International Licensing and R&D Subsidy

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Abstract

R&D rivalry and optimal R&D policies are investigated in an asymmetric four-stage game that involves international licensing. It is found that a government's R&D policy crucially depends on its domestic firm'S bargaining power over the licensing gain. When the firm's bargaining power is greater than one half, the government subsidizes its home firm's R&D investment, while imposes a tax if the firm's bargaining power is less than one half. Additionally, this result does not depend on the status of the firm (the licensor or the licensee). Finally, the effects of two different licensing contracts (fixed-fee v.s. royalty per unit) on governments' optimal R&D policies are investigated.

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Introduction

Licensing is a voluntary form of technology dissemination whereby an innovator can benefit from selling its superior technology to other firms through licensing contracts. In the last few decades licensing has become an important activity in many high-tech industries where licensing is used by the firms as a principal way of profiting from their innovations. The licensing revenues of those industries have increased rapidly, for example, in 1996 alone

US industry received \$136.3 billion in royalties from domestic and international licensees (Degnan, 1998). The licensing income of US corporations from foreign unaffiliated entities has grown steadily over the past few years, especially in the computer software industry, where the annual growth rate was at 12 % during the period of 1985-1996. Meanwhile, these high-tech industries are facing fierce competition in international markets and have been receiving substantial amount of R&D subsidies from their governments in various forms. To access the impact of R&D subsidies on these R&D and licensing-intensive industries, one needs to develop a model, which embeds not only firms' R&D rivalry but also their licensing activities.

The interdependence of governments' R&D policy and firms' R&D rivalry in an international context has been studied for almost two decades. In their seminal work on strategic trade policy, Brander and Spencer (1983) have shown that firms' strategic R&D competition[1] induces governments to subsidize their domestic firms' R&D investments. Cheng (1987) examines a dynamic version of their model with R&D spillovers and reinforces their results. Bagwell and Staiger (1994) extend the Spencer-Brander model to oligopolistic market with R&D uncertainty. They conclude that governments subsidize their home firms' cost-reducing R&D activities regardless of the nature of the downstream competition (Bertrand or Cournot). Qiu and Tao (1998) prove that the R&D cooperation even raises the governments' incentives to subsidize their firms' R&D investments.

In industries where both international licensing and government R&D subsidy are present, it is important to understand how firms' licensing decisions affect governments' R&D policies, and vice versa. we set up a four-stage game with two governments and two firms, who sell their products in a third country. These firms have different R&D efficiencies and have the possibility of purchasing the more advanced technology from their rival through international licensing.

The following three questions are addressed in this paper. (1) Should a government subsidize or tax its firm's R&D investment given the feasibility of international licensing? (2) Should a less efficient firm buy a new technology or develop it itself? (3) Are governments' R&D policies contingent on the type of licensing contracts, i.e. fixed-fee v.s. royalty per unit contract?

[1]Strategic R&D competition means that firms involve at first in R&D competition and then in product competition. R&D competition is nonstrategic if R&D and output are simultaneously determined.

It is found that firms' bargaining power plays a pivotal role in designing the governments' R&D policies. A government should subsidize a domestic firm's R&D activities whenever the firm appropriates higher share of licensing gain as compared to its rival firm; while imposing a tax whenever its domestic firm benefits less from the licensing than the foreign firm. When both firms have the same bargaining power, i.e., when the Nash bargaining solution prevails, both governments should stay laissez-faire.

This result is driven by two effects: a competition effect and a licensing effect. Due to the competition effect, an increase in a government's R&D subsidy reduces the rival's R&D investment. However, licensing reduces both firms' production costs and thus enables a firm to benefit from the superior technology of its rival. Due to the licensing effect, a government's R&D subsidy has a positive effect on the rival firm's R&D investment. Therefore, the competition effect encourages the government to subsidize its firm's R&D activity; while the licensing effect induces the government to Levy a tax on R&D investment. The overall effect by which the types (subsidy or tax) of the governments' R&D policies are determined depends on how the total licensing gain is divided. This result is quite different from those in R&D subsidy literature where the possibility of international licensing is ignored and only the competition effect is considered.

Furthermore, it is shown that whether the less efficient firm (firm 2) will develop a new technology itself or buy it from the more efficient firm (firm 1) depends both on its bargaining power and its R&D cost. Firm 2 will innovate if it has most of the bargaining power over the licensing gain. With higher bargaining power, firm 2's R&D investment will be subsidized and hence the asymmetry between the firms' research capabilities becomes small. If firm 1 has higher bargaining power and firm 2's R&D cost is sufficiently high, firm 2 prefers not to invest in R&D.

In the case of both firms' innovating, the less efficient firm may leapfrog the more efficient firm in the innovation market and becomes licensor, under the condition that the less efficient firm's bargaining power is sufficiently large and the difference in R&D cost between the firms is sufficiently small.

The robustness of this result is investigated under two different types of licensing contracts: fixed-fee licensing and royalty per-unit licensing. It is found that the type of optimal R&D policies (subsidy or tax) is not contingent on the type of licensing contracts. That is, the government subsidizes (taxes) its firm's R&D activities, as long as its firm's bargaining power over licensing gain is greater (less) than a half, no matter whether the firms engage in fixed-fee or royalty per-unit licensing. However, the optimal amount of R&D subsidy or tax are different under different licensing contracts.

This paper proceeds as follows. Section 2 presents the basic model. In Section 3 the governments' optimal R&D policies as well as firms' R&D rivalry and licensing decisions under fixed-fee licensing contract are analyzed . In Section 4 these questions are studied under royalty-per-unit licensing contract. Section 5 concludes.

The Model

In this section, a basic model of R&D competition with patent licensing and government intervention in international markets is developed.

There are two governments and one firm in each of these countries. Governments choose their R&D policies, firms make innovation and licensing decisions and then play a Cournot duopoly game. Following the literature on strategic trade policy we adopt the "third-market model"[2] and assume that the two rival firms from two countries compete exclusively in a third market.

Each government maximizes its social welfare, G_i, which is the difference between its domestic firm's profit π_i and the amount of R&D subsidy[3]. That is,

$$G_i = \pi_i - s_i x_i, \ i = 1, 2 \tag{1}$$

where s_i is the subsidy rate and x_i is firm i's R&D investment.

Firms' unit costs c are identical and constant. However, their R&D investment efficiencies are different and represented by v_1, v_2, where $v_1 \neq v_2$. The efficiency measure of R&D investment can be interpreted as firm i's R&D unit cost. Without loss of generality, firm 1 is taken to be more efficient in its R&D, $v_1 < v_2$. The market demand function is linear, $p = a - Q$, where $Q = q_1 + q_2$.

[2]In a third-market model, a domestic government can do nothing to directly hinder a foreign firm, (i.e. there is no room for import tariffs or quotas), and the natural policy to consider is R&D subsidy policy, which will strategically affects the foreign firm's decision on R&D investment. (See Brander 1995)

[3]Since it is assumed that the firms are competing in a third market, consumer surplus is not concluded in governments' objective function.

Firm i's payoff without licensing is

$$\pi_i^0 = pq_i - (c - f(x_i))q_i - (v_i - s_i)x_i \tag{2}$$

where $f(x_i)$, $i = 1, 2$ is firm i's cost reduction due to x_i units of R&D investment. It is assumed that $f(x_i) \leq c$. R&D investment is subject to diminishing returns, i.e. $f^{'}(x_i) > 0$ and $f^{''}(x_i) < 0$. For simplicity, hereafter the R&D production function is specified by the form

$$f(x_i) = \sqrt{x_i}.$$

After licensing, each firm maximizes its total payoff (profit plus licensing gain). For the time being, we consider fixed-fee licensing. The licensing gain E under fixed-fee licensing is the difference between the highest fee the licensee is willing to pay and the lowest fee the licensor is willing to accept, this difference happens to be the industry's incremental profit. Let firm i be the licensor and firm j the licensee, then

$$E = \pi(c - f_i, c - f_i) - \pi_i(c - f_i, c - f_j) - \pi_j(c - f_i, c - f_j), \tag{3}$$

where $\pi(c - f_i, c - f_i) = 2\pi_i(c - f_i, c - f_i)$, and $\pi_i(c - f_i, c - f_j) = \frac{(a-c+2f_i-f_j)^2}{9}$.

The firms' total payoffs depend on their share (β) of the total licensing gain (E) and are given as follows:

$$\pi_1^T = \pi_1^0 + \beta E \tag{4}$$
$$\pi_2^T = \pi_2^0 + (1 - \beta)E \tag{5}$$

Under fixed-fee licensing, the firms' total payoffs can also be rewritten as

$$\pi_1^T = \pi_1(c - f_1, c - f_2) - (v_1 - s_1)x_1 + \beta E \tag{6}$$
$$\pi_2^T = \pi_2(c - f_1, c - f_2) - (v_2 - s_2)x_2 + (1 - \beta)E \tag{7}$$

Here β is firm 1's bargaining power over the licensing gain and $(1 - \beta)$ is firm 2's bargaining power, $0 \leq \beta \leq 1$. For extreme values of $\beta = 0$ or $\beta = 1$, it implies that one of the firms gets all the licensing gain from the trade while the other firm is made indifferent between accepting or rejecting the licensing deal. The Nash bargaining solution corresponds to $\beta = \frac{1}{2}$. If the licensor (say, firm 1) has all the bargaining power ($\beta = 1$), then the fixed fee equals the licensee's incremental profit, i.e. $F = \pi_2(c - f_1, c - f_1) - \pi_2(c - f_1, c - f_2)$. If the bargaining power lie between 0 and 1, then the licensee's fixed fee will be $F^* = \beta E + \pi_1(c - f_1, c - f_2) - \pi_1(c - f_1, c - f_1)$, which is the licensor's share of licensing gain plus its profit lose due to fixed-fee licensing. From F^*, if the licensee has all the bargaining power, it will only pay the amount of what the licensor loses due to fixed-fee licensing and thereby the licensor is made indifferent between licensing and not licensing. Therefore, the equations (4.6) and (4.7) are equivalent to

$\pi_1^T = \pi_1(c - f_1, c - f_1) - (v_1 - s_1)x_1 + F^*$ and

$\pi_2^T = \pi_2(c - f_1, c - f_1) - (v_2 - s_2)x_2 - F^*$.

The market game is a multistage game with observed actions and complete information. It has four stages.

- Stage 1, governments simultaneously choose their R&D subsidies (R&D subsidy stage).
- Stage 2, firms simultaneously choose their R&D investments knowing the R&D subsidies in both countries (Innovation stage).
- Stage 3, firms engage in licensing activities (Licensing stage).
- Stage 4, firms play a Cournot duopoly game (Production stage).

Our solution concept is that of subgame perfect equilibrium.

Solution to the game

Before solving the game, it is necessary to make clear how firms' decisions on R&D investment are influenced by the possibility of licensing. In strategic R&D rivalry, each firm's incentive to innovate depends on the actions of its rival. When a firm believes that its rival does not innovate, it will surely invest in R&D because the payoff as a Stackelberg leader is greater than the payoff when no firm were to innovate. Therefore, neither firm innovating is no equilibrium in R&D rivalry. When a firm believes that its rival will innovate, the firm will innovate too, since the payoff as a Stackelberg follower is smaller than the payoff it would earn when both firms innovate. Thus, in the absence of licensing, both firms will invest in R&D and tend to overuse their R&D investments in the sense that more R&D is used than required to minimize total costs (Spencer and Brander (1983).

However, allowing for international licensing, the above equilibrium in R&D rivalry will be altered. When a firm knows that it will become a licensee if it does not innovate, the expectation of being a licensee will dampen its incentives to innovate as long as the licensor does not appropriate all the licensing gain. If the firm can develop a new technology only very inefficiently, i.e. if its R&D cost is relatively high, then the non-innovating firm's payoff (as a licensee) may exceed its payoff when both firms were to innovate. Therefore, given the feasibility of licensing, both firms investing in R&D may not be an equilibrium in R&D rivalry[4].

In this game, where both licensing and the governments' intervention in R&D investment are concerned, there are two cases to consider. Case 1, both firms invest in R&D; Case 2, only one firm innovates.

This model is solved by backward induction. To simplify the cases, it is assumed in this model that the firms' R&D costs are relatively high ($v_i \geq \frac{14-3\beta}{18}$) and the firms' effective R&D efficiencies are similar such that fixed-fee licensing will occur[5].

In the Production stage, the firms choose output levels, taking R&D levels as given by the preceding stage. Before licensing, the firms maximize their before-licensing profit π_i^0, yielding the following equilibrium outputs[6]:

$$q_i^{B0} = \frac{a - c + 2f_i^B - f_j^B}{3}, \; i, j = 1, 2 \tag{8}$$

where $f_i^B = f^B(x_i)$ and $f_j^B = f^B(x_j)$.

If only one firm (firm i) innovates, then

$$q_i^0 = \frac{a - c + 2f_i}{3} \text{ , and } q_j^0 = \frac{a - c - f_i}{3} \tag{9}$$

After licensing, both firms use the licensor's (firm i's) technology and their equilibrium outputs are[7]:

$$q_i^{BF} = q_j^{BF} = \frac{(a - c + f_i^B)}{3}, \tag{10}$$

[4]In a dynamic game on R&D rivalry, Katz and Shapiro (1987) also point out that one firm may prefer losing to winning a patent race when there is possibility of licensing.

[5]The case where licensing occurs is the most relevant case in this paper. R&D rivalry and optimal R&D subsidy policy in the absence of licensing have been considered by Spencer and Brander (1983) and many other works in R&D subsidy literature.

[6]Here "B" stands for both firms investing in R&D.

[7]Here "BF" means that both firms innovate and fixed-fee licensing occurs.

where firm i is the licensor and firm j the licensee.

With one firm innovating, the firms' outputs after fixed-fee licensing have the same form as equation (10) but with a different amount of cost reduction f_i.

In the third stage, the firms engage in licensing if and only if the net gain from licensing is positive (i.e. $E \geq 0$). Under fixed-fee licensing, firm i (licensor) licenses its technology to firm j (licensee) if and only if

$$f_i^B \leq \frac{2(a-c)+5f_j^B}{3}. \tag{11}$$

In the case of nearly drastic innovation ($\frac{2(a-c)+5f_j^B}{3} < f_i^B < a-c+2f_j^B$) or drastic innovation ($f_i^B \geq a-c+2f_j^B$), no licensing will occur. If only one firm innovates, then the condition for fixed-fee licensing to occur is

$$f_i \leq \frac{2(a-c)}{3}. \tag{12}$$

In the Innovation stage, each firm choose the optimal level of R&D investment to maximize its total payoff. The firms's total payoff when both of them innovate are:

$$\pi_i^{BT} = \frac{(a-c+2f_i^B-f_j^B)^2}{9} + \beta\frac{(f_i^B-f_j^B)\left[2(a-c)-3f_i^B+5f_j^B\right]}{9} - (v_i-s_i^B)x_i^B \tag{13}$$

$$\pi_j^{BT} = \frac{(a-c+2f_j^B-f_i^B)^2}{9} + (1-\beta)\frac{(f_i^B-f_j^B)\left[2(a-c)-3f_i^B+5f_j^B\right]}{9} - (v_j-s_j^B)x_j^B \tag{14}$$

The associated first order conditions are, respectively,

$$(2+\beta)(a-c)+(4-3\beta)f_i^B+2(2\beta-1)f_j^B = 9(v_i-s_i^B)f_i^B \tag{15}$$

$$(1+\beta)(a-c)+(2-4\beta)f_i^B+(5\beta-1)f_j^B = 9(v_j-s_j^B)f_j^B \tag{16}$$

By Cramer's rule, one obtains the following equilibrium levels of R&D investment:

$$x_i^B = \frac{\left[9(2+\beta)(v_j - s_j^B) - \beta(7+\beta)\right]^2 (a-c)^2}{D^2} \tag{17}$$

and

$$x_j^B = \frac{\left[9(1+\beta)(v_i - s_i^B) - \beta(7+\beta)\right]^2 (a-c)^2}{D^2} \tag{18}$$

where $D = \left[9(v_i - s_i^B) + 3\beta - 4\right]\left[9(v_j - s_j^B) - 5\beta + 1\right] + 4(2\beta - 1)^2$.

Given f_i^B and f_j^B, the licensing condition in Case 1 (11) is satisfied if $\beta \geq \beta_i^{**}$, $\beta_i^{**} = \frac{14(v_j - s_j) - 7(v_i - s_i) - 18(v_i - s_i)(v_j - s_j)}{3(v_j - s_j) - 5(v_i - s_i)}$. This implies that fixed-fee licensing occurs when the difference in the effective R&D costs $(v_i - s_i)$ between the firms are small.

If only one firm invests in R&D, then the first order condition of maximizing the innovating firm's payoff is[8]

$$(2+\beta)(a-c) + (4-3\beta)f_i - 9v_i f_i = 0 \tag{19}$$

From this the equilibrium level of the innovating firm's R&D investment is

$$x_i = \frac{(2+\beta)^2 (a-c)^2}{\left[9v_i - 4 + 3\beta\right]^2}. \tag{20}$$

Given the optimal cost reduction $f_i = \sqrt{x_i}$, the licensing condition in Case 2 (12) can be rewritten as $\beta \geq \beta_i^*, \beta_i^* = \frac{14 - 18v_i}{3}$. This condition indicates that fixed fee licensing occurs only when the innovating firm has relatively high R&D cost, i.e. $v_i \geq \frac{14-3\beta}{18}$. Moreover, if $\frac{6-2\beta}{9} < v_i < \frac{14-3\beta}{18}$ or $v_i \leq \frac{6-2\beta}{9}$, then firm i does nearly drastic or drastic innovation and no fixed-fee licensing occurs.

In the first stage, government i sets R&D subsidy rates s_i $(i = 1, 2)$ on R&D expenditure to maximize G_i. The first order condition of government i is:

$$\frac{dG_i}{ds_i} = \frac{d\pi_i}{ds_i} - x_i - s_i \frac{dx_i}{ds_i} = 0 \tag{21}$$

[8] If only one firm innovates, its government has no incentives to subsidize the firm's R&D investment, thus, $s_i = 0$. (See also below in stage 1).

By the envelope theorem,

$$\frac{d\pi_i}{ds_i} = \frac{\partial \pi_i}{\partial x_j}\frac{dx_j}{ds_i} + x_i \tag{22}$$

Substituting (22) into (21), the optimal R&D subsidy rate is determined by

$$s_i^* = \frac{\partial \pi_i}{\partial x_j}\frac{dx_j}{ds_i} / \frac{dx_i}{ds_i} \tag{23}$$

Where $s_i^* > 0$ corresponds to R&D subsidy and $s_i^* < 0$ to R&D tax.

The following propositions describe the optimal R&D policies under different cases:

Proposition 1 *If only one firm (say, firm i) invests in R&D and licensing occurs, i.e.* $v_i \geq \frac{14-3\beta}{18}$*, the innovator's government will not subsidize the firm's R&D investment.*

Proof. The proof of this proposition is simple. If only firm i innovates, then $\frac{d\pi_i}{ds_i} = x_i$, the first order condition of the innovating firm's government is simplified as $\frac{\partial g_i}{\partial s_i} = -s_i \frac{dx_i}{ds_i} = 0$. Since $\frac{dx_i}{ds_i}$ is positive we have $s_i^* = 0$. ■

The intuition is that governments' intervention in R&D is justified by firms' strategic interaction in their R&D competition. When only one firm undertakes R&D, there is no R&D competition and no profit-shifting effect between the two firms. Therefore, the government of the innovator has no incentive to intervene.

Proposition 2 *If both firms compete in innovation market and licensing occurs, i.e.* $\beta \geq \beta_i^{**}$*, then the optimal R&D policy for each government is, respectively:* $s_1^* > 0$ *and* $s_2^* < 0$ *if* $\beta > \frac{1}{2}$*;* $s_1^* < 0$ *and* $s_2^* > 0$ *if* $\beta < \frac{1}{2}$*; and* $s_1^* = s_2^* = 0$ *if* $\beta = \frac{1}{2}$*.*

Proof: See Appendix.

It is interesting to see that a government's optimal R&D policy depends on its domestic firm's bargaining power over the total licensing gain, instead of on its domestic firm's competitive cost advantage in developing the technology. When a firm's bargaining power is greater than $\frac{1}{2}$, it is optimal for its government to subsidize this firm's R&D investment, regardless of whether it is a licensor or a licensee. On the other hand, when a firm's bargaining power is less than $\frac{1}{2}$, the optimal R&D policy is a tax policy. When firms have the same bargaining power, it is optimal for both governments not to intervene in firms' R&D investments.

Intuitively, this result is due to two effects: the competition effect and the licensing effect. Although an increase in government's R&D subsidy unambiguously increases its own firm's R&D investment ($\frac{dx_i}{ds_i} > 0$), it has two opposite effects on its rival firm's R&D decision. On the one hand, it decreases its rival's R&D investment due to the competition effect. On the other hand, it increases its rival's R&D investment due to the licensing effect. The overall effect depends on how the licensing gain is split between firms. When one firm has most of the bargaining power, the competition effect dominates the licensing effect, and R&D subsidy curtails the rival firm's R&D investment (i.e.$\frac{dx_j}{ds_i} < 0$). As a consequence, it is optimal for the government to subsidize its firm's R&D activities. Conversely, when a firm gains a smaller share from the licensing deal, the licensing effect dominates the competition effect, and R&D subsidy raises the rival's R&D investment (i.e. $\frac{dx_j}{ds_i} > 0$). As a result, it is optimal for the government to tax its firm's R&D investment. Finally, when the Nash bargaining solution prevails, ($\beta = \frac{1}{2}$), the competition effect and the licensing effect are balanced out, and the government's R&D policies do not affect the rival's R&D decision (i.e. $\frac{dx_j}{ds_i} = 0$). In this case, it is optimal for the governments to stay laissez-faire.

This result contrasts the result in R&D subsidy literature where the licensing effect is neglected. In the absence of licensing, both governments have the incentives to subsidize their domestic firms' R&D investment ($s_1^* > 0$ and $s_2^* > 0$), when the firms are engaging in strategic R&D rivalry. The R&D subsidies from the governments support the firms' tendency of overusing R&D investments, which causes both countries become worse off. The feasibility of international licensing, however, makes the two governments cooperate to some extent and softens the firms' excessive competition in innovation market.

Now we want to show under which conditions the less efficient firm prefers not to invest in R&D. To answer the question, compare firm 2's payoff if it does not innovate itself and instead buys the innovation from firm 1 (π_2^F) to the payoff it would earn when both firms innovate (π_2^B). It can be shown that both firms will innovate if the less efficient firm has most of the bargaining power, i.e. $\pi_2^B > \pi_2^F$ if $\beta \leq \frac{1}{2}$. For $\beta > \frac{1}{2}$, firm 2 will innovate if and only if its R&D efficiency (v_2) is relatively high. Otherwise, it will prefer not to innovate.

Proposition 3 *Whether the less efficient firm will invest in R&D depends both on its bargaining power and its R&D costs. If $\beta \leq \frac{1}{2}$, both firms will innovate. If $\beta > \frac{1}{2}$ the less efficient firm innovates only if its R&D efficiency is sufficiently high.*

Proof: See Appendix

The intuition is that, for $\beta \leq \frac{1}{2}$, if both firms innovate, the less efficient firm is subsidized while the more efficient firm is taxed. The firms become relatively symmetric, and it is more profitable for the less efficient firm to invest in R&D as well. In doing so, it can not only share part of the licensing gain but also enhance its fall-back position during the bargaining process (which increases its before-licensing operating profit by reducing its production cost)[9]. However, if $\beta > \frac{1}{2}$, the less efficient firm will be taxed while its rival is subsidized. Firm 1's advantage in developing the technology will sufficiently exceeds firm 2's. In this case, firm 2 as the less efficient firm will prefer not to invest but to buy the technology from firm 1 if its R&D efficiency (v_2) is relatively low. It is shown in Appendix that if $\beta > \frac{1}{2}$ and $v_2 \geq v_2^*$, (v_2^* is derived from $\pi_2^F = \pi_2^B$), then $\pi_2^F \geq \pi_2^B$; and if $\beta > \frac{1}{2}$ and $v_2 < v_2^*$, then $\pi_2^F < \pi_2^B$.

Up to now, the licensor is not identified from the licensee. An interesting question to raise is whether the more efficient firm (firm 1) is the licensor? Indeed, with governments' intervention in R&D, the less efficient firm (firm 2) may leapfrog and become licensor, especially when the less efficient firm has a big bargaining power and the firms are relatively symmetric in R&D efficiencies. The following proposition pins down the licensor and the licensee.

Proposition 4 *If $\beta \geq \frac{1}{2}$, then firm 1 is the licensor. If $\beta < \frac{1}{2}$, firm 1 is the licensor if $(v_2 - v_1) \geq (s_2^B - s_1^B)$, and firm 2 is the licensor if $(v_2 - v_1) < (s_2^B - s_1^B)$.*

Proof: See Appendix.

The intuition is straightforward. When Nash bargaining solution prevails, none of the governments intervene. Firm 1 becomes licensor because of its

[9]There is historical evidence that both firms will innovate to improve their bargaining positions even if licensing after innovation occurs. For instance, ICI and Du Pont had a long standing licensing agreement. Despite of that, Du Pont delibrately carried out research in Polyethylene process technology, on which ICI had the basic patent. (See Taylor, G:D., and Sudnik, P.E., 1984, "DU Pont and the international Chemical Industry", G.K. Hall and Co, Boston, MA.)

higher R&D efficiency. When firm 1's bargaining power is greater than 1/2, it receives R&D subsidy while firm 2 must pay R&D tax. This effectively enlarges the original R&D efficiency difference between the firms and firm 1 maintains the licensor position. However, when firm 1's share of licensing gain is less than 1/2, firm 1 is taxed on its R&D activities while firm 2 is subsidized. This effectively lessens the firms' original R&D efficiency difference, and can eventually make firm 2 more effectively efficient than firm 1 and cause it to become the licensor.

From the above propositions, it is ready to get the subgame perfect equilibrium, which is described in the following Theorem:

Theorem 5 *When fixed-fee licensing after innovation occurs, whether the less efficient firm will develop a new innovation itself depends both on its bargaining power over licensing gain and on its R&D cost.*

1. *If $\beta \leq \frac{1}{2}$ or $\beta > \frac{1}{2}$ and $v_2 \leq v_2^*$, then both firms undertake R&D investments. Governments' R&D policies when licensing occurs depend on the firms' bargaining power over licensing gain:*
    - *If $\beta \neq \frac{1}{2}$, one firm is subsidized (firm 1 if $\beta > \frac{1}{2}$; firm 2, if $\beta < \frac{1}{2}$), and the other firm is taxed (firm 1 if $\beta < \frac{1}{2}$; firm 2, if $\beta > \frac{1}{2}$).*
    - *If $\beta = \frac{1}{2}$, the governments do not interfere in firms' R&D activities.*
2. *If $\beta > \frac{1}{2}$ and $v_2 > v_2^*$then only firm 1 innovates and then licenses to firm 2. In this case the government of firm 1 does not subsidize its domestic firm's R&D investment.*

Extension: Licensing with royalty per unit

In this section we want to check the robustness of the above results by investigating royalty per-unit licensing. Licensing with royalty per unit means that the licensee's payments are based on its output produced with the new technology. According to Gallini and Winter (1985), the optimal royalty rate is the difference between the licensor's and the licensee's unit production costs. That is, $r = f_i - f_j$ (here firm i is still the licensor and firm j the licensee). The net gain under royalty licensing is the product of the optimal royalty rate and the licensee's output produced with the new technology, i.e. $E = rq_j$. Therefore, the firms' total payoffs are:

$$\pi_i^T = pq_i - (c - f_i)q_i - (v_i - s_i)x_i + \beta(f_i - f_j)q_j \quad (24)$$
$$\pi_j^T = pq_j - (c - f_j)q_j - (v_j - s_j)x_j + (1 - \beta)(f_i - f_j)q_j \quad (25)$$

Unlike fixed-fee licensing, the firms' equilibrium outputs after licensing with royalty per unit are different and are given, respectively, by

$$q_i^{BR} = \frac{a - c + (1 + \beta)f_i^{BR} - \beta f_j^{BR}}{3} \quad (26)$$
$$q_j^{BR} = \frac{a - c + (1 - 2\beta)f_i^{BR} + 2\beta f_j^{BR}}{3} \quad (27)$$

If only one firm (say, firm i) innovates, then the firms' outputs are

$$q_i^R = \frac{a - c + (1 + \beta)f_i}{3} \quad (28)$$
$$q_j^R = \frac{a - c + (1 - 2\beta)f_i}{3} \quad (29)$$

Before licensing with royalty per unit the firms' outputs are the same as those in fixed-fee licensing (8).

Note that, different from fixed-fee licensing, the licensor under royalty licensing may deliberately distort the licensee's unit production cost to its own advantage through royalty rate. Under royalty licensing, the effective cost of the licensee is $c - [\beta f_i + (1 - \beta)f_j]$, which depends not only on the optimal royalty rate but also explicitly on its bargaining power, while the licensor's unit cost is $c - f_i$.

In the licensing stage, the licensee is always willing to reach a licensing agreement, regardless of its bargaining power over the licensing gain. This is because its benefit from the cost reduction by using the licensor's technology is at least as large as the royalty payment. Whether the licensor has incentives to sell its superior technology to its competitor depends crucially on its bargaining power. In the existing licensing literature it is usually assumed that the licensor has all the bargaining power. On this assumption, licensing with royalty per unit always occurs, because the licensor can always enjoy a positive net gain (the amount of the licensee's cost reduction) by leaving the licensee indifferent between licensing and not licensing. However, when the licensee is allowed to share the licensing gain with the licensor, a stronger bargaining position of the licensee means also a stronger position in the after-licensing production competition of the licensee. For the licensor, it has incentive to license only if its share of licensing gain is so high that its total payoff is at least as high as its pre-licensing profit, i.e.$\pi_i^T - \pi_i^0 \geq 0$. This gives rise to the condition $\beta \geq \underline{\beta}$, where $\underline{\beta}$ is the threshold, at which $\pi_i^T - \pi_i^0 = 0$.[10] Licensing with royalty per unit occurs only if $\beta \geq \underline{\beta}$. When β is smaller than $\underline{\beta}$, the licensor's licensing gain could not compensate for its loss due to the enhanced competition from the licensee following the licensing deal. The licensor has thereby no incentives to engage in licensing.

Furthermore, if one firm (firm i) undertakes a drastic innovation ($f_i \geq a - c + 2f_j$), and becomes monopoly, then royalty licensing will not occur either. Therefore, the occurrence of royalty per-unit licensing requires two conditions.

Proposition 6 *Under royalty licensing, licensing occurs only if the conditions $\beta \geq \underline{\beta}$ and $f_i < (a - c + 2f_j)$are both satisfied.*

Proof: See Appendix

In the Innovation stage, firms choose their optimal levels of R&D investments by maximizing their total payoffs. The optimal R&D investments under royalty licensing are, respectively,

$$x_i^{BR} = \frac{81\left[(2+5\beta)(v_j - s_j) - 18\beta^2\right]^2 (a-c)^2}{E^2} \tag{30}$$

$$x_j^{BR} = \frac{18^2\beta^2\left[2(v_i - s_i) - \beta\right]^2 (a-c)^2}{E^2} \tag{31}$$

where $E = 2\left[9(v_i - s_i) + 5\beta^2 - 5\beta - 1\right]\left[9(v_j - s_j) - 4\beta^2\right] + 10\beta^2(1-2\beta)^2$.

If only one firm innovates, then this firm's (firm i's) R&D investment is

$$x_i^R = \frac{(2+5\beta)^2(a-c)^2}{4(9v_1 + 5\beta^2 - 5\beta - 1)^2} \tag{32}$$

In the first stage, similar to the case of fixed-fee licensing, the optimal R&D subsidy or tax rates of governments are determined by: $s_i^* = \frac{\partial \pi_i}{\partial x_j}\frac{dx_j}{ds_i} / \frac{dx_i}{ds_i}$.

The equilibrium R&D policies under royalty licensing are described in the following proposition:

[10]The $\underline{\beta}$ is unique root to $(5\beta - 2)(a - c + f_i) + (5\beta^2 + 1)(f_j - f_i) = 0$. It can be shown that $\underline{\beta} < \frac{1}{2}$.

Proposition 7 *If both firm innovate and royalty licensing occurs, then the governments' optimal R&D subsidy rates are:* $s_1^{BR} > 0$ *and* $s_2^{BR} < 0$ *if* $\beta > \frac{1}{2}$*;* $s_1^{BR} < 0$ *and* $s_2^{BR} > 0$ *if* $\beta < \frac{1}{2}$*; and* $s_1^{BR} = s_2^{BR} = 0$ *if* $\beta = \frac{1}{2}$*. When only the more efficient firm innovates, then the innovating firm's government will not intervene in the firm's R&D investment.*

Proof: See Appendix

This proposition means that a government's decision on whether to subsidize or tax its domestic firm's R&D again depends on its domestic firm's bargaining power over licensing gain. Just like in the fixed-fee licensing, with R&D rivalry, the government will subsidize R&D if and only if its domestic firm appropriates higher share of licensing gain than the rival firm. Otherwise the government will either tax the firm's R&D investment or does not intervene in R&D. However, the equilibrium amount of R&D subsidies or taxes will be different under different licensing contracts.

Moreover, the less efficient firm's decision on whether to innovate is similar to the case of fixed-fee licensing. If firm 1 has most of the bargaining power, firm 2 will innovate only when its R&D efficiency is sufficiently high. If firm 2 has higher bargaining power than firm 1, both firms innovate. In this case, under some circumstances, firm 2 leapfrogs the more efficient firm in its R&D investment and becomes the licensor. The following proposition describes this.

Proposition 8 *When* $\beta \geq \frac{1}{2}$*, firm 1 is licensor. When* $\underline{\beta} \leq \beta < \frac{1}{2}$*, firm 1 is licensor if the difference of the firms' R&D efficiency is high, i.e.* $(v_2 - v_1) \geq (s_2^* - s_1^*)$*, and firm 2 becomes licensor if the firms are relatively symmetric* $(v_2 - v_1) < (s_2^* - s_1^*)$*.*

From the above propositions, it is trivial to get the following subgame perfect equilibrium:

Theorem 9 *When licensing with royalty per unit after innovation occurs, the firms' and governments' equilibrium behaviors are the following:*

1. *If* $\underline{\beta} \leq \beta \leq \frac{1}{2}$ *or* $\beta > \frac{1}{2}$ *and* $v_2 \leq v_2^{L*}$*,* [11] *both firms innovate and royalty licensing occurs. Governments' R&D policies depends on* β*.*

[11] Here v_2^{L*} is the critical level at which firm 2 is indifferent between not innovating (and being a licensee) and innovating.

- *If* $\beta \geq \underline{\beta}$ *and* $\beta \neq \frac{1}{2}$, *one firm is subsidized (firm 1 if* $\beta > \frac{1}{2}$; *firm 2, if* $\beta < \frac{1}{2}$), *and the other firm is taxed (firm 1 if* $\beta < \frac{1}{2}$; *firm 2, if* $\beta > \frac{1}{2}$).
- *If* $\beta = \frac{1}{2}$, *governments neither subsidize nor tax their firms' R&D investments.*

2. *If* $\beta > \frac{1}{2}$ *and* $v_2 > v_2^{L*}$,*then only firm 1 invests in R&D. Firm 1's government does not subsidize its R&D investment.*

Conclusion

This paper investigates firms' R&D rivalry as well as the governments' optimal R&D policies by incorporating international licensing. The possibility of international licensing alters both the firms' and the governments' equilibrium behaviors in comparison to the case without licensing. First, anticipating that it can buy a new technology from its rival firm, a less efficient firm prefers not to invest in R&D if it has less bargaining power and its R&D cost is relatively high. If the less efficient firm has most of the bargaining power or its R&D cost is not very high, both firms will invest in R&D. In this case, the less efficient firm may leapfrog the more efficient firm and become the licensor. Second, the governments' designing of optimal R&D policies is also affected by the possibility of international licensing. With only one firm innovating, the innovator's government has no incentive to subsidize its domestic firm's R&D investment. When both firms innovate and licensing occurs, whether to subsidize or to tax its domestic firm's R&D activities crucially depend on firms' bargaining power over licensing gain. A government subsidizes its domestic firm's R&D when the firm has most of the bargaining power, while taxes it when the firm only has a weak bargaining position. When the firms have the same bargaining position in the licensing deal, then it is optimal for the governments not to intervene in R&D. This result is robust to different types of licensing contracts.

Our findings should be useful for a government in designing its optimal R&D policies for international R&D- and licensing-intensive industries. The target of a firm's R&D efficiency and its bargaining power during the licensing process should be scrutinized before the policies are made. When the domestic firm is in a position to appropriate the larger share of the licensing gain, it is optimal for the government to subsidize the firm. Otherwise, laissez-faire or R&D tax policy may be optimal. A government's attempt to subsidize its R&D inefficient firm to leapfrog can only make sense when the firm is able to benefit mostly from the licensing deal and the firms are relatively symmetric in R&D efficiency. To this extent, the usual assumption of the licensor having all the bargaining power in the existing R&D subsidy literature can lead to suboptimal, if not wrong, R&D policies.

Appendix

Proof of Proposition 2: When firm 1 is licensor and firm 2 is licensee and fixed-fee licensing occurs, the following results can be derived.

$\frac{\partial \pi_1^{RF}}{dx_2^{RF}} = -\frac{1}{9\sqrt{x_2}}\left[(1+\beta)(a-c)+2(1-2\beta)\sqrt{x_1}-(1-5\beta)\sqrt{x_2}\right] < 0,$

$\frac{\partial \pi_2^{RF}}{dx_1^{RF}} = -\frac{1}{9\sqrt{x_1}}\left[\beta(a-c)+(2-3\beta)\sqrt{x_1}-2(1-2\beta)\sqrt{x_2}\right] < 0,$

$\frac{dx_2^{RF}}{ds_1} = \frac{36(1-2\beta)\sqrt{x_1}\sqrt{x_2}}{D} > 0$,iff $\beta < \frac{1}{2}$, and

$\frac{dx_1^{RF}}{ds_2} = \frac{36(2\beta-1)\sqrt{x_1}\sqrt{x_2}}{D} > 0$,iff $\beta > \frac{1}{2}$.

Where $D = \left[9(v_1 - s_1^B) - 4 + 3\beta\right]\left[9(v_2 - s_2^B) - 5\beta + 1\right] + 4(2\beta-1)^2$

Furthermore, since $\frac{dx_1^{RF}}{ds_1} > 0$ and $\frac{dx_2^{RF}}{ds_2} > 0$, from the f.o.c. of the governments, it is trivial that for the licensor's government, $s_1^* > 0$ iff $\beta > \frac{1}{2}$, $s_1^* < 0$ iff $\beta < \frac{1}{2}$and $s_1^* = 0$ otherwise, while the licensee's government's optimal subsidy rate is given by $s_2^* > 0$ iff $\beta < \frac{1}{2}$, $s_2^* < 0$ iff $\beta > \frac{1}{2}$and $s_2^* = 0$ otherwise. ■

Proof of Proposition 3:

(1) $\pi_2^B - \pi_2^F$

$= \frac{(a-c+2f_2^B-f_1^B)^2}{9} - \frac{(a-c-f_1)^2}{9} + (1-\beta)\frac{(f_1^B-f_2^B)\left[2(a-c)-3f_1^B+5f_2^B\right]-f_1[2(a-c)-3f_1]}{9} - (v_2 - s_2)(f_2^B)^2$

$= \frac{(f_1^B-f_1)}{9}\left[-2\beta(a-c)+(3\beta-2)(f_1+f_1^B)\right] + \frac{[9(v_2-s_2)-5\beta+1](f_2^B)^2}{9}$

(2) From the first order conditions

(a). $(2+\beta)(a-c)+(4-3\beta)f_1 = 9v_1 f_1$

(b). $(2+\beta)(a-c)+(4-3\beta)f_1^B + 2(2\beta-1)f_2^B = 9(v_1 - s_1^B)f_1^B$

$(a)-(b) \Rightarrow (9v_i - 4 + 3\beta)(f_1 - f_1^B) = 2(1-2\beta)f_2^B - 9s_1^B f_1^B$

When $\beta = \frac{1}{2} \Rightarrow s_1^B = 0 \Rightarrow f_1^B = f_1$

When $\beta < \frac{1}{2} \Rightarrow s_1^B < 0 \Rightarrow f_1^B < f_1$

When $\beta > \frac{1}{2} \Rightarrow s_1^B > 0 \Rightarrow f_1^B > f_1$.

Therefore,

If $\beta = \frac{1}{2}$, then $\pi_2^B - \pi_2^F = \frac{[9(v_2-s_2)-5\beta+1](f_2^B)^2}{9} > 0 \Rightarrow \pi_2^B > \pi_2^F$

If $\beta < \frac{1}{2}$, then $\pi_2^B - \pi_2^F = \frac{(f_1^B - f_1)}{9}\left[-2\beta(a-c) + (3\beta-2)(f_1+f_1^B)\right] + \frac{[9(v_2-s_2)-5\beta+1](f_2^B)^2}{9}$,

where $(f_1^B - f_1) < 0$, $\left[-2\beta(a-c) + (3\beta-2)(f_1+f_1^B)\right] < 0$

and $\frac{[9(v_2-s_2)-5\beta+1](f_2^B)^2}{9} > 0 \Rightarrow \pi_2^B > \pi_2^F$.

If $\beta > \frac{1}{2}$, then $\pi_2^B - \pi_2^F$ can be positive or negative, depending on v_2.

Since $\frac{d(\pi_2^F - \pi_2^B)}{dv_2} = -\frac{d\pi_2^B}{dv_2}$

where $\frac{d\pi_2^B}{dv_2} = \frac{\partial \pi_2^B}{\partial x_1}\frac{dx_1}{dv_2} - x_2$.

Since $\frac{dg_2}{ds_2^B} = \frac{\partial \pi_2^B}{\partial x_1^B}\frac{dx_1^B}{ds_2^B} - s_2^B\frac{dx_2^B}{ds_2^B} = 0$

$\Rightarrow s_2^B = (\frac{\partial \pi_2^B}{\partial x_1^B}\cdot\frac{dx_1^B}{ds_2^B})/\frac{dx_2^B}{ds_2^B}$

where $\frac{dx_1^B}{ds_2^B} = \frac{36(2\beta-1)\sqrt{x_1^B}\sqrt{x_2^B}}{D}$, and

$\frac{dx_2^B}{ds_2^B} = \frac{18\left[9(v_1-s_1^B)-4+3\beta\right]x_2^B}{D}$

$\Rightarrow \frac{\partial \pi_2^B}{\partial x_1^B} = \frac{\left[9(v_1-s_1^B)-4+3\beta\right]s_2^B}{2(2\beta-1)}\cdot\frac{\sqrt{x_2^B}}{\sqrt{x_1^B}}$

Moreover, it is proved that $\frac{dx_1^B}{dv_2} = \frac{36(1-2\beta)}{D}\sqrt{x_1^B}\sqrt{x_2^B}$

$\Rightarrow \frac{d\pi_2^B}{dv_2} = -\frac{x_2^B}{A}\left[9(v_1-s_1^B)-4+3\beta\right]\left[9v_2+9s_2^B-5\beta+1+4(2\beta-1)^2\right]$
< 0

Therefore, $\frac{d(\pi_2^F-\pi_2^B)}{dv_2} = -\frac{d\pi_2^B}{dv_2} > 0$. i.e.

$\forall\, v_2^*$ s.t. if $v_2 \geq v_2^*$, firm 2 prefers not to invest in R&D; if $v_2 < v_2^*$, both firms invest in R&D. ■

Proof of Proposition 4: If $\beta = \frac{1}{2}$, then $s_1^B = s_2^B = 0$. Since $v_1 < v_2$, one obtains $v_1 - s_1^B < v_2 - s_2^B$, and therefore $f_1^B > f_2^B$, firm 1 is the licensor.

If $\beta > \frac{1}{2}$, then $s_1^B > 0, s_2^B < 0$. Since $v_1 < v_2$, one obtains $v_1 - s_1^B < v_2 - s_2^B$, and thus $f_1^B > f_2^B$, firm 1 is still the licensor.

If $\beta < \frac{1}{2}$, then $s_1^B < 0, s_2^B > 0$. one obtains $v_1 - s_1^B < v_2 - s_2^B$ if and only if $(v_2 - v_1) \geq (s_2^B - s_1^B)$. If the firms are relatively symmetric in R&D efficiency such that $(v_2 - v_1) < (s_2^B - s_1^B)$, then $f_1^B < f_2^B$, firm 2 becomes licensor. ■

Proof of Proposition 6: The licensor's payoffs before and after royalty licensing areπ_i^0 and π_i^T , respectively.

$\pi_i^T = \left[q_i^{BR}\right]^2 + \beta(f_i - f_j)q_j^{BR} - (v_i - s_i)x_i$

$\pi_i^0 = [q_i^0]^2 - (v_i - s_i)x_i$

$\pi_i^T - \pi_i^0 = \left[\frac{a-c+(\beta+1)f_i-\beta f_j}{3}\right]^2 - \left[\frac{a-c+2f_i-f_j}{3}\right]^2 + \beta(f_i - f_j)\frac{a-c+(1-2\beta)f_i+2\beta f_j}{3}$
$= \frac{[2(a-c)+(3+\beta)f_i-(\beta+1)f_j][(\beta-1)(f_i-f_j)]}{9} + \beta(f_i - f_j)\frac{a-c+(1-2\beta)f_i+2\beta f_j}{3}$
$= \frac{(f_i-f_j)}{9}\left\{[2(a-c)+(3+\beta)f_i-(\beta+1)f_j](\beta-1)+3\beta[a-c+(1-2\beta)f_i+2\beta f_j]\right\}$
$= \frac{(f_i-f_j)}{9}[(5\beta-2)(a-c)+(5\beta-3-5\beta^2)f_i+(5\beta^2+1)f_j]$
$\Rightarrow$if $(5\beta-2)(a-c)+(5\beta-3-5\beta^2)f_i+(5\beta^2+1)f_j \geq 0$,
then $\pi_i^T \geq \pi_i^0$, and firm i is willing to engage in licensing.
(The proof for the case of one firm innovating is similar.) ■

Proof of Proposition 7: When firm 1 is the licensor and firm 2 is the licensee and royalty licensing occurs, the following results can be derived:
$\frac{\partial \pi_1^T}{\partial x_2} = -\frac{5\beta}{3}f_2' q_2 < 0$, and
$\frac{\partial \pi_2^T}{\partial x_1} = -\frac{(4-2\beta)}{3}f_1' q_2 < 0$
$\frac{dx_2}{ds_1} = \frac{72\beta(1-2\beta)f_1..f_2}{E}$,
where $E = 2[9(v_1-s_1)+5\beta^2-5\beta-1][9(v_2-s_2)-4\beta^2] + 10\beta^2(1-2\beta)^2$.
$\Rightarrow \frac{dx_2}{ds_1} > 0$ iff $\beta < \frac{1}{2}$, and $\frac{dx_2}{ds_1} < 0$ iff $\beta > \frac{1}{2}$.

Furthermore, since, $\frac{dx_1}{ds_1} > 0, \frac{dx_2}{ds_2} > 0$, from the f.o.c. of the governments, it is readily proved that for the licensor's government, $s_1^{BR} > 0$ iff $\beta > \frac{1}{2}$, $s_1^{BR} < 0$ iff $\beta < \frac{1}{2}$,and $s_1^{BR} = 0$ otherwise, while the licensee's government's optimal subsidy rate is given by $s_2^{BR} > 0$ iff $\beta < \frac{1}{2}$, $s_2^{BR} < 0$ iff $\beta > \frac{1}{2}$and $s_2^{BR} = 0$ otherwise. ■

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