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PATENT PROTECTION AND R&D WITH ENDOGENOUS MARKET STRUCTURE

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In a model with endogenous number of innovating firms, we show that whether patent protection increases R&D investment is ambiguous, and depends on the market demand function and the cost of R&D. If the market size increases with number of firms, patent protection reduces R&D investment if the cost of R&D is sufficiently high, and higher product differentiation increases the possibility of lower R&D investment under patent protection. If the market size does not increase with number of firms, patent protection never reduces R&D investment. We find that welfare is lower under patent protection than under no patent protection.

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I. INTRODUCTION

AN IMPORTANT ROLE OF THE PATENT SYSTEM IS TO ENHANCE R&D INVESTMENT by giving the innovator property right on its innovation. Under the current WTO (World Trade Organization) regime, one of the most debated issues is strengthening patent protection across the world and the debate gathered momentum due to the Dunkel proposal in connection with Trade Related Intellectual Property Rights (TRIPS). The basic argument goes as follows. If there is a weak (or no) patent protection, it allows more firms than only the original innovator to use technologies similar to the innovated technology. Hence, the original innovator does not get proper return from its R&D, which, in turn, reduces the innovator's incentive for R&D investment.[1] However, a strong patent protection allows only the original innovator to use the innovated technology, and increases the innovator's incentive for R&D investment by increasing its return from R&D.

Though the above argument is certainly intuitive and appealing, it is important to see how patent protection affects R&D investment when there are many potential innovators. In a simple model with free entry, we show that patent protection may reduce R&D investment if the cost of R&D is sufficiently high and the market size increases with number of firms. Further, higher product differentiation, which may occur due to different brand names, different after sales services, etc., increases the possibility of lower R&D investment under patent protection. If the market size does not increase with number of firms, patent protection never reduces R&D investment. So, whether patent protection increases R&D investment depends on the type of industry, which may differ according to

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[1] Mansfield *et al*. [1981] find that 60% of a sample of their patented innovations is imitated within four years and the average cost of imitation is two-thirds the original cost of innovation. Levin *et al*. [1987] also find the evidences of knowledge spillover in presence of patent protection.

the cost of R&D, number of R&D capable firms and product characteristics that affect the degree of product differentiation.

On one hand, patent protection increases profit of the patent holder by eliminating competition in the product market. But, on the other hand, if there are many active innovators, patent protection reduces each innovator's chance of using the innovated technology, thus reducing each innovator's expected return from R&D. We show that the latter effect dominates the former if there are few active innovating firms. Though it seems paradoxical, the result is quite intuitive. When there are few active firms in the market, the profit of an innovator in the product market is very much similar under patent protection and under no patent protection. However, since patent protection allows only the patent holder to produce the product, it reduces an innovator's expected profit by making the R&D competition as a tournament. So, if the cost of R&D is sufficiently high, which, in equilibrium, ensures fewer active firms, R&D investment may be lower under patent protection than under no patent protection.

We also find that welfare is always lower under patent protection than under no patent protection.

Our result about the R&D reducing effect of patent protection has empirical relevance. Though, patent protection helps to increase R&D in many circumstances, it is found that the effect may be deleterious in some situations (see, e.g., Gallini [2002], Federal Trade Commission [2003] and National Research Council [2003]). Bessen and Maskin [2002] and Bessen and Hunt [2003] show the R&D reducing effect of patent protection in the software industry.

The present paper contributes to the vast literature showing the effects of patent protection on R&D investment and welfare (Chin and Grossman [1990], Gilbert and Shapiro [1990] Klemperer [1990] Segerstrom *et al.*, [1990] Diwan and Rodrik [1991], Grossman and Helpman [1991], Romer [1991], Deardorff [1992], Gallini [1992], Helpman [1993], Taylor [1994], Vishwasrao [1994], Lai [1998], Marjit and Beladi [1998], Fosfuri [2000], Glass and Saggi [2002], Mukherjee and Pennings [2004], Scotchmer [2004], Roy Chowdhury [2005], Hunt [2006], Mukherjee [2006] and Sinha [2006], to name a few).[2] However, the determination of endogenous market structure in our analysis cerates major difference from the previous works where the market structure is given exogenously. It is also worth mentioning that though it follows from Roy Chowdhury [2005] and Mukherjee [2006] that, with a given number of firms, patent protection may reduce R&D investment in absence of imitation or technology licensing if the tournament effect[3] is negative, the result of the present paper does not depend on the tournament effect.

In a more general note, this paper can be related to Moldovanu and Sela [2001], which determines the optimal number of prizes to be allocated in a contest with multiple, non-identical prizes. However, there is an important difference between the present paper and Moldovanu and Sela [2001]. In the present paper, the value of a prize (which is the payoff of an innovating firm) is affected by the number of prizes that will be issued, and the market size and the degree of product differentiation play important roles in the respect, whereas in Moldovanu and Sela [2001], the value of a prize is not affected by the number of prizes that will be issued.

The remainder of the paper is organized as follows. Section 2 describes the basic model and shows the results. Section 3 discusses the implications of some of the assumptions of section 2. Section 4 concludes.

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[2] We refer to Mazzoleni and Nelson [1998] for an overview on the benefits and costs of patent protection.

[3] The tournament effect is the difference between the equilibrium payoffs of the firms in the presence and absence of patent protection when all firms do R&D (see Roy Chowdhury [2005]).

II. THE BASIC MODEL AND THE RESULTS

Consider a world economy with large number of firms. Each firm is able to invent a product by investing K^2 in R&D. However, how many innovators will be able to produce the product will depend on the patent system of the economy.[4] If there is patent protection, ex-post R&D, one of the innovating firms gets patent and becomes the sole producer of the product. Hence, if n firms do R&D, each innovator's probability of getting the patent is $\frac{1}{n}$. In contrast, if there is no patent protection, all innovating firms can produce the products. However, we assume that the products of the firms may be imperfect substitutes, which may be due to different brand names, different after sales services, etc.[5]

We assume that the marginal cost of production for the invented product is constant, and is assumed to be zero, for simplicity.

We consider the following game. At stage 1, the firms decide whether to invest in R&D or not. To avoid the coordination problem in R&D, which does not add anything to the main purpose of this paper, we consider that the firms decide sequentially whether to do R&D or not. A firm decides to invest in R&D as long as its net profit from R&D is non-negative. So, the zero profit condition determines the equilibrium number of firms. At stage 2, the producers take their production decisions simultaneously. If there is patent protection, only the patent holder produces at stage 2. But, under no patent protection, all the innovating firms produce like Cournot oligopolists. We solve the game through

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[4] To show the R&D reducing effect of patent protection in the simplest way, we ignore uncertainty in the R&D process. Therefore, all innovating firms get the knowledge about the new product. However, we will discuss the implications on uncertainty in subsection 3.3.

[5] As a justification for product differentiation, which is independent of the production technology, let us consider the following hypothetical scenario. BMW, Mercedes, Volvo, Audi, Honda and Toyota are trying to invent a new technology that runs cars with solar energy. If there is patent protection, only one firm gets a patent for the invented technology. But, if there is no patent protection, all firms can use their invented technologies. However, when more than one firm produces this new generation car, the consumers may view them differently. For example, even if the cars from these companies have similar technical specifications, which is the concern of the patent system, simply the after sales services previously experienced by the

backward induction. Further, for analytical convenience, we consider number of firms as a continuous variable.

Let us assume that if there are n producers in the market, the inverse market demand function for the ith firm is

$$P = a - q_i - \gamma \sum_{\substack{j=1 \\ j \neq i}}^{n-1} q_j , \tag{1}$$

where $\gamma \in [0,1]$ denotes the degree of product differentiation.[6] The products are isolated for $\gamma = 0$, and they are perfect substitutes for $\gamma = 1$.

II (i). *Patent Protection*

If there is patent protection and n firms do R&D at stage 1, the expected gross profit of the ith innovating firm is $\frac{\pi^m}{n}$, where $\pi^m = \frac{a^2}{4}$. Hence, at stage 1, a firm decides to do R&D until

$$\frac{a^2}{4n} = K^2 . \tag{2}$$

Therefore, the equilibrium number of innovating firms under patent protection is

$$n^{pd} = \frac{a^2}{4K^2} . \tag{3}$$

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consumers from these car companies (which is not a concern of the patent system) may create certain degrees of brand loyal consumers, thus making these cars imperfect substitutes.

II (ii). *No Patent Protection*

If there is no patent protection and n firms do R&D at stage 1, the gross profit of the ith innovating firm is π^c, where $\pi^c = \frac{a^2}{(2+(n-1)\gamma)^2}$. So, at stage 1, a firm decides to do R&D until

$$\frac{a^2}{(2+(n-1)\gamma)^2} = K^2 . \tag{4}$$

Hence, the equilibrium number of innovating firms under no patent protection is

$$n^{pr} = \frac{(a-2K+K\gamma)}{K\gamma} . \tag{5}$$

II. (iii). *Comparing R&D under Patent Protection and No Patent Protection*

Proposition 1: Consider the number of firms as a continuous variable.

(i) Patent protection reduces R&D if $\gamma < 1$ and the cost of R&D is sufficiently large, i.e., $K > \frac{a\gamma}{2(2-\gamma)}$.

(ii) As the products are becoming more differentiated (i.e., γ falls), the possibility of higher R&D under no patent protection increases.

Proof: (i) A firm's gross profit under patent protection (which is the left hand side (LHS) of (2)) is greater than that of under no patent protection (which is the LHS of (4)) if and only if

$$\gamma \underset{<}{\overset{\geq}{}} \frac{2}{(\sqrt{n}+1)} . \tag{6}$$

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[6] This demand function is due to Bowley [1924] and is generated from the utility function $U(q,I) = \sum_{i=1}^{n} aq_i - \frac{1}{2}\left(\sum_{i=1}^{n} q_i{}^2 + 2\gamma \sum_{i \neq j} q_i q_j\right) + I$, where I is the numeraire good.

The right hand side (RHS) of (6) is 1 for $n = 1$, whereas it tends to 0 as $n \to \infty$. This implies that for $\gamma < 1$, there exists $n^*(\gamma) = \frac{(2-\gamma)^2}{\gamma^2}$ such that LHS of (2) is equal to LHS of (4).

Now, define $K^*(\gamma)$ as the cost of R&D such that, given the degree of product differentiation, the equilibrium number of firms is $n^*(\gamma) = \frac{(2-\gamma)^2}{\gamma^2}$. Hence, we have $\frac{a^2}{4n^*} = \frac{a^2}{(2+(n^*-1)\gamma)^2} = K^{*2}$, which gives $K^* = \frac{a\gamma}{2(2-\gamma)}$. Therefore, if $K > (<) K^*(\gamma)$, the equilibrium number of firms doing R&D is lower (higher) under patent protection compared to no patent protection.

(ii) Since LHS of (6) decreases with γ, it proves the result. Q.E.D.

Whether the incentive for R&D is higher under patent protection or under no patent protection depends on the trade-off between higher competition under no patent protection and lower chance of becoming the producer under patent protection. If the product market is very concentrated, competition under no patent protection does not reduce each firm’s profit significantly. Further, product differentiation helps to reduce competition between the firms. So, if the market is very concentrated, the loss of profit due to the lower chance of becoming the producer under patent protection dominates the loss of profit from competition under no patent protection. But, if the product market is not very concentrated, the loss of profit from competition under no patent protection becomes significant and dominates the loss of profit due to the lower chance of becoming the producer under patent protection, thus creates higher incentive for R&D under patent protection. Since, in equilibrium, fewer (more) firms enter the market if the cost of R&D is relatively high (low), R&D investment reduces (increases) with patent protection for sufficiently high (low) cost of R&D.

It should be noted that if the products are perfect substitutes, i.e., $\gamma = 1$, the profit loss from competition under no patent protection is always higher than the profit loss due to the lower chance of becoming the producer under patent protection. Unlike product differentiation, if the products are perfect substitutes, more firms do not increase the total size of the market and thus, do not provide the benefit of higher market size under no patent protection. Our result shows that the benefit of product differentiation is crucial for lower R&D investment under patent protection.

It may be worth mentioning that the main message of Proposition 1 remains even if we consider the firms as integers. However, under the integer constraint, patent protection may not reduce R&D investment for any $\gamma < 1$, and we need to modify Proposition 1(i) slightly. For example, if there are two firms doing R&D, gross profit of each firm under no patent protection is $\frac{a^2}{(2+\gamma)^2}$, which is lower than each firm's expected gross profit under patent protection (which is $\frac{a^2}{8}$), provided γ is sufficiently lower than 1. Hence, with the integer constraint, patent protection can reduce R&D investment for sufficiently high R&D costs provided the products are not very close substitutes.

Though the gross industry profit plus consumer surplus is always higher under no patent protection, patent protection (compared to no patent protection) may reduce the amount of resources to be spent in R&D by reducing the number of innovating firms, if the products are differentiated. Hence, in general, the effect of patent protection on welfare (which is the sum of net industry profit and consumer surplus) is ambiguous if the products are imperfect substitutes.[7] However, the following analysis shows that, given the demand function (1), welfare is always higher under no patent protection than under patent protection.

Using (3), we find that welfare under patent protection is

$$W^{pd} = \frac{a^2}{8}, \tag{7}$$

whereas using (5) and realizing that the net profits of the firms under no patent protection are zero, welfare under no patent protection is

$$W^{pr} = \frac{(a-K)(a-2K+K\gamma)}{2\gamma}. \tag{8}$$

The comparison of (7) and (8) shows that $W^{pd} \overset{\geq}{\underset{<}{-}} W^{pr}$ provided

$$a^2\gamma \overset{\geq}{\underset{<}{-}} 4a^2 - 12aK + 4aK\gamma + 8K^2 - 4K^2\gamma. \tag{9}$$

RHS of (9) increases with γ, and it is greater than the LHS of (9) at $\gamma = 0$.

Hence:

Proposition 2: Given the demand function *(1)*, welfare is higher under no patent protection than under patent protection.

III. DISCUSSION

III (i). *Possibility of Iimitation*

Section 2 has assumed away the possibility of imitation under no patent protection. In other words, we implicitly assume that the critical knowledge about the new technology can be acquired only through indigenous R&D, which may be due to the existence of tacit

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[7] If the products are perfect substitutes, it is clear that patent protection reduces welfare since it increases both the total amount to be spent in R&D and market concentration.

knowledge. However, the common criticism against lack of patent protection is the possibility of imitation by the competitors that reduces profit of the initial innovator. We now examine the effect of imitation under no patent protection on the above analysis.

Assume that each firm has the capability of imitating the technology of the competitor at a cost $I^2 < K^2$. However, it should be remembered that imitation would be a possibility only under no patent protection.

Since the cost of imitation is lower than the cost of innovation, if a firm innovates the new technology under no patent protection, it is optimal for the remaining firms to imitate this technology rather than inventing it through own R&D. However, imitation will occur until the net profit of each imitator is 0. Hence, it is trivial that if all the imitators get zero net profit, the net profit of the initial innovator will be negative, which implies that there will be no innovation under no patent protection. However, innovation occurs under patent protection. Therefore, it is immediate that, in absence of the integer constraint, which implies that, in equilibrium, the net profits of the firms are zero, patent protection always increases R&D, and supports the standard argument for patent protection.

However, if there are multiple innovators, no patent protection can increase R&D investments even in the presence of imitation if the net profit of each imitator is not equal to 0, which is possible if we consider the firms as integers instead of considering the number of firms as a continuous variable. This is shown in Figure 1.

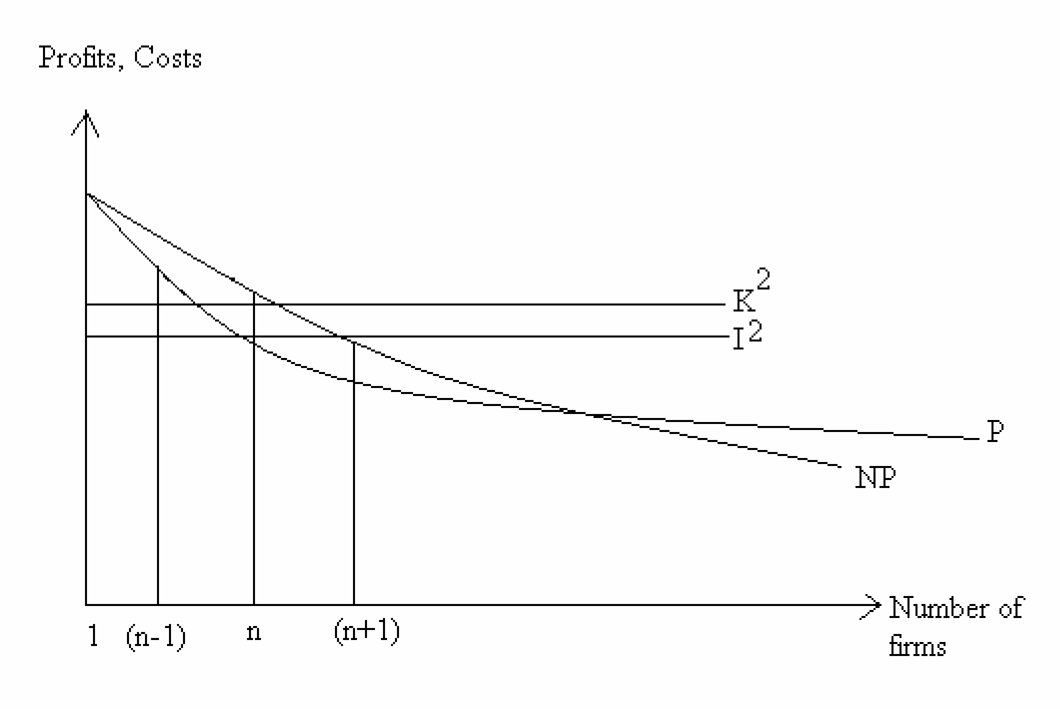

Figure 1

Higher R&D under No Patent Protection than under Patent Protection in Presence of Imitation

The curves P and NP show the expected gross profit of a firm under patent protection and under no patent protection respectively. The lines K^2 and I^2 show the costs of R&D and imitation. Figure 1 considers the situation where $\pi_i^P(n) > K^2 > I^2 > \pi_i^P(n+1)$ and $\frac{\pi_i^{NP}(n-1)}{(n-1)} > K^2 > \frac{\pi_i^{NP}(n)}{n}$, which implies that there are n firms under no patent protection but $(n-1)$ firms under patent protection. This is in contrast to the standard argument for patent protection, and confirms our result of the previous section. However, it must be noted that $(n-1)$ firms do carry out original innovation under patent protection, while, under no patent protection, only one firm does original innovation and other $(n-1)$ firms do imitative innovation.[8]

III (ii).. *The Effect of Technology Licensing*

It may seem from our analysis in section 2 that if, under patent protection, the monopolist patent holder has the option to license its technology to other firms, patent protection never reduces R&D investment. However, there are at least two simple arguments against technology licensing.

First, it is well documented in the literature that often technology licensing is very costly (see, e.g., Teece [1977 and 1981] and Federal Trade Commission [2003]). So, it is immediate that if technology licensing is sufficiently costly, it reduces the patent holder's incentive for licensing the technology to the potential competitors by reducing the gain from technology licensing significantly. Therefore, technology licensing does not occur for sufficiently high cost of licensing, and our results remain.

Secondly, even if technology licensing is not costly, it may be possible that, under patent protection, the monopoly patent holder has no incentive to license the technology to his competitors. Let us assume that the monopoly patent holder can license his technology against an up-front fixed-fee and there is no cost of technology licensing. As mentioned in Katz and Shapiro [1985], fixed-fee licensing is the optimal choice of the licenser if there is lack of information about the licensee's output that is necessary for the provision of output royalty in the licensing contract.[9] Given our demand and cost specifications, *ex-post*

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[8] Since the net profit of each imitator is greater than the net profit of the innovator under no patent protection, it may create the free-rider problem, and may not encourage a firm to do the original innovation. This problem can be resolved with mixed strategies of the firms between R&D and imitation, or with different time preferences of the firms. However, since this complication does not add to the main purpose of this paper, we assume away the free-rider problem by considering a pre-assigned sequence of R&D decision of the firms.

[9] Rostoker [1984] shows that, technology licensing contract uses royalty alone 39% of time, fixed-fee alone 13% of time, and royalty plus fixed-fee 46% of time, among the firms surveyed.

innovation, the profit of the monopoly patent holder under no licensing is $\frac{a^2}{4}$. However, under licensing, if there are n firms competing in the product market (which implies that the patent holder licenses its technology to other $(n-1)$ firms), the total industry profit under licensing is $\frac{na^2}{(2+(n-1)\gamma)^2}$, and this is lower than the patent holder's monopoly profit provided $\gamma > \frac{2(\sqrt{n}-1)}{(n-1)} \equiv \gamma^*$.[10] For example, if $n=2$, we find that $\gamma^* = .8$. So, if $\gamma > .8$, under patent protection, the monopoly patent holder has no incentive to license the technology to a competitor. Hence, even if there is no cost of technology licensing, our analysis of section 2 is unaffected if the products are sufficiently substitutable and technology licensing occurs against fixed-fee.

If there is no informational problem about the licensee's output, the patent holder can use output royalty along with up-front fixed-fee while designing the licensing contract. In this situation, the patent holder always finds it profitable to license the technology, and the increase in profit under patent protection through licensing may always help to generate higher R&D investment under patent protection compared to no patent protection. However, it must be noted that as the number of licensing contracts increase, it may require significant amount of information about the outputs of the licensees, and may reduce the effectiveness of output royalty in the licensing contract. Hence, in this situation, the patent holder's incentive for fixed-fee licensing increases, and our discussion about the effect of fixed-fee licensing may become more relevant.

III (iii). *Stochastic R&D Process*

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[10] Note that technology licensing is profitable provided the industry profit is higher under licensing than under no licensing.

In section 2, we have considered a simple deterministic R&D model to show the trade-off between competition under no patent protection and the lower probability of becoming the sole producer under patent protection. Let us now consider the implications of uncertainty in the R&D process. So, along with the uncertainty about getting patent protection, a stochastic R&D process will also create uncertainty about inventing the new technology. On one hand, stochastic R&D will reduce a firm's chance of inventing the technology. On the other hand, given that a firm is successful in R&D, stochastic R&D will increase the successful innovator's profit by reducing its competitors' chance of inventing the technology. The following example will show that, for a given number of firms, whether the difference in the expected profit of the producers under patent protection and under no patent protection is higher under uncertain R&D or under deterministic R&D is ambiguous. Therefore, the following example suggests that, not only the R&D reducing effect of patent protection remains under stochastic R&D process, the net gain from R&D under no patent protection compared to patent protection may be higher under stochastic R&D compared to deterministic R&D. Hence, stochastic R&D may strengthen the possibility of higher R&D investment under no patent protection compared to patent protection.

Let us assume that there are three risk-neutral symmetric firms, each with the independent probability of success (failure, respectively) in R&D denoted by z $(1-z$, respectively), and there is no technology licensing. Therefore, the expected gross profits of a firm under patent protection and under no patent protection are respectively

$$\pi^P = z(z^2\frac{\pi^m}{3} + 2z(1-z)\frac{\pi^m}{2} + (1-z)^2\pi^m)$$

and $$\pi^{NP} = z(z^2\pi^t + 2z(1-z)\pi^d + (1-z)^2\pi^m)\ ,$$

where π^m, π^d and π^t are the profits of a producer when there are respectively one firm, two firms and three firms producing the product. Comparison of the expected gross profits shows that $\pi^P > (<) \pi^{NP}$ provided

$$z((\frac{\pi^m}{3} - \pi^t) - (\pi^m - 2\pi^d)) + (\pi^m - 2\pi^d) > (<) 0$$

or $$z(\frac{\pi^m}{3} - \pi^t) + (1-z)(\pi^m - 2\pi^d) > (<) 0 . \tag{10}$$

If $\gamma = 0$, LHS of (10) negative, and for $\gamma = 1$, given our demand and cost specifications, we get that LHS of (10) is positive. Since LHS of (10) is continuous in γ over $[0,1]$, it is immediate that, for a given z, there exists a critical γ, say $\hat{\gamma}(z)$, such that the expected gross profit of each firm is higher under patent protection (no patent protection) if $\gamma > (<) \hat{\gamma}(z)$. So, if $\gamma < \hat{\gamma}(z)$, there are costs of R&D such that all three firms find it profitable to do R&D only under no patent protection, thus showing that the R&D reducing effect of patent protection remains under stochastic R&D.

Let us now assume that $z = 1$, and γ is such that $\pi^P = \pi^{NP}$ or $\frac{\pi^m}{3} = \pi^t$ (i.e., $\gamma = \frac{2}{\sqrt{3}+1}$, see (6)). Hence, given that $\frac{\pi^m}{3} = \pi^t = K^2$, it implies that, under deterministic R&D and for this cost of R&D, the incentive for R&D is the same under patent protection and under no patent protection. Now, consider the effect of z on π^P and π^{NP}. We find that $\frac{\partial \pi^P}{\partial z} > 0$ for $z < 1$, and at $\gamma = \frac{2}{\sqrt{3}+1}$, $\frac{\partial \pi^{NP}}{\partial z} < 0$ for $z \to 1$.[11] Therefore, it is

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[11] For $z \to 1$, $\frac{\partial \pi^{NP}}{\partial z} \overset{\geq}{\underset{<}{-}} 0$ provided $3\pi^t - 2\pi^d \overset{\geq}{\underset{<}{-}} 0$. We know from (6) that $\pi^m \overset{\leq}{\underset{>}{-}} n\pi^n$ for $\gamma \overset{\leq}{\underset{>}{-}} \frac{2}{\sqrt{n}+1}$, and $\frac{2}{\sqrt{n}+1}$ increases with lower n falls, since $n > 1$. Therefore, at $\gamma = \frac{2}{\sqrt{3}+1}$, we have $3\pi^t = \pi^m < 2\pi^d$.

immediate that if $\gamma = \frac{2}{\sqrt{3}+1}$, for the K^2 at which $\pi^P(z=1) = \pi^{NP}(z=1) = K^2$, we get $\pi^{NP}(z \to 1) > K^2 > \pi^P(z \to 1)$. Hence, this example shows that the net gain from R&D can be higher under no patent protection than under patent protection for stochastic R&D, while it is the same under patent protection and under no patent protection for deterministic R&D. So, stochastic R&D (compared to deterministic R&D) may increase the possibility of lower R&D under patent protection than under no patent protection.

It should be noted that the above example has assumed away any relationship between the R&D investment and the probability of success in R&D. However, if the firms can influence the R&D success probability through its choice of R&D investment, it will further complicate the matter and a fully blown up model is required to analyze this aspect. We leave this issue for future research.

III (iv). *A Different Demand Formulation*

The analysis of section 2 has considered a demand function that is widely used in the literature and is due to Bowley [1924]. An important feature of this demand function is to increase the market size with number of firms. Our discussion on perfect substitutes after Proposition 1 suggests that one may expect R&D investment to be always higher under patent protection than under no patent protection if the number of firms does not affect the market size. The purpose of this subsection is to see whether this is indeed the case if number of firms does not affect the market size and the products are imperfect substitutes that reduce the intensity of competition under no patent protection.

Let us now consider the demand function due to Shubik and Levitan [1980] that eliminates the effect of the number of firms on the market size.[12] Further, like section 2, we assume away imitation, technology licensing and uncertainty in R&D, and consider the number of firms as a continuous variable.

If there are n producers in the market, the inverse demand function for the i th firm is

$$p_i = a - \frac{(n+\gamma)}{(1+\gamma)}\left(\frac{\gamma}{n+\gamma}q_1 + \frac{\gamma}{n+\gamma}q_2 + \dots + q_i + \dots + \frac{\gamma}{n+\gamma}q_n\right), \tag{11}$$

where γ shows the degree of product differentiation. If $\gamma = 0$, (11) becomes $p_i = a - nq_i$ and implies that the products are isolated. But, the products are perfect substitutes when $\gamma \to \infty$ and the inverse demand function (11) becomes $p_i = a - (q_1 + q_2 + \dots + q_i + \dots + q_n)$.

If there is patent protection, only one firm produces in the market even if there are n firms doing R&D at stage 1. Hence, the expected gross profit of the i th innovating firm is $\frac{\pi^m}{n}$, where $\pi^m = \frac{a^2}{4}$. Therefore, the number of firms under patent protection is determined by the condition similar to equation (2), and it is

$$\frac{a^2}{4n} = K^2. \tag{12}$$

However, the analysis is affected by this new demand formulation when there is no patent protection. If n firms do R&D under no patent protection, the gross profit of the i th innovating firm is $\pi^c = \frac{a^2(1+\gamma)(n+\gamma)}{(2n+\gamma n+\gamma)^2}$. Therefore, the equilibrium number of innovating firms under no patent protection is determined by

$$\frac{a^2(1+\gamma)(n+\gamma)}{(2n+\gamma n+\gamma)^2} = K^2. \tag{13}$$

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[12] Though the demand functions due to Bowley [1924] and Shubik and Levitan [1980] behave similarly for a given number of firms, they perform differently as number of firms change. One may refer to Martin [2002] for a discussion on this issue.

The comparison of LHS of (12) and LHS of (13) shows that the former is always greater than the latter. Therefore, for a given number of firms doing R&D, the incentive for R&D is always higher under patent protection than under no patent protection. Hence, the following result is immediate.

Proposition 3: Given the demand function (11), where the number of firms does not affect the market size, the R&D investment is always higher under patent protection than under no patent protection.

Since here, patent protection always increases the R&D investment and also increases market concentration compared to no patent protection, it is trivial that, for the demand function (11), welfare is always lower under patent protection than under no patent protection.

IV. CONCLUSION

An important role of patent protection is to increase innovation. The basic argument considers that patent protection prevents competition in the product market and increases the innovator's return from R&D, thus increasing the incentive for R&D.

However, if there are many potential innovators, patent protection may affect the equilibrium number of innovating firms and therefore, may affect R&D investment. We show that whether patent protection increases R&D investment is ambiguous. Patent protection may reduce R&D investment if the cost of R&D is sufficiently high and the number of affects the size of the market. So, whether patent protection increases R&D investment may depend on the type of industry that may differ according to the cost of

R&D and the number of R&D capable firms. We also find that welfare reduces with patent protection.

We discuss the implications of imitation, technology licensing, stochastic R&D process and different types of market demand function on our results.

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