The Role of Licensing
in a Vertically Differentiated Product Market

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Abstract

This paper studies a four-stage, asymmetric duopoly game involving R&D and licensing. Using vertical differentiation model with product innovations, this paper analyzes R&D and licensing game in an industry made of an incumbent monopolist expecting entry by late-starter(s). Even when no leapfrogging in technological innovation is possible, it is shown that the incumbent cannot block the entry into the low quality product once the incumbent innovates. In the absence of technology licensing, the possible entry into the low quality market serves to reduce the incumbent's incentive to incur high sunk costs of developing a high-quality product. The model shows that technology licensing increases the incumbent's incentive to develop a high quality product along with inviting competition into the low quality market. The model also suggests that technology licensing, using only the two-part tariff contracts, can not perfectly implement the fully collusive monopoly outcome due to the commitment problem. This commitment problem may serve to explain why the licensor may want to remain in the market even after the licensing agreement has been reached. The implication of having multiple potential entrants and its impact on the commitment problem is also discussed. Finally, in the leapfrogging entrant case, either the entrant or the incumbent can develop the high quality product, depending on R&D costs. It is shown that the licensing outcome always dominates the non-licensing one unlike the non-leapfrogging case.

I. Introduction

In many technology-intensive industries around the world, firms are heavily involved in R&D to maintain or even improve their position in the market.[1] This worldwide increase in R&D investment forces the firms to actively engage in licensing as well. Due to the rising costs of technology development, a firm has a strong incentive to recover its investment cost quickly by licensing its own technology before competitors produce a vying technology. A firm seeking to maximize the rents from its technology may be able to achieve higher profits by licensing its technology before the competition duplicates the product. Technology licensing is an attractive option to a potential entrant as well, especially when the R&D costs are high. Therefore, as the cost of technology increases, technology licensing will also increase.[2]

According to Sahay et al (1996), international technology licensing to nonaffiliated firms has been rising at average annual rates of over 18 per cent, and domestic technology licensing has been rising at annual rates of over 10 per cent. At the same time, Department of Justice and FTC 1995 Antitrust Guidelines for the Licensing of Intellectual Property includes statements regarding the potential efficiency benefits of licensing and cross-licensing, according to Grindley and Teece (1997).

Therefore, it is not surprising to find that the issue of R&D and licensing has been on the research agenda of many economists for the past two decades. Gilbert and Newbery

[1] Following two examples of technology licensing has close relation to the present paper. **(1)** "Digital Equipment Corp. is expanding its licensing agreement with Samsung Electronics Co. Ltd., …. Under the agreement, Samsung will have rights to future Alpha implementations. Under the previous license, Samsung only had access to the past two generations." [Computer Reseller News, n777, Feb 23, 1998, pp. 127] **(2)** "It licensed 64K DRAM design from Micron Technologies in a successful attempt to shorten the time in learning and production, … Samsung once again decided to source circuit design from Micron Technology to shorten the time gap with Japan and the U.S. in 256K DRAM commercialization. … the subsequent move to the 1M DRM by Japanese firms opened up new opportunities for Samsung and other Korean firms to penetrate the U.S. market, allowing them to emerge as dominant suppliers of the 64K DRAM and 256K DRAM. … Texas Instruments filed a suit against Samsung and eight Japanese chipmakers charging infringement of patents for DRAM designs, … Both Samsung and Hyundai ended up paying royalties on the past and future sales of their memory products. … When firms refuse to supply technology, a sophisticated firm seeking the technology can develop its own technology, as was the case for 4M DRAM." [Kim (1997)]

[2] According to Grindley and Teece (1997), for example, the cost of manufacturing facilities have risen dramatically in semiconductor industry. A new wafer fabrication plant cost $10-20 million in 1975 (4-kilobit DRAM), $300-400 million in 1990 (16-megabit DRAM) and over $1 billion in 1991 (256-megabit DRAM).

(1982) and Reinganum (1983) started the stream of papers on the incentive to innovate. [Vickers (1986), Beath et al. (1987), Delbono (1989), Sorenson (1995)][3] Gilbert and Newbery (1982) showed that an incumbent monopolist with a first-mover advantage will preempt potential entrants by inventing and patenting a new technology. On the other hand, Reinganum (1983) presented an R&D race model in which the incumbent firm losses the race to a potential entrant since the incumbent does not have enough incentive to innovate.

In the meantime, Salant (1984) was the first to demonstrate that licensing of innovation can change the research decision. With the licensing of innovation available, the more efficient potential entrant always achieves the innovation. Gallini (1984) took a different approach to licensing by showing that an incumbent firm may license its production technology to deter a potential entrant from pursuing R&D activity.

These studies are followed by a new stream of literature on licensing and its effect on R&D and product market. Shapiro (1985), Kamien and Tauman (1986), Katz and Shapiro (1986), Gallini and Wright (1990) mainly consider licensing contracts between the non-producing innovator and a licensee(s) in the product market. However, there are studies on the licensing contracts between product market competitors as well.

Marjit (1990) claims that despite the general belief that fully collusive monopoly outcome is achievable through proper licensing contracts, it is not likely that the perfectly collusive outcome is achieved if the game does not include a punishment stage. However, he shows that a firm with advanced technology can sell the knowledge to a less advanced competing firm and still remain in the business. Rockett (1990a, 1990b) discusses the ability of the licensor to select the quality of the technology to license or to whom to license for the licensor's own advantage in the case of process innovation. Eswaran (1994) also examines how the incumbent in a market threatened by entry can exploit its first-mover advantage by licensing its technology not to a potential entrant but to firms that would have remained outside the industry.

The Majority of economic analysis on technology licensing have focused on models with identical consumers and homogeneous products. Although this setup simplifies the analysis enormously, the assumption of homogeneity is far from being a realistic

[3] Among these, Beath et al (1987) and Sorenson (1995) adopts vertically differentiated product market.

portrayal of the real world, especially when new and better products are pouring into the market everyday. The homogeneity assumption precludes coexistence of different quality products in a market.[4] This is quite an extreme result when many firms are found to be producing not just a single product but rather lines of products made of various qualities. Kotabe et al. (1996) refers to the phenomenon of firms cannibalizing their own products by releasing a new generation product as 'product overlap'. In hyper-competitive markets, leading firms are better off by developing next generation products even when those products might cannibalize the sales of their older counterparts.

The present paper examines a four-stage asymmetric duopoly game involving R&D and licensing. By using a vertical differentiation model with product innovations, this paper investigates R&D and licensing in an industry where an incumbent monopolist is threatened by new competition.

The analysis focuses on product innovations instead of process innovations. The licensing firm is assumed to maximize its combined profit from both technology-licensing and product-manufacturing. The licensee maximizes its profit net of licensing payment to the licensor. In order to keep the model as simple as possible, network externality or compatibility issues will not be discussed. To make the analysis tractable, the number of qualities will be restricted to two, denoted by high-quality and low-quality.

This paper first studies the simplest case in which leapfrogging in technological innovation is not possible. The model shows that technology licensing increases the incumbent's incentive to develop a high quality product while inviting competition into the low quality market.

This paper presents the possibility that a firm (entrant) can actually benefit from its rival's (incumbent) innovations due to the multi-product incumbent's lenient behavior. However, given the sequential leadership allowed in the model, the incumbent chooses to totally block the entry by not innovating and producing the low quality product only. Therefore, it can be concluded that in the absence of technology licensing, the possible entry of new rivals into the low quality market weakens the incumbent's incentive to invest in R&D.

[4] For example, in a model with homogeneous consumers, there can be only one level of quality that survives in the market when the technology in question is related to product innovation.

All these results will change dramatically when technology licensing is introduced into the model. Rather than blocking entrants, the incumbent may choose to develop a high-quality product while licensing the low-quality product to a potential entrant, using a two-part tariff. It is shown that licensing encourages the incumbent firm to produce and market "newer generation" products in a situation where the innovation never occurs without licensing.

Unlike the models that exploit homogeneous consumers and products, the model used in this paper suggests that technology licensing, using only the two-part tariff contracts, does not perfectly implement the monopoly (fully collusive) outcome due to the commitment problem. In this paper, this commitment problem may serve to explain why the licensor may want to remain in the market even after the licensing agreement has been reached.

Although this paper focuses mainly on an industry with a single potential entrant, the implication of having multiple potential entrants is also discussed. The leapfrogging entrant case is also analyzed. In contrast to the non-leapfrogging case, it turns out that the incumbent cannot deter the entry by crowding the market with diversified products. It is shown that either the entrant or the incumbent can develop the high quality product, depending on the size of R&D costs. Although, the incumbent cannot fully block entry, the licensing outcome always dominates the non-licensing outcome.

The paper is organized as follows. In section II, the model and the assumptions used in the analysis will be outlined. In section III, the monopoly equilibrium without the threat of entry is considered. In section IV, the main model of duopoly R&D and licensing game is presented. Section V discusses the changes in result when some of the assumptions are released. Section VI concludes the analysis.

II. Model

The following assumptions will be used throughout this paper to make the analysis as simple as possible.

Consider a good that can be produced in two distinct levels of quality, denoted by q_L and q_H, where q_L is the lower and q_H is the higher level of quality. The levels of quality, q_L and q_H, may represent two different generations of a product, such as 32-bit versus 64-bit microprocessor or 32MB versus 64MB RAM. That is, even though the firms can choose the generation of a product to produce through R&D effort, all the products from same generation are regarded as the same by the consumers. This assumption may seem to be too simplifying but it is commonly observed in many hi-tech industries. The technological evolution in the micro-processor industry following so-called 'Moore's law' could be seen as a good example.

p_H and p_L denote the corresponding prices for each quality. A consumer buys no more than one unit of the product given the qualities available in the market. Consumers differ in their income and they will be identified by their income level, θ, that is assumed to be uniformly distributed over the interval [0, 1]. More specifically, consumer preferences are generated by the following utility function:

$$\begin{aligned} u_\theta &= q(\theta - p) && \text{if type-}\theta \text{ consumer buys a unit of good with quality } q \text{ at price } p. \\ & q_0\theta && \text{if type-}\theta \text{ consumer buys none of the products.} \end{aligned} \qquad (1)$$

where $\theta - p$ is the consumer's disposable income devoted to the consumption of the numeraire good. This implies that consumers with higher income enjoy quality improvements more than low income consumers. Each consumer selects the best available package of price and quality that will maximize his utility without violating budget constraint. Thus, every consumer prefers more quality to less and a consumer with higher θ is willing to pay more for the same product than a consumer with lower θ. Consumers can observe available qualities and prices before they make the purchase decision. If the consumer decides to buy, he purchases only one unit of the product that

provides the highest utility. If the utility does not exceed $q_0\theta$ with any of the currently available quality-price combination, then the consumer will not buy any of the products.

Marginal consumer θ_H is defined as the consumer type who is indifferent between (q_H, p_H) and (q_L, p_L), i.e., $q_H(\theta_H - p_H) = q_L(\theta_H - p_L)$. Also, marginal consumer θ_L is indifferent between (q_L, p_L) and not buying at all, i.e., $q_L(\theta_L - p_L) = q_0\theta$. Given these conditions, it can be easily shown that

$$\theta_L = q_L p_L/(q_L - q_0) \quad \text{and} \qquad (2)$$
$$\theta_H = (q_H p_H - q_L p_L)/(q_H - q_L).$$

For simplicity, q_0 is assumed to be zero. If a consumer chooses not to make a purchase, then the consumer's utility is zero. Then (2) can be rewritten as follows:

$$\theta_L = p_L \quad \text{and} \qquad (2')$$
$$\theta_H = (q_H p_H - q_L p_L)/(q_H - q_L).$$

Note that the marginal consumer type θ_L depends only on the price and not on the quality level of low quality product after this simplification. This marginal consumer will enjoy zero utility either by spending all the income on purchasing the product in question or by not buying at all. Using (2′), demand for each product can be defined as follows:

$$D_L(p_H, p_L) = \theta_H - \theta_L = q_H(p_H - p_L)/(q_H - q_L) \qquad (3)$$
$$D_H(p_H, p_L) = 1 - \theta_H = [q_H(1 - p_H) - q_L(1 - p_L)]/(q_H - q_L)$$

This paper focuses on a situation where a monopolist incumbent meets the challenge from a prospective entrant. Initially, the market is monopolized. The monopolist firm will be called the incumbent and already owns the technology to produce the lower quality product. The other firm is a potential entrant who may enter the market only after it acquires the production technology in question.

The possibility of technological leapfrogging is not considered in the main analysis. In this model, the incumbent's potential R&D develops the higher quality product. The entrant either develops the technology to produce the low quality product at a cost, F_L, or attains the license for the technology from the incumbent, assuming both parties agree to a contract. Although the non-leapfrogging assumption seems to be a rather stringent restriction to the model, it is not hard to observe a situation where the technological gap is so large that the later entrant can only hope to catch up with the leading innovator. This simplifying assumption will be released later to enable the entrant to develop high quality product.

The competition between firms occurs over four stages when the licensing is introduced to the model. In the first stage, the incumbent decides whether to perform R&D to acquire the technology to produce high quality product. In the second stage, the incumbent decides whether to license its technology to the entrant, and if so, which technology. If the incumbent decides to license one of its technologies, it makes an offer to the potential entrant. Based on this offer, the entrant decides whether to enter the market and the method of acquiring the technology; either through its own R&D, or by signing the licensing contract offered by the incumbent. In the last stage, all competitors choose which product to produce and play a simultaneous pricing game. The simultaneous choice of price signifies the absence of a price leader. This type of ordering between price competition and R&D decisions is widely accepted throughout the literature since investment decisions are often more permanent than price choices. In fact, price competition often takes place under conditions where product development decisions cannot be reversed.

The costs of production are assumed to be constant and are normalized to zero. It is also assumed that in the case where both firms compete with products of equal quality and prices, each will serve half of the market demand for this product. However, there are fixed R&D costs for developing the technology to produce the low and high qualities. The fixed cost associated with developing low quality is represented with F_L. The fixed cost of developing high quality product when it already has the technology to produce low quality product is represented as F_{LH}. Finally, the fixed cost of developing high quality without previous technology to build on is denoted as F_{OH}, and it is assumed that

$F_{OH} \geq F_L + F_{LH}$. These fixed costs are sunk once the firms enter into the price competition stage. If the incumbent only produces low quality product, R&D costs need not be considered in the incumbent's maximization problem. As for F_L, the stronger patent protection is reflected in the bigger fixed imitation cost for the potential entrant because it is harder to invent around the patent.

For the solution concept, Subgame Perfect Nash Equilibrium is adopted. Proceeding backwards, first the Nash equilibrium in prices from the final stage of the game is considered, then the R&D and licensing decisions of the entrant and finally R&D and licensing decisions of the incumbent is analyzed.

Finally, the following are the notational conventions used throughout the paper (exceptions will be noted as they arise).

$X_{c\,d\,e\,g}^{a\,b}$ where

$X = \pi$ (profit), p (price)

$a = f$ (leapfrogging)

$b = I$ (incumbent), E (entrant), M (monopolist)

$c = R$ (innovate), N (not innovate)

$d = t$ (licensing)

$e = S$ (single product), D (dual product).

$g = H$ (high quality), L (low quality)

III. Benchmark Case – Monopoly

This section considers the profit maximizing problem of a monopolist who does not face any threat of entry as a benchmark case. First, the problem of a single-product monopolist is considered. It can only produce a single product of quality q_i and maximize its profit by choosing the price p_i where $i = L$ or H. It can be shown that the single-product monopolist should solve the following maximization problem.

$$\underset{p_i}{Max} \quad \pi_S^M = p_i(1-\theta_i) - F_i = p_i(1-p_i) - F_i \qquad \text{where} \quad F_i = \begin{cases} 0 & \text{if} \quad i = L \\ F_{LH} & \quad\quad i = H \end{cases}$$

Since it is assumed that the monopolist already has the technology to produce the low quality product, the monopolist does not need additional R&D expenditure when it decides to produce low quality product. Solving the first order condition shows that the single-product monopolist chooses the price $p_S^M = 1/2$ regardless of the quality and the corresponding profit is $\pi_S^M = 1/4 - F_i$.

This implies that the single product monopolist does not have any incentive to develop the high quality product due to the positive R&D cost involved in doing so, given the demand condition used in the model. That means

$$\pi_S^M = \pi_L^M = 1/4 . \tag{4}$$

This is a result of employing the simplified utility function. Since it fortifies the incumbent monopolist's inertia toward innovation, this should not affect the qualitative outcome of the analysis especially when the goal is to show the pro-innovation effect of licensing.

Now consider the case where the monopolist may produce both q_L and q_H through R&D and sells both of them in the market. The monopolist maximizes its profit by choosing the prices of high and low quality goods accordingly. The maximization problem is shown as follows using (3):

$$\begin{aligned} \underset{p_L,\, p_H}{Max} \quad \pi_D^M &= p_L(\theta_H - \theta_L) + p_H(1-\theta_H) - F_{LH} \\ &= \frac{p_L q_H (p_H - p_L)}{q_H - q_L} + \frac{p_H[q_H(p_H - 1) - q_L(p_L - 1)]}{q_H - q_L} - F_{LH} \end{aligned} \tag{5}$$

where F_{LH} is the R&D cost for developing high quality product when a firm already owns the technology for low quality product.

Solving this maximization problem (5) with respect to prices results in the following two first order conditions.

$$p_L = \frac{p_H(q_L + q_H)}{2q_H} \text{ and } p_H = \frac{q_H - q_L + p_L(q_L + q_H)}{2q_H}. \quad (6)$$

Solving these together will give the following price equilibrium which maximizes profit for a multi-product monopolist.

$$p_{DL}^M = \frac{q_L + q_H}{q_L + 3q_H} \text{ and } p_{DH}^M = \frac{2q_H}{q_L + 3q_H}. \quad (7)$$

The corresponding profit in this case is

$$\pi_D^M = \frac{q_H}{q_L + 3q_H} - F_{LH}. \quad (8)$$

It is easy to show that the monopolist's incentive to develop new and better products depends on q's and F_{LH}. If $\pi_D^M = \frac{q_H}{q_L + 3q_H} - F_{LH} > \pi_S^M = \frac{1}{4}$ or alternatively $F_{LH} < \frac{q_H - q_L}{4(q_L + 3q_H)}$, then the monopolist would want to invest in the R&D activity.

IV. Duopoly (No Leapfrogging in R&D)

Whether the potential entrant can make a technological leap beyond the incumbent makes a significant difference in the course of analysis. In this section, the non-leapfrogging case in which the single potential entrant cannot achieve leapfrogging through its own R&D effort is analyzed. It is further assumed that the potential entrant cannot achieve the technology required for high quality product even with licensing. The change in the

resulting equilibrium from introduction of multiple potential entrants or leapfrogging is illustrated in the next section on extensions. It will be assumed that the R&D cost is small enough so that the entrant has an enough incentive to enter the market, i.e., $F_L < q_H(q_H - q_L)/(4q_H - q_L)^2$. Otherwise, it will be a trivial case where the entrant never enters the market.

1. R&D game without licensing

Figure 1 depicts the extensive form of R&D game when there is no licensing. The case where the monopolist develops the high quality product and the entrant enters the market is considered first. In this case, there are two possible outcomes depending on whether the incumbent competes or not with the entrant in the low quality product.

First, when the incumbent enters the market with its own R&D for the low quality product and the incumbent produces only the high quality, the entrant's and the incumbent's profit maximization problems can be shown as

$$\underset{p_L^E}{Max} \quad \pi_L^E = \frac{p_L^E q_H (p_H^I - p_L^E)}{q_H - q_L} - F_L, \tag{9}$$

$$\underset{p_H^I}{Max} \quad \pi_H^I = \frac{p_H^I [q_L (p_L^E - 1) - q_H (p_H^I - 1)]}{q_H - q_L} - F_{LH}. \tag{10}$$

Outcome of the pricing game and corresponding profits can be shown as follows:

$$p_H^I = \frac{2(q_H - q_L)}{4q_H - q_L}, \qquad p_L^E = \frac{q_H - q_L}{4q_H - q_L},$$

$$\pi_H^I = \frac{4q_H (q_H - q_L)}{(4q_H - q_L)^2} - F_{LH}, \qquad \pi_L^E = \frac{q_H (q_H - q_L)}{(4q_H - q_L)^2} - F_L. \tag{4}$$

Next, in the case where the incumbent produce both qualities, the entrant's profit can be shown as

$$\pi_L^E = \begin{cases} \dfrac{p_L^E q_H (p_H - p_L^E)}{q_H - q_L} - F_L \\ \dfrac{p_L^E q_H (p_H - p_L^E)}{2(q_H - q_L)} - F_L \\ -F_L \end{cases} \quad \text{if} \quad \begin{cases} p_L^E < p_L^I \\ p_L^E = p_L^I \\ p_L^E > p_L^I \end{cases}$$

while the incumbent's corresponding profit is

$$\pi_L^I = \begin{cases} \dfrac{p_H [q_L (p_L^E - 1) - q_H (p_H - 1)]}{q_H - q_L} - F_H \\ \dfrac{p_L^E q_H (p_H - p_L^E)}{2(q_H - q_L)} + \dfrac{p_H [q_L (p_L^E - 1) - q_H (p_H - 1)]}{q_H - q_L} - F_H \\ \dfrac{p_L^I q_H (p_H - p_L^I)}{q_H - q_L} + \dfrac{p_H [q_L (p_L^E - 1) - q_H (p_H - 1)]}{q_H - q_L} - F_H \end{cases} \quad \text{if} \quad \begin{cases} p_L^E < p_L^I \\ p_L^E = p_L^I \\ p_L^E > p_L^I \end{cases}.$$

The profit maximizing price for the entrant is be $p_H/2$ as long as the incumbent's price on low quality product is higher than $p_H/2$. However, the entrant is always willing to beat the incumbents price by an infinitesimally small margin when the incumbent's price is equal to or less than $p_H/2$. On the other hand, the incumbent is not always willing to beat the entrant's price on low quality product since the incumbent has to consider the combined profit from both the high and low quality products.[5]

The only way the incumbent can have positive sales of low quality product is by setting its price equal to zero. In this way, the incumbent can neither attain positive

[5] To find out the exact choke price, the incumbent's overall profit from selling both products should be compared with its profit from selling only the high quality product π_H^I. Given p_H and p_L^E, if the incumbent's price p_{DL}^I is infinitesimally lower than the entrant's price, the incumbent serves the whole low quality demand. However, it can be easily shown that even if $p_{DL}^I < p_L^E$, $\pi_D^I \le \pi_H^I$ if $p_{DL}^I \le p^{choke} = \dfrac{q_H + q_L - 2q_H\sqrt{4q_H^2 + 5q_L^2}}{(4q_H - q_L)(3q_H + q_L)}$. Therefore, the incumbent will never set the price of low quality product lower than p^{choke} and will always lose the price competition to the entrant on the low quality product.

market share in the low quality product sales with positive profit nor drive the entrant out of the market if it produces both high and low quality products. When the entrant's price on the low quality product is low enough, the competition in the low quality product sales only lowers the incumbent's profitability from the sales of high quality product.[6] The overall profit of the monopolist with positive sales of low quality product in this case will be $\pi_D^I = (q_H - q_L)/(4q_H) - F_{LH}$ with $p_{DH}^I = (q_H - q_L)/(2q_H)$ while both firms' prices on the low quality product are zero.

Since $\pi_H^I \geq \pi_D^I$, the incumbent will always chooses to sell only high quality product once he decides to innovate in the first stage of the game. Knowing that it is neither credible nor optimal for the incumbent to deviate from this equilibrium once the incumbent develops the high quality product, the entrant always enters the market as long as $F_L < q_H(q_H - q_L)/(4q_H - q_L)^2$ when it observed the incumbent's development of high quality product.

Proposition 1. *In the subgame where the incumbent acquired the high-quality product technology while no licensing is available, the entrant will always enter the market by developing the low quality product if* $F_L < q_H(q_H - q_L)/(4q_H - q_L)^2$ *, and the incumbent will only produce the high quality product.*

It should be noted that the incumbent cannot threaten the entrant with zero profit once the incumbent acquires the production technology for the low quality product. When the incumbent develops the new technology, the entrant can expect that competition for the low quality product will be less intense. Therefore, incumbent's development of high quality product gives the potential entrant more of an incentive to enter the market with low quality product. Once the entrant actually enters the market by developing the product, it attempts to recover the sunk cost and to maximize its profit whether it is negative or positive.

Finally, when the incumbent firm decides not to develop the production technology for high quality product and chooses to produce only low quality product, there can be no

[6] See Judd (1985) and Martinez-Giralt (1989).

further entry. The potential entrant can produce only the low quality product if it decides to enter the market. In addition, the entrant's profit can only be negative, assuming a positive R&D cost, according to the nature of Bertrand competition. Consequently, the potential entrant stays out of the market, and the profit of the incumbent remains the same as that of a single-product monopolist producing low quality product without the threat of entry, which is $1/4$.

It can be easily shown that $\pi_H^I = \frac{4q_H(q_H - q_L)}{(4q_H - q_L)^2} - F_H < \pi_L^M = \frac{1}{4}$; in other words, the resulting profit from innovation can never be greater than the profit from blocking entry by not innovating. Therefore, the outcome of the innovation subgame will always be outweighed by the outcome of entry-blocking, no-innovation subgame. While exiting from low quality production raises the innovating incumbent's profitability, that profit level is still lower than no-innovation entry-blocking profit. Without licensing, the incumbent will not invest in R&D.

Proposition 2. *For the incumbent in the R&D game where no licensing is available, the resulting profit in no-innovation subgame always outweighs the profit in innovation subgame. Therefore in the equilibrium, the incumbent always chooses to block the entry by not innovating.*

2. R&D game with licensing

Figure 2 depicts the trimmed version of the extensive form representation of the R&D and licensing game. Consider the two-part tariff of $rD_L(p_H, p_L) + A$ where r is the per-unit royalty and A is the lump-sum payment for licensing the technology. The royalty is paid according to the units sold while the lump-sum payment is paid up front when the licensing agreement is reached. First, the equilibrium of the two-part tariff licensing subgame is derived where the incumbent produces only high quality product and the entrant produces only low quality product. Once again, the equilibrium should be subgame perfect. Therefore the pricing game will be solved first.

Given r and A, the entrant's and incumbent's profit maximization problems are

$$\underset{p_L}{Max} \quad \pi_{tL}^{E} = (p_L - r)D_L - A = \frac{q_H(p_H - p_L)(p_L - r)}{q_H - q_L} - A \tag{11}$$

$$\underset{p_H}{Max} \quad \pi_{tH}^{I} = p_H D_H + rD_L + A - F_{LH} \tag{12}$$

$$= \frac{p_H[(p_L - 1)q_L - (p_H - 1)q_H]}{q_H - q_L} + \frac{r \cdot q_H(p_H - p_L)}{q_H - q_L} + A - F_{LH}.$$

Solving each maximization problem (11) and (12) with respect to corresponding price results in following first order conditions.

$$\frac{q_H(p_H - 2p_L + r)}{q_H - q_L} = 0 \text{ and } \frac{q_H(1 + r - 2p_H) + q_L(p_L - 1)}{q_H - q_L} = 0. \tag{13}$$

The best response functions obtained from rearranging these first order conditions can be shown as follows.

$$p_{tL}^{E\,BR}(p_H; r, A) = \frac{r + p_H}{2} \text{ and } p_{tH}^{I\,BR}(p_L; r, A) = \frac{(p_L - 1)q_L + (r + 1)q_H}{2q_H} \tag{14}$$

Solving these simultaneously, the pricing equilibrium of the second stage can be shown as follows.

$$p_{tL}^{E\,*}(r, A) = \frac{q_L - (1 + 3r)q_H}{q_L - 4q_2} \text{ and } p_{tH}^{I\,*}(r, A) = \frac{(r - 2)q_L + 2(1 + r)q_H}{4q_H - q_L}. \tag{15}$$

Now, these can be used to solve the second stage problem where the licensing agreement is decided. The entrant takes the licensing offer as long as $\pi_{tL}^{E} \geq \pi_{L}^{E}$. Therefore, it can be safely assumed that the incumbent sets the lump-sum payment A so

that $\pi_{tL}^{E} = \pi_{L}^{E}$ is satisfied given the per-unit royalty of *r* without loss of generality. In this case, it can be shown that

$$A = (p_L^E - r)(\theta_H - \theta_L) - \pi_L^E = \frac{q_H(p_H - p_L^E)(p_L^E - r)}{q_H - q_L} - \frac{q_H(q_H - q_L)}{(4q_H - q_L)^2} + F_L$$

$$= \frac{r(r-2)q_H(q_H - q_L)}{(4q_H - q_L)^2} + F_L . \qquad (16)$$

The maximization problem for the incumbent becomes

$$\underset{r}{Max} \quad \pi_{tH}^{I} = \frac{q_H\{[-4 + r(7-2r)]q_L + [4 + r(2-7r)]q_H\}}{(4q_H - q_L)^2} + F_L - F_{LH} \qquad (17)$$

Once again, by solving this maximization problem with respect to *r*, the optimal choice of per-unit royalty by the incumbent can be shown as

$$r^*(q_L, q_H) = \frac{7q_L + 2q_H}{4q_L + 14q_H} . \qquad (18)$$

Here is the equilibrium of licensing subgame where the licensing agreement utilizes a two-part tariff and the incumbent pulls out of the low quality production.

$$r = \frac{7q_L + 2q_H}{4q_L + 14q_H}, \qquad A = F - \frac{q_H(q_H - q_L)(2q_H + 7q_L)(26q_H + q_L)}{4(4q_H - q_L)^2(7q_H + 2q_L)^2},$$

$$p_{tH}^{I} = \frac{8q_H + q_L}{14q_H + 4q_L}, \qquad \pi_{tH}^{I} = \frac{q_H(116q_H^2 - 52q_Lq_H + 17q_L^2)}{4(4q_H - q_L)^2(7q_H + 2q_L)} + F_L - F_{LH},$$

$$p_{tL}^{E} = \frac{5q_H + 4q_L}{14q_H + 4q_L}, \qquad \pi_{tL}^{E} = \frac{q_H(q_H - q_L)}{(4q_H - q_L)^2} - F_L \qquad (19)$$

Even though the licensing equilibrium does not recover the joint profit to the multi-product monopolist level, the incumbent's profit can be greater than the no-innovation, no-licensing profit i.e., $\pi_{tH}^{I} > \pi_{L}^{M}$ as long as the following condition is satisfied:

$$F_{LH} < \frac{(q_H - q_L)(2q_H{}^2 - 12q_H q_L + q_L{}^2)}{2(4q_H - q_L)^2(7q_H + 2q_L)^2} + F_L \qquad (20)$$

The licensing enables the innovating incumbent to recover part of its R&D cost and enables the incumbent to manipulate (though not fully) the entrant's behavior through per-unit royalty rate. Also it is more likely for the incumbent to innovate, the bigger the difference in qualities, the higher the R&D cost associated with low quality product and finally, the lower the R&D cost associated with high quality product.

Proposition 3. *With licensing, the incumbent's incentive to innovate increases. The incumbent chooses to innovate if* $F_{LH} < \frac{(q_H - q_L)(2q_H{}^2 - 12q_H q_L + q_L{}^2)}{2(4q_H - q_L)^2(7q_H + 2q_L)^2} + F_L$ *is satisfied while it never chooses to innovate without licensing.*

3. Summary of non-leapfrogging case

For simplicity, define $q_H = \lambda q_L$.

1) When $F_L > \frac{\lambda(\lambda - 1)}{(4\lambda - 1)^2}$, the entrant will not enter regardless of the incumbent's innovation. Therefore, the incumbent should make the innovation decision based on the comparison between the single product monopoly profit and the dual product monopoly profit.

If $F_{LH} < \frac{\lambda - 1}{4(3\lambda + 1)}$, the incumbent should innovate.

If $F_{LH} > \frac{\lambda - 1}{4(3\lambda + 1)}$, the incumbent should not innovate.

2) When $F_L < \frac{\lambda(\lambda - 1)}{(4\lambda - 1)^2}$, the entrant will always enter and crowd out the incumbent from the low quality product market when the incumbent innovates. Since the licensing profit is greater than the non-licensing profit in the subgame where the incumbent innovates, the incumbent should make the innovation decision based on the comparison between the single product monopoly profit (π_L^M) and the licensing profit (π_{tH}^I).

If $F_H < \frac{(\lambda - 1)(2\lambda^2 - 12\lambda + 1)}{2(4\lambda - 1)^2(7\lambda + 2)} + F_L$, the incumbent should innovate.

If $F_H > \frac{(\lambda - 1)(2\lambda^2 - 12\lambda + 1)}{2(4\lambda - 1)^2(7\lambda + 2)} + F_L$, the incumbent should not innovate.

Since the incumbent may innovate only if licensing is available, it can be concluded that licensing may facilitate innovation and competition simultaneously where innovation and entry would otherwise be blocked due to incumbent inertia.

4. A way to guarantee the multi-product monopoly level of joint profit

Now the question arises why licensing agreement with a two part tariff is not sufficient to guarantee maximum combined-profit of incumbent and entrant. It is shown that the monopoly profit (perfectly collusive outcome) can never be reached with a two-part tariff alone.

Comparing this two-part tariff licensing equilibrium with the multi-product monopolist equilibrium, it can be shown that $p_{tL}^E > p_{DL}^M$ and $p_{tH}^I < p_{DH}^M$. This is also

verifiable from each firm's first order condition for the pricing game evaluated at the monopoly equilibrium.

For the innovation-licensing equilibrium to achieve fully collusive monopoly outcome, the following two conditions should be satisfied at the same time.

$$\frac{\partial \pi^{E}}{\partial p_L}(p_L = p_{DL}^{M},\ p_H = p_{DH}^{M}) = \frac{q_H[q_L(r-2)+3rq_H]}{(q_H - q_L)(3q_H + q_L)} = 0 \qquad (21)$$

$$\frac{\partial \pi^{I}}{\partial p_H}(p_L = p_{DL}^{M},\ p_H = p_{DH}^{M}) = \frac{q_H[q_L(r-1)+q_H(3r-1)]}{(q_H - q_L)(3q_H + q_L)} = 0. \qquad (22)$$

For (21) to be true, the per-unit royalty rate specified in the agreement must be $r = \frac{2q_L}{3q_H + q_L}$ but then at this royalty rate, (22) will be $-\frac{q_H}{3q_H + q_L} < 0$. In other words, the incumbent has an incentive to lower its price on the high quality product. The agreement is not sub-game perfect in that the incumbent will deviate from the joint profit maximizing price since it sees opportunity to further increase self-profit in the actual competition stage.

On the other hand, for (22) to be true, the per-unit royalty rate specified in the agreement must be $r = \frac{q_H + q_L}{3q_H + q_L}$, but once again, at this royalty rate (21) will be $\frac{q_H}{3q_H + q_L} > 0$. In other words, the entrant has an incentive to raise its price on the low quality product to further increase self-profit in the actual competition stage.

Note that this royalty rate is equal to the monopolist's price on the low quality product. This indicates that the licensee will not make any per-unit profit and is compensated with only the initial lump-sum payment. But then in the actual competition stage, the licensee has an incentive to deviate from this price. The licensee actually sets a higher price which would result in positive per-unit profit in addition to the lump-sum payment already paid. This price increase would lower the sales, thereby cutting the licensor's profits from the royalty payments.

It is shown that the traditional approach of vertical control fails to maximize joint profit that can be distributed between the two agents arbitrarily. However, it can be shown that the multi-product monopoly level of joint profit can be recovered by introducing another tool in addition to the two-part tariff.

It is set up in this model that the incumbent gives the entrant an offer of licensing. Therefore, the incumbent must first convince the entrant that the licensing package does not give the incumbent itself any incentive to deviate from the equilibrium that the agreement establishes. That is, the incumbent has to make the licensing offer such that there is no room for an opportunistic behavior on its side if the entrant chooses the multi-product monopoly price. This problem can be constructed as follows.

Objective: Given $p_L = p_{DL}^M = \frac{q_L + q_H}{q_L + 3q_H}$ and $p_{tH}^{I\ BR}(p_{DL}^M; r, A) = \frac{(p_L - 1)q_L + (r+1)q_H}{2q_H}$,

the per-unit royalty, *r*, has to be chosen so that $p_{tH}^{I\ *}(p_{DL}^M; r, A) = p_{DH}^M = \frac{2q_H}{q_L + 3q_H}$.

The solution to this problem is that the incumbent set its royalty level at $\frac{q_L + q_H}{q_L + 3q_H}$ so that $p_{tH}^{I\ BR}(p_{DL}^M; r, A) = \frac{2q_H}{q_L + 3q_H}$. It should be noted that this is equal to the multi-product monopolist's price for the low quality product, exactly what the incumbent wants to achieve through the licensing agreement. This poses a problem to the task at hand. The entrant has an incentive to deviate from $p_L^E = p_L^M$. The entrant's first order condition for the pricing game suggests that at the multi-product monopolist prices (p_{DL}^M, p_{DH}^M) and $r = (q_L + q_H)/(q_L + 3q_H)$, the entrant has an incentive to raise its price to $1/2$.

The only way to prevent the entrant from raising its price from the multi-product monopoly level is by putting direct pressure on the low quality product. This includes maximum price maintenance and maintaining a (hoax) competition. The reason why it is named the 'hoax competition' is that it does nothing unless the entrant deviates from the intended equilibrium. The incumbent does not need to make any profit out of its own low quality product production since it does not make any difference whether the incumbent

makes the profit by selling directly or by receiving royalty payments from the competitor's sales.

However, there is one small caveat in this equilibrium even if the incumbent can successfully enforce this pricing policy. For this licensing offer to be acceptable to the entrant, it a requires negative lump-sum payment from the licensee to the licensor. In other words, the incumbent actually compensates the entrant for the loss of profit that could have been acquired without the licensing agreement. The amount of side payment from the licensor to the licensee would be equal to the profit that would be earned in the equilibrium without a licensing agreement, $\pi_L^E = \frac{q_H(q_H - q_L)}{(4q_H - q_L)^2} - F_L$. The profit of the incumbent in this case is $\pi_D^M - \pi_L^E = \frac{q_H}{q_L + 3q_H} - \frac{q_H(q_H - q_L)}{(4q_H - q_L)^2} - F_{LH} + F_L$. If following condition is satisfied, the incumbent will choose to give the license to the potential entrant:

$$F_{LH} < \frac{(q_H - q_L)(4q_H^2 - 12q_Hq_L + q_L^2)}{4(4q_H - q_L)^2(3q_H + q_L)^2} + F_L . \qquad (23)$$

It can be also easily seen that (23) is a more generous condition than (20) from two-part tariff alone case. Despite the fact that there is still no guarantee that the incumbent will innovate, it is shown that the incentive of the incumbent to innovate has further increased by the possibility of achieving fully collusive joint profit.

Proposition 4. *By using a restricting device on the entrant's price in addition to the two-part tariff, the incumbent can achieve fully collusive outcome. The incentive for the incumbent to innovate is further increased from the case with only a two-part tariff.*

As Shapiro (1985) has pointed out, this type of side payment is likely to be illegal under the antitrust laws. One thing to note is that this side payment does not have to be in the form of cash. It can be in the form of a free technology transfer that can be used by the entrant for the production of unrelated products. Considering the fact that licensing of

not a single but multiple technologies is gaining more popularity in the rapid developing industry, this could be a reasonable option to consider.

V. Extension

1. Multiple Entrants

It should be noted that the resulting licensing-equilibrium can change dramatically when there are not one but multiple potential entrants. To simplify matters considerably, it will be assumed that there are only two potential entrants. However, this would be sufficient to provide general results given the Bertrand price competition setup.

The incumbent offers same licensing contracts to both entrants simultaneously and potential entrants also make the licensing decision simultaneously. With any positive royalty rate, the following normal form (*Figure 3*) describes the payoff to the entrants when a licensing offer is made to both entrants. Without loss of generality, it will be assumed that when one of the entrants chooses to license and the other decides to develop the technology itself, the one without a licensing agreement serves the whole market at a price infinitesimally lower than the royalty rate.

It is always in the interest of the incumbent that at least one of the potential entrants accepts the licensing offer and only the licensee(s) has a positive market share. If the licensing offer is set by the incumbent such that $rD_L(p_H, p_L = r) - F_L > 0$ and $-A = rD_L(p_H, p_L = r) - F_L + \varepsilon$, then at the Nash equilibrium, both entrants license the technology and not make any profit except the negative lump-sum payment from the licensor. The incumbent's combined profit in this case can be shown as

$$\underset{p_H, r}{Max}\, \pi_+^I = p_H D_H(p_H, p_L = r) - rD_L(p_H, p_L = r) + 2F_L - F_{LH} \qquad (24)$$

given that $p_L = r > F_L / D_L(p_H, p_L = r)$.

However, the incumbent can also set the contract such that $r = r_o$ and $-A = 0 + \varepsilon$ where $r_o D_L(p_H, p_L = r_o) - F_L = 0$. Both firms still license the technology at the Nash equilibrium, although the incumbent can collect the combined profit of

$$\begin{aligned} \underset{p_H}{Max}\, \pi_o^I &= p_H D_H(p_H, p_L = r_o) + 2 p_L \cdot D_L(p_H, p_L = r_o)/2 - F_{LH} \\ &= p_H D_H(p_H, p_L = r_o) + F_L - F_{LH} \end{aligned} \qquad (25)$$

given that $p_L = r_o = F_L / D_L(p_H, p_L = r_o)$ due to the Bertrand competition.

By comparing (24) and (25), it can be shown that the incumbent chooses to set a positive royalty rate since (24) ≥ (25).[7] Here, the competition between the licensees prevents any opportunistic behavior from the licensees. Even though symmetry among the potential entrants was assumed here, it would be interesting to extend the case so that potential entrants have different levels of R&D costs to acquire the technology. It is likely that licensing the technology to the potential entrant with highest imitation (R&D) cost would result in the highest revenue for the incumbent as long as the post licensing marginal costs are the same for all the entrants. [see Rockett (1990), Eswaran (1994)]

2. Duopoly with Potential Leapfrogging in R&D

In this section, the equilibrium with a potential entrant that can actually achieve technological leapfrogging through its R&D efforts is considered. In other words, the entrant can actually skip the low quality manufacturing stage and directly enter into the high quality production stage. Unlike the non-leapfrogging entrant case, the entrant may enter either as a low quality producer or as a high quality producer. This means that the incumbent can only block the entry into one of the two sectors but not both. In the non-leapfrogging case, the incumbent could block the entry perfectly by simply producing the

[7] At a royalty rate $r = r_o$ such that $r_o D_L(p_H, p_L = r_o) - F_L = 0$, (24) and (25) are the same. However, the incumbent can choose any $r \geq r_o$ to maximize the combined profit in (24). Therefore, (24) cannot be smaller than (25).

low quality product alone. It is assumed that the entrant's R&D cost for high quality product is small enough so that developing high quality is a viable option for the potential entrant, i.e., $F_{OH} < 4q_H(q_H - q_L)/(4q_H - q_L)^2$. Otherwise, the result is equivalent to the non-leapfrogging entrant case.

When both incumbent and entrant develop high quality product and produce only the high quality product, each firm loses the fixed cost that it spent on the development of this technology. This outcome, therefore will be dominated by any equilibrium where both firms make non-negative profits.

The question arises, then, whether there can be an equilibrium where both firms develop the technology required in the production of high quality product but one of the firms decides not to produce the high quality product. Since the game is played only once, the possession of high technology cannot serve as a tool of punishment. The developer of the technology only benefits when the technology is used for physical production and sales.

Since the equilibrium where the incumbent develops the high quality product and the entrant only develops the low quality product were discussed earlier in non-leapfrogging entrant case, the discussion is limited to the cases where the entrant actually leapfrogs and the incumbent uses only the low quality production technology. This will require only a minor adjustment from the results derived before. Since the incumbent only has the technology to produce low quality product, there are at least two relevant possibilities that needs our attention. All outcomes of the leapfrogging case will be denoted by superscript f.

In the first case of leapfrogging, the entrant actually develops the technology to produce the high quality product all by itself. The resulting profits can be easily derived using (4).

•No-license equilibrium where

Incumbent: *produces the low quality product only*

Entrant: *produces the high quality product only*

$$\pi_H^{fE} = \frac{4q_H(q_H - q_L)}{(4q_H - q_L)^2} - F_{OH}, \qquad \pi_L^{fI} = \frac{q_H(q_H - q_L)}{(4q_H - q_L)^2} \tag{26}$$

In the next case, the entrant acquires the technology to produce low quality product from the incumbent through technology licensing and further develops it into the technology to produce high quality product. Once again, the licensing equilibrium under a two-part tariff is analyzed. The first constraint would be that the two part tariff should allow the licensee to enjoy at least the profit attainable without the technology licensing.

•Licensing-low-quality with the two-part tariff equilibrium where

Incumbent: *produces the low quality product only*

Entrant: *produces the high quality product only*

$$\pi_{tL}^{fI} = \frac{q_H(16q_H^4 + 36q_H^2q_L^2 + 8q_Hq_L^3 + 21q_L^4)}{4(4q_H - q_L)^2(3q_H^3 + q_H^2q_L + 4q_Hq_L^2 + q_L^3)} + F_{OH} - F_{LH},$$

$$\pi_{tH}^{fE} = \frac{4q_H(q_H - q_L)}{(4q_H - q_L)^2} - F_{OH} \qquad (27)$$

Comparing π_{lL}^{fI} with π_{L}^{fI}, it can be shown that

$$\pi_{tL}^{fI} - \pi_{L}^{fI} = \frac{q_H(2q_H^2 + 2q_Hq_L + 5q_L^2)^2}{4(4q_H - q_L)^2(3q_H^3 + q_H^2q_L + 4q_Hq_L^2 + q_L^3)} + F_{OH} - F_{LH} > 0. \qquad (28)$$

The incumbent does not develop high quality product but it gains more profit than through the non-licensing duopoly equilibrium by licensing its low quality technology. Note that in this case, the licensing agreement should guarantee the entrant the high quality producer's profit since the incumbent does not actually have the high quality technology. Therefore, at a subgame where the incumbent chooses not to innovate, the incumbent will choose to license its technology for producing low quality product thereby allowing the entrant to develop the technology into that used in high quality product.

Finally, π_{tL}^{fI}, payoff to the non-innovating-but-licensing incumbent should be compared to that of the innovating incumbent to determine the final equilibrium of the innovation and licensing game.

It is known from the last section that the equilibrium payoff to the innovating incumbent regardless of the potential of the entrant's leapfrogging is

$$\pi_{tH}^{fI} = \frac{q_H(116q_H^{\ 2} - 52q_Lq_H + 17q_L^{\ 2})}{4(4q_H - q_L)^2(7q_H + 2q_L)} + F_L - F_{OH}, \tag{29}$$

and it can be shown that

$$\pi_{tH}^{fI} - \pi_{tL}^{fI} = \frac{q_H(q_H - q_L)(236q_H^{\ 4} + 164q_H^{\ 3}q_L + 375q_H^{\ 2}q_L^{\ 2} + 172q_Hq_L^{\ 3} + 25q_L^{\ 4})}{4(4q_H - q_L)^2(7q_H + 2q_L)(3q_H^{\ 3} + q_H^{\ 2}q_L + 4q_Hq_L^{\ 2} + q_L^{\ 3})} + F_L - F_{OH} \tag{30}$$

This may or may not be positive depending on the R&D costs.

Therefore it can be concluded that it is not certain whether the incumbent would innovate or not with available licensing when it faces a potential leapfrogging entrant. If the fixed cost associated with developing the technology to produce high quality product is large enough, the incumbent may want to license its technology for low quality product to the entrant and continue to sell the low quality product, while allowing the entrant further develop the technology into that used in high quality product. In this case, the incumbent's inertia toward innovation is reinforced with licensing. On the other hand, if the fixed cost of innovation is low enough, then the licensing provides the incumbent an incentive to innovate. However, there is no strategic deterrence of innovation as in the case of non-leapfrogging entrant. As long as the fixed R&D cost is sufficiently small, there will be an innovation either by the incumbent or the entrant. After all, the joint profit of both the incumbent and the entrant increases with licensing regardless of who develops the technology required for high quality product.

As is the case in non-leapfrogging case, by implementing additional way to control the entrant's pricing behavior, the incumbent can achieve fully collusive monopolist

profit (net of the payment the entrant). In the case of leapfrogging entrant, the way to achieve this would be full line licensing and full line (hoax) competition. It can be shown that to guarantee the collusive outcome, the incumbent should license both the high and low quality production technology at a royalty rate equivalent to the multi-product monopolist's price and maintains (hoax) competition on both products. The incumbent only has to pay a side payment equivalent to the entrant's profit in the case without the licensing agreement. The resulting profits can be shown as follows:

$$\pi_{tD}^{fI} = \pi_{D}^{M} - \pi_{H}^{fE} \quad \text{and} \quad \pi_{tD}^{fE} = \pi_{H}^{fE}. \tag{31}$$

VI. Conclusion

Using a vertical differentiation model with product innovations, this paper investigates R&D and licensing games in an industry where an incumbent monopolist is threatened by new competition.

In the case where leapfrogging is not allowed in technological innovation, it is shown that technology licensing increases the incumbent's incentive to develop a high quality product while inviting competition into the low quality market. However, whether the innovation and licensing is realized still depends on the actual R&D costs.

A potential entrant can actually benefit from the incumbent's product innovation. By taking advantage of the multi-product incumbent's lenient behavior in price competition, an entrant can totally encroach upon the low-quality market. However, given the sequential leadership allowed in the model, the incumbent chooses to totally block the entry by producing the low quality product only. Therefore, it can be concluded that in the absence of technology licensing, the possible entry into the low quality market serves to reduce the incumbent's incentive to incur high sunk costs of developing a high-quality product.

When technology licensing is introduced into the model, rather than blocking entrants, the incumbent may choose to develop a high-quality product while licensing the low-quality product to a potential entrant, using a two-part tariff. Licensing raises the

incumbent's incentive to develop and market "newer generation" products without fearing the threat of potential entry.

Unlike the models that exploit homogeneous consumers and products, the model used in this paper suggests that technology licensing, using only the two-part tariff contracts, does not perfectly implement the monopoly (fully collusive) outcome due to the commitment problem. However, it is suggested that the fully collusive outcome can be realized by employing a controlling device for the licensee's price in addition to the two-part tariff. This additional device includes price ceiling (that is more likely to be illegal) and 'hoax' competition.

The implication of having multiple potential entrants is also discussed. Due to the competitive pressure between the multiple licensees, there is no commitment problem in this case. Finally in the leapfrogging entrant case, it is shown that the licensing outcome always dominates the non-licensing one despite the ambiguity of who becomes the innovator.

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Figure 1. Trimmed version of Extensive Form R&D game without Licensing

R: Innovate
N: Do not innovate
I: Incumbent
E: Entrant

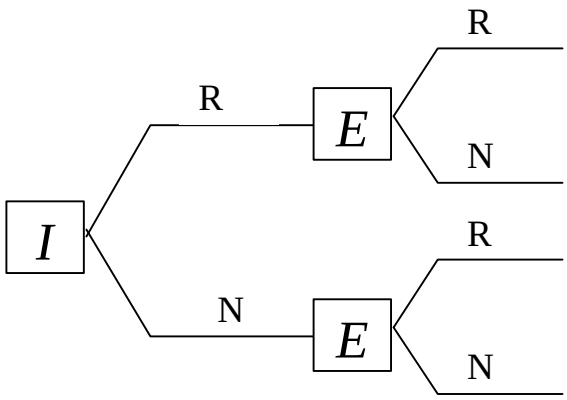


Figure 2. Trimmed version of Extensive Form R&D game with Licensing

(Non-Leapfrogging case)

R: Innovate
N: Do not innovate
t: License
n: Do not license
I: Incumbent
E: Entrant

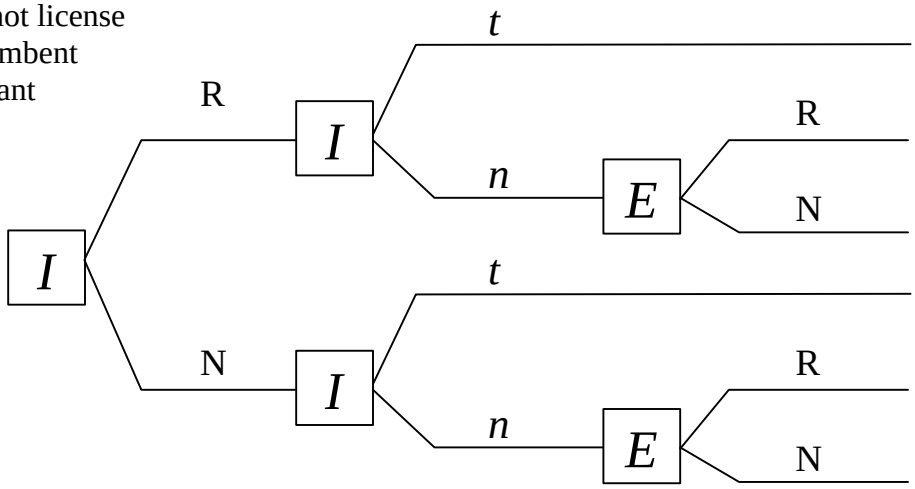


Figure 3. *The payoff matrix to entrants when a technology licensing is offered*

$$\psi_1 = rD_L(p_H, p_L = r) - F_L,$$
$$\psi_2 = (p_L - r)D_L(p_H, p_L) - A,$$
$$\psi_3 = p_L D_L(p_H, p_L) - F_L.$$

entrant 1 entrant 2	Licensing	No licensing And Own R&D	Do not enter
Licensing	$-A$ $-A$	ψ_1 $-A$	0 ψ_2
No licensing and own R&D	$-A$ ψ_1	$-F_L$ $-F_L$	0 ψ_3
Do not enter	ψ_2 0	ψ_3 0	0 0