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Research Joint Ventures, Licensing, and Industrial Policy

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RESEARCH JOINT VENTURES, LICENSING, AND INDUSTRIAL POLICY[1]

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Abstract

This paper reconsiders the explanation of R&D subsidies by Spencer and Brander (1983) and others by allowing firms to license their innovations and to pool their R&D investments. We show that in equilibrium R&D joint ventures are formed and licensing occurs in a way that eliminates the strategic benefits of R&D investment in the export oligopoly game. Nevertheless, national governments are driven to subsidize their own national firms in order to increase their strength in the joint venture bargaining game. Therefore, our analysis suggests an alternative explanation of the observed proliferation of R&D subsidies.

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1. INTRODUCTION

In a seminal paper Spencer and Brander (1983) analyze international R&D rivalry and show that nation states have an incentive to subsidize R&D expenditures of their home based export industries to give them a strategic advantage in the subsequent export market game. In equilibrium all nations engage in such activities, which makes the attempts to gain an advantage self-defeating. Governments are thus caught in a dilemma: as they all pay subsidies, their welfare is reduced; yet, for each single nation the alternative of no subsidization reduces welfare even more.

Spencer and Brander (1983) propose their model as an explanation of the observed proliferation of R&D subsidies. And they suggest that this explanation becomes increasingly relevant as international agreements ban export subsidies that, in the past, served a similar purpose.[1]

This explanation of R&D subsidies is similar in spirit to a number of contributions that explain the strategic benefit of commitment devices in an oligopoly context. For example, Fershtman and Judd (1987) show that the owner of an oligopolistic firm can effectively mimic a Stackelberg leader by delegating decisions to a manager who is rewarded for aggressive behavior, for example by appropriately rewarding a combination of sales *and* profits. Yet, in equilibrium, all owners of firms make use of that device; hence, in equilibrium, strategic delegation to managers is self-defeating.

The present paper revisits the Spencer and Brander (1983) analysis. The motivation for our analysis is the observation that in a Cournot market game firms have an incentive to license their innovations to competitors[2] and to pool their R&D investments.

We introduce the possibility of pooling R&D investments and licensing innovations into the Spencer and Brander analysis. This drastically changes the equilibrium outcome. In particular, R&D subsidies no longer grant a strategic advantage in the Cournot market game, since efficient licensing gives rise to equal marginal costs to all firms, regardless of which firm is subsidized by its government. Nevertheless, governments still tend to subsidize their domestic firms to give them an advantage in the bargaining game that determines how the costs and benefits of the innovation are shard. These subsidies do not only play an entirely different role, they are also lower than the subsidies that solve the Spencer and Brander (1983) model. Therefore, our analysis suggests an alternative explanation of observed R&D subsidies.

There is a large literature on international R&D rivalry and R&D subsidies, and on research joint ventures (RJVs) and licensing. For example, Cheng (1987) considers a dynamic version of the Spencer and Brander (1983) model

[1] See also Brander and Spencer (1983) and Brander (1995).

[2] Generally, the literature has observed that an "outside" patent holder, who is not also a user of that innovation, should auction a limited number of licenses (see Kamien (1992)), whereas an "insider" should use royalty contracts (see, Wang (1998)).

with R&D spillovers which reinforces their results. Bagwell and Staiger (1994) extend the Spencer-Brander model to include R&D uncertainty. They show that governments tend to subsidize their domestic firms' R&D activities regardless of whether there is either Bertrand or Cournot competition. And Qiu and Tao (1998) show that R&D cooperation tends to further increase the governments' incentive to subsidize their national firms' R&D investments.

Research joint ventures have become increasingly popular ever since the National Corporation Research Act was passed in the U.S. in 1984, and similar legislation was passed in the European Union in 1985, taking exemption from Article 85 for certain R&D arrangements. Numerous research papers have analyzed various kinds of RJVs, ranging from R&D cooperation, where firms only coordinate their R&D investments, to RJV cartelization, where firms coordinate or even jointly conduct their R&D activities and share innovations but remain competitors in the product market (see Kamien, Muller, and Zang (1992) and Miyagiwa and Ohno (2002)).

Like the literature on RJV cartelization we assume that firms coordinate and jointly conduct their R&D activities, and share innovations. However, we go one step further and assume that firms write an optimal RJV contract that includes royalty licensing of innovations to member firms. By intelligently using royalty rates, firms can prevent the increased competition that would occur if innovations were simply passed on for free to the members of the RJV. This use of royalty licensing as part of an optimal RJV contract is an essential ingredient of our analysis.

We also mention that firms do not only have an incentive to license their innovation to competitors; they are often given additional incentives to do so. For example, the European Community provides subsidies to foster R&D cooperation. Some of these programs, e.g. *EUREKA*, are financed by each firm's home government. Moreover, programs such as *ESPRIT* or *RACE* require a result-sharing agreement between the cooperating firms (Fölster, 1995). Such arrangements have become fairly widespread.

This paper proceeds as follows. Section 2 introduces the basic model. Section 3 explains why and how we model the pooling of R&D investments combined with the licensing of innovations. Section 4 solves the game without RJVs and licensing, which serves as our benchmark model. Section 5 solves the subgame perfect equilibrium of the full game with RJVs and licensing and compares it with that of the benchmark model. Section 6 specializes to a linear model, states necessary and sufficient conditions for positive subsidies and for drastic and non-drastic innovations, and summarizes some comparative statics. Section 7 concludes with a discussion of some critical issues.

2. THE MODEL

We employ the model of R&D rivalry introduced by Spencer and Brander (1983) as our base model. In that base model, two firms, one in each of two countries, serve the same export market in a third country. That export market is a homogeneous good Cournot duopoly under complete information. Before choosing their outputs firms engage in cost reducing R&D, the results of which become common knowledge. And before they play the R&D and subsequent Cournot market games, national governments may offer an input based R&D subsidy with the intention of giving their own national firm a competitive advantage.

We extend that base model by allowing firms to pool their R&D investments and set up a R&D joint venture (RJV) combined with licensing the innovation to its members.

This is done in the framework of the following sequential stage game:

STAGE 1 Governments simultaneously choose the R&D subsidy rates, s_i, per unit of R&D investment, x_i. Their choice becomes public information.

STAGE 2 Firms either set up a R&D joint venture and negotiate the terms of the joint ownership *cum* licensing contract, and invest accordingly, or go alone and simultaneously choose their R&D investments (the detailed assumption are spelled out in Section 3.).

STAGE 3 Firms observe the R&D investments and terms of the licensing contract and play a Cournot market game.

Firms maximize profits, and governments maximize welfare which, in the present framework, is the difference between their domestic firm's profit and the subsidy paid to that firm.

We denote outputs by $q := (q_1, q_2)$, aggregate output by $Q := q_1 + q_2$, the inverse market demand function by $P(Q)$, firms' unit cost before the innovation by c, firms' R&D investment by $x := (x_1, x_2)$, the R&D production function by $f(x_i)$, and subsidy rates by $s := (s_1, s_2)$.

Inverse demand is twice continuously differentiable with $P'(Q) < 0$ and $\frac{\partial}{\partial q_j}(P'(Q)q_i) < 0$, $i, j = 1, 2$. The latter assures that the q's are strategic substitutes and also that firms' profits are strictly concave functions of their own output.

The R&D production function $f(x)$ indicates the cost reduction caused by an investment x. It is assumed to be twice continuously differentiable with $f'(x) > 0$, $f''(x) < 0$ everywhere. Finally, the initial unit cost is such that both firms serve the market if they do not innovate, i.e., $0 \leq c < P(0)$.

We rule out "drastic" innovations, i.e. we assume that the innovation subgame does not have an equilibrium that implements monopoly. In Section 6. we will show exactly how this constrains the choice of the function f.

3. RESEARCH JOINT VENTURE CUM LICENSING

Starting from the base model firms have an incentive to pool their R&D investments and to license their innovation. We take this into account by including an additional stage to the base game in which firms negotiate the formation of an R&D joint venture (RJV) combined with a licensing scheme. If these negotiations fail, firms go alone and simultaneously choose their investments x, as in the base model by Spencer and Brander (1983).

We characterize the RJV by a contract (x_L, r_L, t_1, t_2) that stipulates the level of the joint R&D investment, x_L, the licensing fee, r_L, and the transfers to its members, (t_1, t_2). In principle, such a contract can take many forms. However, in order to maximize the gains from the joint venture, the following properties must be satisfied:

1. The joint R&D investment, x_L, should maximize the sum total of firms' net profits.
2. The license fee r_L should be a royalty rate per output unit that is equal to the cost reduction due to the innovation, i.e. $r_L = f(x_L)$; as a result, the effective unit cost is made equal to the unit cost before the innovation, $c + r_L - f(x_L) = c$.
3. The transfers should solve the Nash bargaining game between the members of the RJV subject to budget and participation constraints.

The choice of license fee is rationalized as follows. If firms pay no royalty per output unit, their unit cost is diminished by the innovation which gives rise to more aggressive behavior in the Cournot market game and hence to a mutual destruction of profits. This can only be prevented by arranging licensing in the form of a royalty rate r_L where r_L is set equal to the cost difference caused by the innovation, i.e. $r_L = f(x_L)$. This way, the effective unit cost, i.e. the unit cost plus royalty fee, is equal to the unit cost before the innovation, which completely neutralizes the competition effect of the innovation.[3]

4. THE BENCHMARK CASE WITHOUT RJVS AND LICENSING

In this section, we briefly review the game without RJV and licensing, which serves as benchmark. This game corresponds to the model by Spencer and Brander (1983).

[3] One may ask: why not set an even higher royalty rate at such a level that the monopoly solution is implemented? We assume that this would lead to intervention by the antitrust authorities in the export market. Therefore, the RJV cannot raise the effective unit cost above the level of the pre-innovation unit cost c.

The subgame perfect equilibrium of that game consists of the equilibrium strategies $\sigma := (q^N(x), x^N(s), s^N)$ and the payoff functions of the Cournot, R&D investment, and subsidy subgames:

$$\Pi_i(q, x_i, s_i) := (P(Q) - c + f(x_i))\, q_i - (1 - s_i)x_i \tag{1}$$

$$\Pi_i^N(x, s_i) := \Pi_i(q^N(x), x_i, s_i) \tag{2}$$

$$G_i^N(s) := \Pi_i^{N*}(s) - s_i x_i^N(s), \tag{3}$$

where

$$\Pi_i^{N*}(s) := \Pi_i^N(x^N(s), s_i). \tag{4}$$

The strategies σ are a subgame perfect equilibrium if for all $i = 1, 2$:

$$\left.\frac{\partial \Pi_i}{\partial q_i}\right|_{q=q^N(x)} \leq 0, \quad \text{and} \quad q_i^N(x) \left.\frac{\partial \Pi_i}{\partial q_i}\right|_{q=q^N(x)} = 0, \quad \forall x, s \tag{5}$$

$$\left.\frac{\partial \Pi_i^N}{\partial x_i}\right|_{x=x^N(s)} \leq 0, \quad \text{and} \quad x_i^N(s) \left.\frac{\partial \Pi_i^N}{\partial x_i}\right|_{x=x^N(s)} = 0, \quad \forall s \tag{6}$$

$$\left.\frac{\partial G_i^N}{\partial s_i}\right|_{s=s^N} \leq 0 \quad \text{and} \quad s_i^N \left.\frac{\partial G_i^N}{\partial s_i}\right|_{s=s^N} = 0, \tag{7}$$

provided the second order conditions are satisfied.[4]

If drastic innovations are excluded, the game may have a symmetric equilibrium in which both firms choose the same equilibrium outputs and the same R&D investments, and governments choose the same subsidy rates. If such an equilibrium exists, one has:

Proposition 1 (Spencer and Brander (1983)) *If the benchmark game has a symmetric equilibrium, the equilibrium subsidy rates are*

$$s_1^N = s_2^N = \frac{\frac{\partial \Pi_i^{N*}(s)}{\partial x_j} \frac{\partial x_j^N(s)}{\partial s_i}}{\frac{\partial x_i^N(s)}{\partial s_i}} =: s_N. \tag{8}$$

In section 6. we solve a linear example and state necessary and sufficient conditions for existence of a symmetric equilibrium with and without subsidies, and for drastic and non-drastic innovations.

5. Solution of the full game with RJVs and licensing

We now characterize the joint venture and subsequent Cournot subgames for arbitrarily given nonnegative subsidy rates s.

[4]The assumptions concerning P assure concavity of $\Pi_i(q, x_i, s_i)$ in q_i. However, suitable concavity properties of $\Pi_i^N(x, s_i)$ and $G_i^N(s)$ in x_i resp. s_i must also be satisfied.

As we already pointed out, the joint venture contract $\{r_L, x_L, t_1, t_2\}$ prescribes royalty licensing with the royalty rate $r_L = f(x_L)$ and fixed transfers from the RJV to firms, $t := (t_1, t_2)$. An immediate implication is that in the subsequent Cournot subgame the effective unit cost of member firms is equal to the pre–innovation unit cost c. Member firms thus maximize their operating profit plus transfer payment, $\pi_i(q, c) + t_i$, by choosing their own output q_i, where the operating profit π_i is a function of q, as follows:

$$\begin{aligned} \pi_i(q,c) &:= (P(Q) - c + f(x_L) - r)\, q_i \\ &= (P(Q) - c) q_i. \end{aligned} \tag{9}$$

Obviously, the maximizer of $\pi_i(q, c) + t_i$ is the same as that of $\pi_i(q, c)$. Therefore,

Proposition 2 (Cournot Subgames) *The equilibrium strategies of the Cournot subgames, $q^L(x)$, are*

$$q_i^L(x) = \begin{cases} q_0^N & \text{if the RJV was formed} \\ q_i^N(x) & \text{otherwise,} \end{cases} \tag{10}$$

where $q_0^N := q_i^N(0)$ (which is the symmetric equilibrium output in the benchmark case without licensing for $x = 0$ (see (5)). And the associated equilibrium operating profit if a RJV is formed is

$$\pi^L := \pi(q_0^N, q_0^N, c) \tag{11}$$

Using this result the other elements of the equilibrium RJV contract $\{t(s), x_L^*(s)\}$ have to maximize the total surplus of the firms that form the RJV,

$$\max_{x_L} \Phi(x_L, s) := 2\pi^L + 2f(x_L)q_0^N - (1 - s_1 - s_2)x_L, \tag{12}$$

and solve the following Nash bargaining problem (subject to budget (14) and participation constraints (15)):

$$\max_{t_1,t_2} \left(\pi^L + t_1 - \Pi_1^{N^*}(s)\right)\left(\pi^L + t_2 - \Pi_2^{N^*}(s)\right) \tag{13}$$

$$\text{s.t.} \quad t_1 + t_2 = 2f\left(x_L^*(s)\right) q_0^N - x_L^*(s)\,(1 - s_1 - s_2) \tag{14}$$

$$\pi^L + t_i \geq \Pi_i^{N^*}(s),\ i = 1, 2. \tag{15}$$

Proposition 3 (Joint Venture Subgame) *In equilibrium, the RJV is formed and the RJV contracts for all possible RJV subgames, $\{r_L(s), x_L^*(s), t(s)\}$, are characterized as follows:*

$$r_L(s) = f(x_L^*(s)) \tag{16}$$

$$f'(x_L^*(s))2q_0^N = 1 - s_1 - s_2 \tag{17}$$

$$\Pi_i^L(s) := \pi^L + t_i(s) = \frac{\Phi^L(s) + \Pi_i^{N^*}(s) - \Pi_j^{N^*}(s)}{2}, \quad i, j = 1, 2, i \neq j \tag{18}$$

$$\Phi^L(s) := \Phi(x_L^*(s), s) \tag{19}$$

PROOF: We already showed that (16) is the optimal royalty rate. (17) is the first order condition of (12); therefore, (17) characterizes the optimal R&D investment $x_L^*(s)$. It remains to be shown that the RJV is formed and that equilibrium transfers are characterized by (18), (19). This is shown, in two steps, as follows: we solve the restricted Nash bargaining problem that ignores the two participation constraints (15), and then show that the solution of the restricted bargaining problem actually satisfies the omitted constraints.

Substituting the budget constraint (14) into the Nash product (13), the restricted Nash bargaining problem reduces to the maximization of

$$\max_{t_1} \left(\pi^L + t_1 - \Pi_1^{N^*}(s)\right)\left(\Phi^L(s) - \pi^L - t_1 - \Pi_2^{N^*}(s)\right). \tag{20}$$

Computing the first order condition and using (15) one obtains the two equilibrium transfers and thus the total payoffs of the two member firms as stated in (18), (19).

Finally, compute the difference $\Pi_i^L(s) - \Pi_i^{N^*}(s)$, for $i, j = 1, 2, i \neq j$, and one finds, by the fact that $\Phi^L(s)$ is the maximum sum of profits,

$$\Pi_i^L(s) - \Pi_i^{N^*}(s) = \frac{1}{2}\left(\Phi^L(s) - \left(\Pi_i^{N^*}(s) + \Pi_j^{N^*}(s)\right)\right) \geq 0. \tag{21}$$

This confirms that the participation constraints omitted in the restricted Nash bargaining problem are indeed not binding and the RJV is formed.

□

Finally, we use the subgame perfect equilibrium of the RJV subgames to solve the subsidy game played between national governments whose payoff function is $G_i^L(s) = \Pi_i^L(s)(s) - s_i x_L^*(s)$.

The first order conditions of government i are: $\partial G_i^L / \partial s_i \leq 0$, and $s_i \partial G_i^L / \partial s_i = 0$, where

$$\frac{\partial G_i^L(s)}{\partial s_i} = \left(\frac{\partial \Phi^L(s)}{\partial s_i} - 2x_L^*(s) - 2s_i \frac{\partial x_L^*(s)}{\partial s_i}\right) + \left(\frac{\partial \Pi_1^{N^*}(s)}{\partial s_i} - \frac{\partial \Pi_2^{N^*}(s)}{\partial s_i}\right). \tag{22}$$

PROPOSITION 4 *Suppose the functions $G_i^L(s)$ are concave in s_i. Then, the introduction of RJVs and licensing does not eliminate the incentive to subsidize R&D investments. However, compared to the benchmark game, it gives rise to lower equilibrium subsidy rates.*

PROOF: We evaluate the partial derivatives $\partial G_i^L(s)/\partial s_i$ at the point where $s = (s_N, s_N)$ and show that they are negative. Since these derivatives are monotone decreasing (by the assumed concavity), the equilibrium subsidy rate s_L must be lower than s_N.

First, notice that the term in the second parenthesis on the RHS of (22) vanishes. Since (s_N, s_N) is an equilibrium of the game without licensing.

By the first order conditions of government i in the game without licensing (where $s^N = (s_N, s_N)$,

$$\left.\frac{\partial G_1^L(s_1, s_N)}{\partial s_1}\right|_{s=s^N} = \left.\left(\frac{\partial \Pi_1^{N*}(s)}{\partial s_1} - x_1^N(s) - s_N \frac{\partial x_i^N(s)}{\partial s_1}\right)\right|_{s=s^N} = 0 \qquad (23)$$

$$\left.\frac{\partial G_2^L(s_N, s_2)}{\partial s_2}\right|_{s=s^N} = \left.\left(\frac{\partial \Pi_2^{N*}(s)}{\partial s_2} - x_2^N(s) - s_N \frac{\partial x_2^N(s)}{\partial s_2}\right)\right|_{s=s^N} = 0. \qquad (24)$$

Of course, $s = s^N$ implies $x_1^N(s) = x_2^N(s)$. Therefore, by (23)–(24), $\partial \Pi_1^{N*}/\partial s_1 = \partial \Pi_2^{N*}/\partial s_2$.

Next, observe that, due to the first order condition concerning x_L, eq. (17),

$$\begin{aligned}\frac{\partial \Phi^L(s)}{\partial s_i} &= f'(x_L^*(s))\frac{\partial x_L^*(s)}{\partial s_i}Q^L + x_L^*(s) - (1 - s_i - s_j)\frac{\partial x_L^*(s)}{\partial s_i} \\ &= x_L^*(s)\end{aligned} \qquad (25)$$

Therefore, combining these results, one obtains

$$\left.\frac{\partial G_i^L(s)}{\partial s_i}\right|_{s=s^N} = -\left.\left(x_L^*(s) - 2s_N \frac{\partial x_L^*(s)}{\partial s_i}\right)\right|_{s=s^N} < 0, \qquad (26)$$

as asserted. □

We conclude that subsidies are also a feature of the model with RJVs and licensing. However, they serve an entirely different purpose than in the Spencer and Brander (1983) model. When RJVs and licensing are feasible, firms no longer use R&D investments to gain a strategic advantage in the Cournot market game. And therefore, governments can no longer use subsidies to enhance their domestic firms' share in the export market. The only purpose of subsidies is to improve the position of their domestic firm in the bargaining over the division of the RJV's profit. The level of equilibrium subsidies depends upon the productivity of R&D investment, as we will show explicitly in the following linear example.

6. A LINEAR EXAMPLE

We now consider a linear version of the above models. This permits us to explicitly solve the game and to illustrate our results.

We parameterize the productivity of R&D investment by an efficiency parameter y and with slight abuse of notation now write f as a function of x and y.

Let $P(Q) := 1 - q_1 - q_2$, $f(x_i, y) := \sqrt{x_i}/y$, where y is an efficiency parameter (a higher y indicates lower R&D efficiency). Also, we normalize the before-innovation unit cost to $c = 0$.

We characterize the symmetric equilibrium, and derive conditions on y that assure existence of such an equilibrium and rule out drastic innovations that implement monopoly.

6.1. *Equilibrium subsidies in the absence of licensing*

In the no-licensing case, the equilibrium outputs in the production stage are

$$q_i^N(x) = \frac{\gamma + 2\sqrt{x_i} - \sqrt{x_j}}{3\gamma}. \tag{27}$$

Given the subsidy rates s, the equilibrium investments in R&D are

$$x_i^N(s,\gamma) = \frac{4\left(2\gamma - 3(1-s_j)\gamma^3\right)^2}{A} \tag{28}$$

$$A := (4 - 12(2 - s_i - s_j)\gamma^2 + 27(1-s_i)(1-s_j)\gamma^4)^2. \tag{29}$$

Firms' equilibrium profits in the R&D subgame and the governments' payoff functions are,

$$\Pi_i^{N*}(s,\gamma) = \frac{\left(9(1-s_i)\gamma^2 - 4\right)(1-s_i)\left(2\gamma - 3(1-s_j)\gamma^3\right)^2}{A} \tag{30}$$

$$G_i^N(s,\gamma) = \frac{\left(9(1-s_i)^2\gamma^2 - 4\right)\left(2\gamma - 3(1-s_j)\gamma^3\right)^2}{A} \tag{31}$$

And the symmetric equilibrium subsidy rate is

$$s_1^N(\gamma) = s_2^N(\gamma) = \frac{3\gamma^2 - 1 - \sqrt{1 - 10\gamma^2 + 9\gamma^4}}{6\gamma^2} =: s_N(\gamma), \quad i = 1, 2. \tag{32}$$

PROPOSITION 5 (BENCHMARK MODEL) *Consider the linear model. The equilibrium subsidy rates of the benchmark model are positive if and only $\gamma \geq 1$.*

Note, a low γ means high productivity of R&D investment. Therefore, government subsidies have a role to play only if that productivity is sufficiently low. In turn, if $\gamma < 1$, productivity of R&D investment is high, and it becomes optimal for governments to actually tax R&D investments.

6.2. *Equilibrium subsidies with licensing*

The linear version of the game with licensing has the following solution: The equilibrium outputs are obviously $q_i^L(0) = \frac{1}{3}$; therefore, $Q^L = \frac{2}{3}$. The equilibrium investment is

$$x_L^*(s,\gamma) = \frac{1}{9(1-s_1-s_2)^2\gamma^2}. \tag{33}$$

And the equilibrium transfers from licensing are

$$\Pi_i^L(s,\gamma) = \frac{1 + 2(1-s_i-s_j)\gamma^2}{18(1-s_i-s_j)\gamma^2} + \frac{\Pi_i^{N*}(s,\gamma) - \Pi_j^{N*}(s,\gamma)}{2} \tag{34}$$

The symmetric equilibrium subsidy rate, $s_1 = s_2 = s_L$, solves the following first order condition (recall, subsidy rates cannot be negative)

$$\left.\frac{\partial G_i^L(s_i, s_L, \gamma)}{\partial s_i}\right|_{s_i=s_L} = \frac{1}{18}\left(\frac{1+2s_L}{(2s_L-1)^3\gamma^2} + \frac{72\gamma^2(1-3(1-s_L)\gamma^2)}{(2-3(1-s_L)\gamma^2)(2-9(1-s_L)\gamma^2)^2}\right) \leq 0. \tag{35}$$

Proposition 6 (Full Model) *Consider the linear model. If RJV (combined with licensing) are allowed for, governments subsidize their domestic firm's R&D investments if and only if* $1 < \gamma < 2.62$.

Proof: As one can easily confirm, $\frac{\partial G_i^L(s_i, 0, \gamma)}{\partial s_i} \leq 0$ if $\gamma \geq 2.62$ or $\gamma < 1$. Therefore, $s_L = 0$ is a solution of (35), i.e. the equilibrium is a corner solution, for all $1 > \gamma$ and $\gamma \geq 2.62$. Whereas, if $1 < \gamma < 2.62$, $\frac{\partial G_i^L(s_L, s_L, \gamma)}{\partial s_i} = 0$ for some $s_L > 0$. □

We mention that $\gamma = 1$ is a borderline case in which no solution exists.

Therefore, the set of R&D efficiency parameter γ for which equilibrium subsidies are positive is bounded.

6.3. *Exclusion of "drastic innovations"*

As we now show, the conditions concerning γ that assure existence of a symmetric equilibrium also imply that the game has no equilibria that implement monopoly.

Proposition 7 (Non-drastic innovation) *Consider the linear model. The R&D subgames have no asymmetric equilibria that implement monopoly if and only if* $\gamma > \sqrt{\frac{2}{3}}$.

Proof: Without loss of generality, consider firm 1 as the potential monopoly. Denote the smallest R&D investment by firm 1 that crowds out firm 2, provided firm 2 has made no R&D investment, by $\bar{x}_1$, and the associated equilibrium output by $\bar{q}_1$. Then, $(\bar{q}_1, \bar{x}_1)$ must satisfy the conditions:

$$P(\bar{q}_1) = c = 0 \tag{36}$$

$$\left(P(\bar{q}_1)\bar{q}_1\right)' = -f(\bar{x}_1). \tag{37}$$

The first condition assures that $q_2 = 0$ is a best reply to $(\bar{q}_1, \bar{x}_1)$, and the second assures that $(\bar{q}_1, \bar{x}_1)$ is firm 1's best reply to $q_2 = 0$. Therefore,

$$f(\bar{x}_1) = -P'(\bar{q}_1)\bar{q}_1 = 1, \quad \bar{x}_1 = \gamma^2. \tag{38}$$

Now suppose the game has an asymmetric equilibrium with $x = \bar{x} := (\bar{x}_1, 0)$, $q_1^N(x), q_2^N(x)$ which then yields the monopoly outcome since $q_1^N(\bar{x}) = \bar{q}_1$ and $q_2^N(\bar{x}) = 0$. Then, $x_1 = \bar{x}_1$ must be a best reply to $x_2 = \bar{x}_2 = 0$. However, by (27), one has

$$\frac{d}{dx_1}\Pi_1\left(q_1^N(x), q_2^N(x), x_1\right)\Big|_{x_2=0} = 0 \iff x_1 = \frac{4\gamma^2}{(9\gamma^2-4)^2} =: x_1^*.$$

Therefore, x_1^* is the best reply to $x_2 = 0$ and $x_1^* < \bar{x}_1 \iff \gamma > \sqrt{\frac{2}{3}}$, and we conclude that the game has no asymmetric equilibrium that implements monopoly if and only if $\gamma > \sqrt{\frac{2}{3}}$. □

The condition in Lemma 7 is equivalent to the exclusion of a "drastic" innovation.

6.4. *Comparison of equilibrium outcomes*

Table 1 states the symmetric equilibrium outcomes; the subsidy rates, s_N, s_L, and (with slight abuse of notation) the R&D investments, x_N, x_L , total subsidy levels, $S_j := 2s_jx_j$, $j = N, L$, and profits, for different values of the efficiency parameter γ for the games with and without licensing.[5]

	R&D efficiency parameter γ									
	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	3	17
s_N	.119	.075	.053	.040	.031	.025	.021	.018	.013	.000
s_L	.107	.063	.039	.025	.016	.009	.004	.000	.000	.000
x_N	.065	.038	.026	.019	.015	.012	.010	.008	.006	$\to 0$
x_L	.125	.074	.051	.038	.030	.024	.020	.016	.012	$\to 0$
S_N	.015	.006	.003	.002	.001	.001	$\to 0$	$\to 0$	$\to 0$	$\to 0$
S_L	.027	.009	.004	.002	.001	$\to 0$	$\to 0$	$\to 0$	$\to 0$	$\to 0$
Π_i^{N*}	.106	.109	.110	.110	.111	.111	.111	.111	.111	.111
Π_i^L	.160	.144	.135	.129	.125	.123	.121	.119	.117	.111

Table 1: Equilibrium outcomes with and without licensing

This shows that all these variables, except Π_N, are monotone increasing in R&D efficiency (measured by a decreasing γ). Only Π^N is decreasing in R&D efficiency, which is due to the fact that, in the absence of RJVs and licensing the higher subsidy rates induced by increased R&D efficiency make firms compete more vigorously in the export market, as we know already from Spencer and Brander (1983). Moreover, it shows how the introduction of RJVs and licensing lowers the equilibrium subsidy rate for each given γ and reaches $s_L = 0$ for all $g > 2.62$ while s_N approaches zero only as γ approaches 17 (from below).

[5]Note, efficiency of R&D investment is decreasing in γ.

7. CONCLUSION

The present paper has reconsidered the explanation of R&D subsidies by Spencer and Brander (1983) and others. We enriched their model by allowing firms to form a RJV that pools R&D investments and licenses innovations. This modification has drastic implications. In equilibrium, firms form a RJV and write a optimal contract that makes the innovation available to all member firms in exchange for royalties based on a fixed royalty rate. That rate is set in such a way that innovations do not change the intensity of competition.

As a result, governments cannot use R&D subsidies to enhance their domestic firms' market share, and therefore the explanation of R&D subsidies proposed by Spencer and Brander (1983) no longer holds. Nevertheless, governments still subsidize R&D investments, although to a smaller extent, but only in order to improve their firms' bargaining position in RJV subgame.

A critical assumption of our analysis is that the RJV can commit to pay out transfers to its members before the market game is played. Therefore, transfers must be independent of how firms actually behave in the market game. In other words, the RJV must stick to the RJV contract even if firms later act in an unexpected way that gives rise to either a budget surplus or deficit. Such commitment power may be difficult to achieve if the RJV is co-owned by its member firms. However, firms can, as an alternative, replace the RJV by an independent firm, provided this independent firm is endowed with sufficient financial resources to bear a potential deficit. Also, the independent firm must be bound by a contract that requires the innovation to be licensed to both firms.[6]

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[6]If the RJV is not bound by such a contract, it will generally not license the innovation to both firms (Kamien and Tauman, 1986).

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