comparison to the R&D cost, the more helpful the patent system will be for the innovator to improve the quality of the products, thereby increasing the social welfare. This study finds that the R&D decision-making of innovators depends on the profitability of the new product instead of on patent protection. Even if the innovator produces high quality products under patent protection, the social welfare will certainly be increased, because monopoly resulting from the patent will greatly reduce the consumers' surplus.

The remainder of this paper is organized as follows. Section 2 describes the model used in this paper, the consumers' behavioral hypotheses, and the cost structure and competitive strategy of the firm, and then the equilibrium value of various economic variables is worked out. Section 3 discusses the effects of a patent on the equilibrium and work out the consumers' surplus and social welfare. Finally, the conclusions are given in Section 4.

2. Basic Model and Equilibrium

Considering a commodity with quality differentiation is produced by at most two firms, which are one innovator and one imitator. The innovator produces new product and initiates a new market after it has spent the R&D cost. The imitator does not have the ability to develop a new product, but it can imitate the product of the innovator to produce its own product and thereby enter the market.

The two firms carry out a two-stage non-cooperative game. The first stage is one of product quality competition.

At this stage, the innovator decides whether or not to develop a new market, while at the same time predicting if there will be an imitator entering the market following it. It then chooses the commercial quality if it decides to develop this market. The imitator first decides whether or not to enter the market following the innovator and then chooses the product quality. At the second stage, the two firms encounter simultaneous price competition. As this market equilibrium is a subgame perfect equilibrium, the backward induction is used for solving this model, so as to obtain the product quality, quantity, price and profit of the two firms in equilibrium, as well as to obtain the consumers' surplus and social welfare.

2.1. Firm and Consumer

At the first stage, the innovative and imitators carry out quality competition in turn. Let z_I be the quality level of the innovator. Its range is $z_I \in [\underline{z}, \bar{z}]$ with $\bar{z} - \underline{z} = 1$. In order to supply this product, the innovator will encounter an R&D cost at first. This cost is expressed as $K/(\bar{z} - z_I + 1)$, where K is an exogenous parameter. Therefore, the R&D cost of the innovator, $K/(\bar{z} - z_I + 1)$ is between $K/2$ and K. The R&D cost increases with the product quality. The value of K varies with the industry and the economic environment. It is obvious that K can reflect the amount of the R&D cost, therefore K and R&D cost are regarded as having the same economic meaning in the following text.

The imitator will produce a product of quality z_E. Its cost is the imitation cost, which is proportional to the R&D cost of the innovator. Let the imitation cost be

$$K(z_I - z_E)^2/(\bar{z} - z_I + 1).$$

According to this setting, the higher the product quality of the innovator is, the higher the R&D cost will be, and the higher the imitation cost as well. In addition, the closer the product quality of the imitator (z_E) is to the product quality of the innovator (z_I), the lower the imitation cost will be. Obviously, the imitator enjoys a cost advantage comparing to the innovator. According to the imitation cost function, if the imitator produces a product of the same quality as that of the innovator, there will be no cost, i.e., the imitation cost is 0. However, the imitator will face the trade-off problem of cost advantage and price competition. It can certainly reduce the imitation cost by imitating the product of the innovator, but the closer the product qualities of the two firms are to each other, the more severe the price competition will be.

The two firms will carry out price competition during the second stage. Let the production cost be 0; the innovator and the imitator will determine their specific price levels simultaneously (let them be p_I and p_E, respectively), and their output will be q_I and q_E, respectively. The profit function of innovator and that of imitator can be expressed respectively and as follows:

$$\pi_I = p_I q_I - K/(\bar{z} - z_I + 1) \tag{1}$$

and

$$\pi_E = p_E q_E - K(z_E - z_I)^2/(\bar{z} - z_I + 1) \tag{2}$$

Benefiting from the research findings of Pepall [15] and Tirole [23], this paper assumes that each consumer buys at most one unit of the good. Let θ_j be the parameter of the preferences of consumer j for product quality. Therefore, the utility function of consumer j enjoys the utility

$$U(z, p; \theta_j) = \theta_j z - p$$

if he buys a unit of product of quality z by paying the price p and $U(z, p; \theta_j) = 0$ if he dose not purchase. The consumer with a higher θ will have a higher willingness to pay for the product quality. Let θ be the uniform distribution between $\bar{\theta}$ and $\underline{\theta}$, and $\bar{\theta} = \underline{\theta} + 1$.

For a concise analysis without losing important economic meaning, this study makes the following two hypotheses:

H-1 (hypothesis of willingness to pay):

$$4/3 \le \bar{\theta} < 2,$$

and

H-2 (hypothesis of lower bound of quality):

$$(2 - \bar{\theta})/3(\bar{\theta} - 1) < \underline{z} = \bar{z} - 1.$$

The hypothesis of willingness to pay guarantees that the consumers' purchasing power is enough to attract two and only two firms to enter the market. However, the hypothesis of lower bound of quality guarantees that all of the consumers will be willing and able to buy goods of a certain quality. With these two hypotheses, the market will be a completely covered duopoly market in equilibrium.3 There is only one marginal consumer (represented by $\hat{\theta}$), and his utility from consuming a high quality good is the same as that from using a low quality good, i.e.,

$$z_H \hat{\theta} - p_H = z_L \hat{\theta} - p_L$$

in which the subscripts H and L represent the variables related to high quality and low quality goods, respectively. At this price competition stage, the two firms face the demands as follows:

$$q_H = (p_H, p_L) = \bar{\theta} - \hat{\theta} = \bar{\theta} - (p_H - p_L)/(z_H - z_L),$$

and

$$q_L = (p_H, p_L) = \hat{\theta} - \underline{\theta} = (p_H - p_L)/(z_H - z_L) - \underline{\theta}.$$

Furthermore, the demand of low quality product can also be rewritten to

[3] Gabszewicz and Thisse [5], [6] and Shaked and Sutton [19], [20] proved that a natural oligopoly results from vertical product differentiation.

$$q_L = (p_H - p_L)/(z_H - z_L) - \bar{\theta} + 1 .$$

2.2. Stage II: Price Competition

As the backward induction shall be used for solving this model, the analysis begins with the price competition at Stage II. At this stage, both the innovator and the imitator have already chosen a specific product quality level, but it is undetermined as to which company will produce higher quality goods, therefore the two firms are temporarily marked by the quality level. When equilibrium is reached at this stage, the price (p_H^*), output (q_H^*) and revenue (R_H^*) of the firm producing high quality products will be:

$$p_H^* = (\bar{\theta} + 1)(z_H - z_L)/3 , \quad (3)$$

$$q_H^* = (\bar{\theta} + 1)/3 , \quad (4)$$

and

$$R_H^* = (\bar{\theta} + 1)^2 (z_H - z_L)/9 .$$

The price (p_L^*), output (q_L^*) and revenue (R_L^*) of the firm producing low quality products will be:

$$p_L^* = (2 - \bar{\theta})(z_H - z_L)/3 , \quad (5)$$

$$q_L^* = (2 - \bar{\theta})/3 , \quad (6)$$

and

$$R_L^* = (2 - \bar{\theta})^2 (z_H - z_L)/9 .$$

The comparison finds that the firm producing products of higher quality will have a higher price, a larger market share and a higher revenue, and that the larger the $\bar{\theta}$ is, i.e., the higher the consumers' willingness to pay, the more likely the selling price of, the output of and the revenue of the high quality product firm will increase.

2.3. Stage I: Quality Competition

At the first stage, the two firms determine the quality in turn. The innovator determines the quality of the new product before the imitator chooses the product quality. Therefore, when the product quality

$$z_I \quad (\underline{z} \le z_I \le \bar{z})$$

of the innovator is given, the imitator will have two alternative production strategies. First, it can choose to produce products of a higher quality than the innovator, i.e., $z_I < z_E$, which is called the high quality strategy. Second, it can produce products of a lower quality than the innovator, i.e., $z_E < z_I$, which is called the low quality strategy. Different quality strategies will cause the imitator to face different profit functions and profit levels. The imitator will choose the strategy with higher profit.

2.3.1. Quality Strategies of the Imitator

The high quality strategy and the low quality strategy of the imitator are further discussed below.

Consider the high quality strategy first. If the imitator produces higher quality product than the innovator dose, i.e., $z_I < z_E$. Thus, the profit function of the imitator can be obtained by substituting Eq. (3) and Eq. (4) into Eq. (2):

$$\pi_E(z_I, z_E) = (\bar{\theta} + 1)^2 (z_E - z_I)/9$$

$$- K(z_E - z_I)^2 /(\bar{z} - z_I + 1).$$

Therefore, the product quality of the imitator is

$$z_E^* = \min\{\bar{z}, z_I + A(\bar{\theta})(\bar{z} - z_I + 1)/K\} \quad (7)$$

Where

$$A(\bar{\theta}) = (\bar{\theta} + 1)^2 /18$$

From Eq. (7), it can be confirmed that there exists a value of z such that the two arguments in the parenthesis are equal. Denote it by z_1 and

$$z_1 = \bar{z} - A/(K - A).$$

Therefore, the choice of the imitator for product quality will be

$$z_E^* = z_I + A(\bar{\theta})(\bar{z} - z_I + 1)/K$$

when $z_I < z_1$, and $z_E^* = \bar{z}$ when $z_I > z_1$.

Suppose that the innovator exceeds the critical point, i.e., $z_I > z_1$. If the imitator adopts the high quality strategy, the price competition between the firms will be very severe. Consequently, the imitator will be induced to maximize the quality differentiation and choose $z_E^* = \bar{z}$. The corresponding profit function will be:

$$\pi_E = 2A(\bar{\theta})(\bar{z} - z_I) - K(\bar{z} - z_I)^2 /(\bar{z} - z_I + 1) ; \quad (H1)$$

If the product quality of the innovator is lower than the critical point, the severity of the price competition will be reduced. Therefore, the imitator will be able to fully exert its cost advantage with no need to maximize the quality differentiation. Therefore the imitator will choose the following product quality,

$$z_E^* = z_I + A(\bar{\theta})(\bar{z} - z_I + 1)/K,$$

resulting in the corresponding profit function will be:

$$\pi_E = A(\bar{\theta})^2 (\bar{z} - z_I + 1)/K . \quad (H2)$$

Next, consider the low quality strategy. The imitator may also produce products of a lower quality than the innovator, i.e. $z_I > z_E$. In this case, the profit function of the imitator can be found by substituting Eq. (5) and Eq. (6) into Eq. (2):

$$\pi_E(z_I, z_E) = (2-\bar{\theta})^2 (z_E - z_I)/9$$
$$-K(z_I - z_E)^2 /(\bar{z} - z_I + 1).$$

Then the optimum product quality of the imitator will be:

$$z_E^* = \min\{\underline{z}, z_I - B(\bar{\theta})(\bar{z} - z_I + 1)/K\}, \qquad (8)$$

Where

$$B(\bar{\theta}) = (2-\bar{\theta})^2 / 18$$

From Eq. (8), it can be confirmed that there exists a value of z such that the two arguments in the parenthesis are equal. Denote it by z_2 and

$$z_2 = \bar{z} - (K - B)/(K + B)$$

Therefore, the choice of the imitator for product quality will be $z_E^* = \underline{z}$ when $z_I < z_2$, and

$$z_E^* = z_I - B(\bar{\theta})(\bar{z} - z_I + 1)/K$$

when $z_I > z_2$. The imitator faces a trade-off between reducing price competition and exerting cost advantage.

When the cost advantage of the imitator is exerted completely

$$(z_I > z_2)$$

And

$$z_E^* = z_I - B(\bar{\theta})(\bar{z} - z_I + 1)/K$$

is chosen, the corresponding profit function will be:

$$\pi_E = B(\bar{\theta})^2 (\bar{z} - z_I + 1)/K; \qquad \text{(L1)}$$

If the quality differentiation is maximized ($z_I < z_2$), then $z_E^* = \underline{z}$ is chosen. The corresponding profit function will be:

$$\pi_E = 2B(\bar{\theta})(z_I - \underline{z}) - K(z_I - z_E)^2 /(\bar{z} - z_I + 1). \qquad \text{(L2)}$$

The imitator chooses its quality strategy by comparing the profits of both the high quality and low quality strategies.

2.3.2. The Decision-making of Innovators and Market Equilibrium

After solving the optimum product quality of the imitator, the innovator can choose its optimum quality. The relative magnitude of z_1, z_2, $\bar{z}$ and $\underline{z}$ will influence the profit and decision-making of the two firms, and this relative magnitude is closely related to the magnitude of K. Their relationship can be resolved into five cases, which are:

Case I:

$$0 \le K < B(\bar{\theta});$$

Case II:

$$B(\bar{\theta}) \le K < A(\bar{\theta});$$

Case III:

$$A(\bar{\theta}) \le K < 2A(\bar{\theta});$$

Case IV:

$$2A(\bar{\theta}) \le K < 2A(\bar{\theta}) + B(\bar{\theta})$$

And Case V:

$$2A(\bar{\theta}) + B(\bar{\theta}) \le K.$$

In Case I and Case II, the relative low value of K implies the cost of developing new product is relatively low. Therefore, the imitator will adopt the high quality strategy and maximize the product differentiation, i.e., it will choose

$$z_E^* = \bar{z}$$

Based on the quality decision-making of the imitator, the optimum quality of the innovator is

$$z_I^* = \underline{z}.$$

Therefore, the product quality of the innovator will be lower than that of the imitator. With this choice, the cost of developing the new product must meet the condition of

$$0 \le K < 4B(\bar{\theta})$$

so as to ensure the innovator makes a positive profit, and then it will choose to enter the market. Otherwise, the market is vanished.

The reason for the innovator choosing the lowest quality can be observed from the interaction between the two firms. In the case that K is relatively small and the imitator adopts the high quality strategy, the higher the product quality of the innovator is, the smaller the product quality differentiation and the lower the imitation cost will be. This results in a more severe price competition in later stage and causes the profit to be reduced. Therefore, in order to avoid severe price competition, the optimum product quality of the innovator will be $\underline{z}$, i.e., maximized product differentiation.

The above discussion concludes that the quality and profit of the innovator are lower than that of the imitator. The conclusion that the innovator has lower profit, though is different from the first mover advantage shown in the literatures, is very popular in real world4. However the conclusion is consistent with the high quality advantage proposition in the literature. This reaches the following proposition:

Proposition I: If the market is a laissez-faire market with

[4] Please refer to Golder and Tellis [7].

$$0 \le K < 4B(\overline{\theta})$$

then

(1) both the innovator and the imitator enter the market;

(2) product differentiation is maximized; and

(3) the profit of the imitator is higher than that of the innovator, i.e. the imitator has the second mover advantage.

Proof: The product quality of the innovator is $z_I^* = \underline{z}$, and the product quality of the imitator is $z_E^* = \overline{z}$. The prices of the innovator and the imitator will be $p_I^* = (2-\overline{\theta})/3$ and $p_E^* = (\overline{\theta}+1)/3$, respectively, and the outputs will be

$$q_I^* = (2-\overline{\theta})/3$$

And

$$q_E^* = (\overline{\theta}+1)/3$$

Consequently, the profits will be

$$\pi_I^* = (2-\overline{\theta})^2/9 - K/2$$

And

$$\pi_E^* = (\overline{\theta}+1)^2/9 - K/2$$

With

$$\pi_E^* > \pi_I^* .$$

The above conclusion is obtained when K is relatively small. In Case III, Case IV and Case V, K is relatively large, the cost of developing a new product is relatively high. Under the threat of the competition from the imitator, the innovator will have no profit at all. Therefore, the innovator will not enter the market at the very start, and the imitator has no way to enter. Consequently, there will be no firms in the market.5

The market structure varies with the value of K, i.e., the cost of developing the new product of the innovator. If this cost is relatively high, the innovator will not enter the market, as the imitator will share the market. Therefore, there will be no firms in the market. If this cost is relatively low, the two firms will exist in the market simultaneously, the product differentiation will be maximized, and the imitator will have the second mover advantage. It is obvious that imitation is likely to occur in the industry when there is a low R&D cost and the imitator enjoys more profits than the innovator dose. Consequently, this will weaken the incentives to innovate. The story is completely different from the industry when there is a high R&D cost. Thus, R&D cost must be considered when granting patents.

[5] The innovator may use quality as an entrance deterrent to prevent the imitator entering the market and become a limited monopoly firm. However, the profit is negative. Thus there will be no firms in the market.

In terms of social welfare, as there are no firms in Cases III, IV and V, only Cases I and II are discussed. The social welfare is the sum of the firm's profit and the consumers' surplus. It can be expressed as:

$$W_f = \pi_I + \pi_E + CS$$

where CS is the consumers' surplus:

$$CS = \int_{\overline{\theta}-1}^{\hat{\theta}} (s\underline{z} - p_I)ds + \int_{\hat{\theta}}^{\overline{\theta}} (s\overline{z} - p_E)ds .$$

Based on the equilibrium quality and price of the two firms, the marginal consumer can be found as

$$\hat{\theta} = (2\overline{\theta}-1)/3$$

The first term of the CS is the surplus of the consumers who consume low quality products, which is

$$CS_I = \overline{z}(5\overline{\theta}-4)(2-\overline{\theta})/18 - \overline{\theta}(2-\overline{\theta})/6.$$

The second term of the CS is the surplus of the consumers who buy high quality products, which is

$$CS_E = \overline{z}(5\overline{\theta}-1)(\overline{\theta}+1)/18 - (\overline{\theta}+1)^2/9.$$

Therefore, the social welfare is

$$W_f = \overline{z}(2\overline{\theta}-1)/2 - (5\overline{\theta}-4)(2-\overline{\theta})/18 - K.$$

In the laissez-faire market, the lower the R&D cost invested in the industry is, the higher the quality attained by technology will be, and the higher the consumers' willingness to pay for the quality, and the larger the social welfare will be.

3. Monopoly under Strict Patent Protection and Its Economic Effects

If the government adopts the strict patent protection policy to help innovators research and develop products, this will prevent imitators with a cost advantage from entering the market and robbing the innovator's profit. Under the strict patent protection policy, the innovator will be the monopolist of the market, without the threat of imitators. At this point, the market will be uncovered and the consumers have only one option for product quality.

3.1. Equilibrium Under Strict Patent Protection

Under the strict patent protection, the innovator will monopolize the market, and only half of the consumers will buy the products of this firm. The optimum choice of this monopoly firm can be divided into the following four cases according to the relative magnitude of the K value. These four outcomes are:

(i)

$$0 \le K \le \overline{\theta}^2/4$$

The value of developing new product is relatively small and the innovator produces the highest quality, i.e., $z_m^* = \bar{z}$. The price is $p_m^* = \bar{z}\bar{\theta}^2/2$, and the profit is

$$\pi_m = \bar{z}\bar{\theta}^2/4 - K.$$

(ii)

$$\bar{\theta}^2/4 \le K \le \min\{\bar{\theta}^2, \bar{\theta}^2(z+1)^2/16\}$$

If the value of K is not low enough, then the highest quality will not be the optimal choice for the innovator. The firm will produce a quality level lower than

$$\bar{z},\ z_m^* = \bar{z} + 1 - 2K^{0.5}/\bar{\theta}.$$

The price will be

$$p_m^* = \bar{\theta}^2(\bar{z}+1)/2 - \bar{\theta}K^{0.5}$$

and the profit will be

$$\pi_m = (\bar{z}+1)\bar{\theta}^2/4 - \bar{\theta}K^{0.5}.$$

(iii)

$$\bar{\theta}^2 \le K < \bar{\theta}^2(\bar{z}-1)/2$$

If the value of K is large, the optimum choice of the monopoly firm will be to produce the lowest quality, i.e.

$$z_m^* = \underline{z}.$$

The price and profit will be

$$p_m^* = \underline{z}\bar{\theta}^2/2$$

and

$$\pi_m = (\bar{z}-1)\bar{\theta}^2/4 - K/2$$

respectively.

(iv)

$$K \ge \bar{\theta}^2(\bar{z}-1)/2$$

If the value of K is very high, i.e., the cost of developing new product is very high, the innovator will refrain from embarking on R&D, and the new market will not be initiated.

Therefore, the following proposition can be obtained from the above analysis:

Proposition II: Under the strict patent protection, the optimum choice of the firm will vary with the R&D cost. When the R&D cost is very high, even strict patent protection will not increase the firm's willingness to perform R&D, and the new market will not be initiated.

Proof: Please refer to Appendix II.

According to the above proposition, the R&D cost will influence the profit of the innovator, which will then influence its willingness to develop the new market. When the R&D cost is too high, i.e., the case of

$$\bar{\theta}^2(\bar{z}-1)/2 \le K$$

even if there is patent protection, the monopoly profit is negative. Therefore, the firm will not develop the new product.

When the monopoly profit is positive, the R&D cost will still influence the quality of the product. According to the cost function of the innovator, upgrading has two adverse effects on profit. On one hand, the product price and revenue can be increased, while on the other hand, the R&D cost will also increase. When K is relatively low, the increments of the R&D cost resulting from improving the product quality will be smaller than those of when K is high. Therefore, when K is lower, the profit of the innovator will be increased by improving the quality and the higher quality of goods will benefit the firm. On the contrary, if the K value is large enough, the lowest quality must be chosen to avoid the increase in cost. This result matches the conclusion of the duopoly market in the sense that if the R&D cost is low, the new product will be likely to come into the market. Furthermore, under the protection of patent policy, if the innovator enters the market, its product quality will not be lower than that in the free market. However, the consumers' surplus and the social welfare may not be higher under the patent protection policy. It needs further discussions.

3.2. Comparison of Social Welfare and Policy Implications

The effect of implementing strict patents protection on social welfare may serve as a criterion to determine whether to implement a strict patent protection or not. The consumers' surplus and social welfare varies substantially with the R&D costs, and thus the value of K. The social welfare with varies values of K is described below:

(i)

$$0 \le K < \bar{\theta}^2/4:$$

Here the consumers' surplus is

$$CS_m = \bar{z}\bar{\theta}^2/8$$

which is added to the firm's profit to obtain the social welfare

$$W_m = 3\bar{z}\bar{\theta}^2/8 - K.$$

(ii)

$$\bar{\theta}^2/4 \le K < \min\{\bar{\theta}^2, \bar{\theta}^2(\bar{z}+1)^2/16\}:$$

Here the consumers' surplus is

$$CS_m = \bar{\theta}^2(\bar{z}+1)/8 - \bar{\theta}K^{0.5}/4$$

and the social welfare is

$$W_m = 3\bar{\theta}^2(\bar{z}+1)/8 - 5\bar{\theta}K^{0.5}/4.$$

(iii)

$$\bar{\theta}^2 \le K < \bar{\theta}^2(\bar{z}-1)^2/2:$$

In this case, the consumers' surplus is

$$CS_m = (\bar{z}-1)\bar{\theta}^2/8$$

and the social welfare is

$$W_m = 3\bar{\theta}^2(\bar{z}-1)/8 - K/2.$$

(iv)

$$K \ge \bar{\theta}^2(\bar{z}-1)^2/2:$$

With a greatly high R&D cost, even strict patent protection cannot push the innovator to enter the market, so there is no social welfare.

It is found that, given K, social welfare will increase as the increase in the consumers' willingness to pay (θ), and the higher of the upper bound of product quality level ($\bar{z}$). The increase in $\bar{z}$ can increase the consumers' surplus and firm's profit simultaneously, so the social welfare must be increased. In addition, the increase in θ which represents the increase in the overall wealth of society and the average income of the people, and thus increase the social welfare. Therefore, using the strict patent protection policy to create a market or to change the market structure is more likely to increase social welfare.

The following proposition is obtained by comparing the above welfare levels to that in the laissez-faire market.

Proposition III: (The Timing of Implementing the Strict Patent Protection) By comparing the benefit level in the laissez-faire market with that after the implementation of the strict patent:

(i)

When

$$0 \le K < 4B(\bar{\theta}) = 2(2-\bar{\theta})^2/9,$$

the social welfare level achieved by implementing strict patent protection is lower than that by laissez-faire market.

(ii)

When

$$4B(\bar{\theta}) = 2(2-\bar{\theta})^2/9 \le K < \bar{\theta}^2(\bar{z}-1)/2,$$

the social welfare level achieved by implementing strict patent protection is higher than that by laissez-faire market.

(iii)

When

$$\bar{\theta}^2(\bar{z}-1)/2 \le K,$$

no matter whether the patent protection policy is implemented or not, the firm is unwilling to develop a new market, so there is no social welfare.

Proof: Please refer to Appendix II.

According to the aforesaid proposition, when the consumers' willingness to pay ($\bar{\theta}$) and the product quality level ($\bar{z}$) are given, the R&D cost or K value will be the key in determining the effect of the implementation of the strict patent protection policy. If the R&D cost is very small, the profit from R&D is enough to induce the innovation. Therefore, implementing strict patent protection will create a monopoly market and decrease social welfare. If the R&D cost is moderate, the strict patent protection provides adequate incentive to innovator to invest and create new market. Consequently, the strict patent protection policy is actually effective on encouraging R&D and increasing the social welfare. However, if the R&D cost is too high, the strict patent protection is not enough to stimulate the firm to embark on R&D or to develop new markets. This result is coincident with the case of a laissez-faire market; the social welfare is not increased, and the patent protection policy is impotent. It is obvious that the government must be very cautious when implementing the strict patent protection policy and should pay more weight on the R&D costs of across different industries.

4. Conclusion

This paper uses the vertically differentiated duopoly market and an R&D cost function that increases with the quality to annotate the competition between the innovation and imitation of firms, as well as discusses the effect of implementing strict patent protection policy. The result shows that the innovator cannot use quality as an entrance deterrent to prevent the imitator from entering the market. Therefore, the innovator will enter the market and produce goods of the lowest quality only if the R&D cost is relatively low. The imitator will produce goods of the highest quality based on its cost advantage, as it has a larger market share and higher profit, i.e., the second mover advantage and the high quality advantage. On the other hand, if the R&D cost is relatively high, the innovator will not develop the new market; therefore, there will be no firm in the market.

The purpose of implementing strict patent protect policy is to provide the innovator with appropriate incentives for innovating. It is found that the patent system shall not be implemented if the R&D cost of is very low. In this case, the innovator can enjoy positive profit with or without strict patent protect policy. Meanwhile, the participation of the imitator will help increase the consumers' surplus and social welfare. If the R&D cost is too high, innovative behavior cannot be induced even if the patent system is implemented. If the R&D cost is moderate, in order to provide the innovator with an inducement for R&D, the patent system can be used to protect its profit and to increase the social welfare.

For further studies, a patent game in dynamic settings centers a major consideration. This paper discusses the case of imitators with cost advantage in a static model. When this advantage is strong enough, the second mover advantage seems to be the consequent conclusion. In a dynamic setting, the innovator often gains a monopoly profit for a period of time after the new product is introduced (before the imitator enters the market). Therefore, this dynamic variation may be considered in subsequent studies to review the effectiveness of second mover advantage. The discussion about the effect of patent implementation should aim at the influence of R&D cost on the length and breadth of optimum patents.

Appendices

Appendix 1. Market Equilibrium in a Laissez-Faire Market

The π_E and π_I values are influenced by the relative magnitude of z_1, z_2, $\bar{z}$ and $\underline{z}$, and then by K, $A(\bar{\theta})$ and $B(\bar{\theta})$. In addition, K is an exogenous variable. Therefore, the natural oligopoly market is divided into five cases for discussion based on K, namely,

$$0 \le K < B(\bar{\theta}),\ \ B(\bar{\theta}) \le K < A(\bar{\theta}),\ A(\bar{\theta}) \le K < 2A(\bar{\theta}),$$
$$2A(\bar{\theta}) \le K < 2A(\bar{\theta}) + B(\bar{\theta})$$

And

$$2A(\bar{\theta}) + B(\bar{\theta}) \le K .$$

Case I: When $0 \le K < B(\bar{\theta})$, z_1 and z_2 are greater than $\bar{z}$. Therefore, the profit from the high quality strategy is (H2), and the profit from the low quality strategy is (L2), shown as (H2) > (L2). The imitator adopts the high quality strategy, so $z_E^* = \bar{z}$. Due to the profit maximization behavior of the innovator,

$$z_I^* = \underline{z},\ \ \pi_I^* = 2B(\bar{\theta}) - K/2$$

and

$$\pi_E^* = 2A(\bar{\theta}) - K/2 .$$

Case II: In the range of

$$B(\bar{\theta}) \le K < A(\bar{\theta}),\ \underline{z} < z_2 < \bar{z} < z_1$$

but the relative magnitude of z_I and z_2 is uncertain; therefore, there are two probabilities due to the different positions of z_I. First, if $z_I < z_2$, the imitator will adopt the high quality strategy due to (H2) > (L2), so

$$z_E^* = \bar{z}$$

As mentioned in the above case

$$z_I^* = \underline{z},\ \ \pi_I^* = 2B(\bar{\theta}) - K/2$$

And

$$\pi_E^* = 2A(\bar{\theta}) - K/2$$

due to the profit maximization behavior of the innovator. It shall be noted that the innovator will develop the product's market only if $\pi_I^* > 0$. The condition is $K < 4B(\bar{\theta})$. Otherwise there will be no market. Secondly, if $z_2 < z_I$ then the imitator will adopt the high quality strategy due to (H2) > (L1). However, the determined profit is negative, due to the profit maximization behavior of the innovator, so there will be no market.

Case III: In the range of

$$A(\bar{\theta}) \le K < 2A(\bar{\theta})$$

it is the case that

$$z_1 < \underline{z} < z_2 < \bar{z}$$

However, the relative magnitude of z_I and z_2 is uncertain, so there are two probabilities due to the different positions of z_I: $z_I < z_2$ and $z_2 < z_I$. It is found by repeating the aforesaid procedure that π_I^* is negative in any probability; therefore, there will be no market.

Case IV: When

$$2A(\bar{\theta}) \le K < 2A(\bar{\theta}) + B(\bar{\theta})$$

it is the case that

$$\underline{z} < z_1 < z_2 < \bar{z}$$

There are three probabilities according to the position of z_I, namely,

$$z_I < z_1 < z_2,\ \ z_1 < z_I < z_2$$

And

$$z_1 < z_2 < z_I$$

However, π_I^* must be negative in any probability; therefore, there will be no market.

Case V: When

$$2A(\bar{\theta}) + B(\bar{\theta}) \le K,\ \ \underline{z} < z_2 < z_1 < \bar{z}$$

There are three probabilities according to the position of z_I by repeating the above procedure

$$z_I < z_2 < z_1,\ \ z_2 < z_I < z_1$$

And

$$z_2 < z_1 < z_I$$

However, π_I^* must be negative in any probability. Therefore, there will be no market.

This proves Proposition I.

Appendix 2. The Timing of Implementing Strict Patent Protects and Equilibrium

Under the strict patent, the innovator becomes the monopoly firm. When its profit is maximized, the optimum quality is

$$z_m^* = \bar{z} + 1 - (2/\bar{\theta})K^{0.5}$$

Since z_m is bounded, there are four cases according to the values of K , i.e.:

(i) If

$$0 \le K < \bar{\theta}^2 / 4$$

then the optimal quality chosen by the innovator is $z_m^* = \bar{z}$. The profit is

$$\pi_m^* = \bar{\theta}^2 \bar{z} / 4 - K > 0 .$$

(ii) If

$$\bar{\theta}^2 / 4 \le K < \bar{\theta}^2$$

then the optimal quality chosen by the innovator is

$$z_m^* = \bar{z} + 1 - (2/\bar{\theta})K^{0.5}$$

Therefore, the profit is

$$\pi_m^* = \bar{\theta}^2 (\bar{z}+1)/4 - \bar{\theta} K^{0.5}$$

However, this profit is positive only if

$$K < \bar{\theta}^2 (\bar{z}+1)^2 / 16$$

otherwise there is no market.

(iii) If

$$\bar{\theta}^2 \le K$$

then the optimal quality chosen by the innovator is

$$z_m^* = \underline{z}$$

Therefore the corresponding profit is

$$\pi_m^* = \bar{\theta}^2 (\bar{z} - 1)/4 - K/2 .$$

However, this profit is positive only if

$$K < \bar{\theta}^2 (\bar{z} - 1)/2$$

otherwise there is no market.

(iv) If

$$K \ge \bar{\theta}^2 (\bar{z} - 1)/2$$

Then

$$\pi_m^* < 0 .$$

Proposition II can be obtained by integrating (i), (ii), (iii) and (iv).

The social welfare of alternative market structure must be discussed according to the magnitude of K . A duopoly market exists only if

$$0 \le K < 4B(\bar{\theta}) = 2(2 - \bar{\theta})^2 / 9$$

In this case,

$$W_f = \bar{z}(2\bar{\theta} - 1)/2 - (2 - \bar{\theta})(5\bar{\theta} - 4)/18 - K$$

is the corresponding social welfare. If strict patent protection policy is implemented, the market is monopoly and the social welfare is

$$W_m = 3\bar{\theta}^2 \bar{z} / 8 - K$$

The comparison between W_m and W_f gives that the social welfare in the monopoly market is lower because

$$\bar{\theta}^2 / 4 > 4B(\bar{\theta}).$$

If

$$2(2 - \bar{\theta})^2 / 9 \le K < \bar{\theta}^2 (\bar{z} - 1)/2$$

the monopoly market is the only possible market structure. Therefore, the social welfare is higher and implementing strict patent protection is preferred. If

$$\bar{\theta}^2 (\bar{z} - 1)/2 \le K$$

no form of market exists. This completes the proof of Proposition III.

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