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Research Joint Ventures, Optimal Licensing, and R&D Subsidy Policy

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Abstract

We reconsider the justifications of R&D subsidies by Spencer and Brander (1983) and others by allowing firms to pool R&D investments and license innovations. 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 subsequent oligopoly game. Nevertheless, governments subsidize their domestic firms in order to raise their bargaining position in the joint venture. This holds true regardless of whether governments offer either unconditional or conditional subsidies. This suggests an alternative explanation of the observed proliferation of R&D subsidies.

JEL Classifications: L13, O34

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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 justification 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 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 optimal 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 shared. These subsidies play an entirely different role. Therefore, our analysis suggests an alternative justification of observed R&D subsidies.

The present paper considers both unconditional and conditional subsidies. Under unconditional subsidies, in equilibrium firms form an RJV and governments offer subsidies that are lower than the equilibrium subsidies in the Spencer and Brander (1983) model. Remarkably, our main finding holds

[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).

even if governments are able to commit to a menu of subsidies that are conditional on forming resp. not forming an RJV. In that case, in equilibrium governments offer subsidies only conditional on not forming an RJV. However, this does not reestablish the Brander and Spencer (1983) result, since in equilibrium firms still form an RJV and thus forgo to collect the subsidies offered to them. Nevertheless, governments are driven to offer subsidies in order to raise their domestic firm's default payoff, which increases their share of the surplus of the RJV.

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 with R&D spillovers which reinforces their results. Bagwell and Staiger (1994) extend the Spencer and Brander (1983) 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 D'Aspremont and Jacquemin, 1988, Kamien, Muller, and Zang, 1992, Miyagiwa and Ohno, 2002).

Like the literature on RJV cartelization we assume that firms jointly conduct their R&D activities and then share the innovation of the RJV. However, we go one step further and assume that firms write an optimal RJV contract that includes royalty licensing of the innovation to member firms. By using optimal 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 the optimal RJV contract is an essential ingredient of our analysis.

We also mention that firms not only have an incentive to cooperate in R&D and license their innovation to competitors; they are often given additional incentives to do so. Evidence shows that subsidizing cooperative R&D projects has become an important tool of industrial policy. For example, the European Community provides subsidies to foster R&D cooperation using a variety of instruments such as the European Research Coordination Agency (EUREKA), the European Strategic Program for R&D in Information Technology (ESPRIT), the Base Research in Industrial Technology for Europe (BRITE), and R&D in Advanced Communication Technologies in Europe (RACE). Some of these programs, e.g., *EUREKA*, are financed by each firm's home government. Moreover, programs such as *ESPRIT* and *RACE* require a result–sharing agreement between the cooperating firms (see Socorro, 2006, Fölster, 1995).

The paper proceeds as follows. Section 2 introduces the model. Section 3 explains why and how we model the pooling of R&D investments combined with the licensing of the innovation. Section 4 solves the game without RJV and licensing, which serves as our benchmark model. Section 5 solves the subgame–perfect equilibrium of the full game with RJV, licensing, assuming unconditional subsidies, and compares it with that of the benchmark model. Section 6 extends the analysis to the case of a menu of conditional subsidies. Section 7 concludes.

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. The 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 an R&D joint venture (RJV) combined with licensing the innovation to its members. That RJV is taken to be an independent entity, co-owned by firms, that exclusively conducts R&D and makes its innovation available to member firms in exchange for royalty payments.

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 choose whether to form an RJV. If both firms agree to form an RJV, they negotiate the terms of the joint ownership *cum* licensing contract and the RJV's R&D investment. If they do not agree, they go alone and simultaneously choose the R&D investments (the detailed assumption is spelled out in section 3).

STAGE 3 Firms observe the R&D investment(s) 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' constant 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 $\partial \left(P'(Q)q_i\right) / \partial q_j < 0$, $i, j = 1, 2$. 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 $f(x_i)$ indicates the cost reduction caused by an investment x_i. It is assumed to be twice continuously differentiable with $f'(x_i) > 0$, $f''(x_i) < 0$ everywhere and $f(x_i) \leq c$. Finally, the initial unit cost is such that both firms serve the market if they do not innovate, i.e., $0 \leq c < P(0)$.

To illustrate the analysis we also compute an example that employs functional forms frequently used in the related literature (see, for example, Qiu and Tao, 1998, D'Aspremont and Jacquemin, 1988). There, $P(Q) := a - Q, Q := q_1 + q_2$, and $f(x_i) := \min\{\sqrt{x_i}/\gamma, c\}$, where γ is an efficiency parameter (a higher γ indicates lower R&D efficiency).[3]

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

3 RESEARCH JOINT VENTURE CUM LICENSING

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 royalty rate, 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 R&D investment of the RJV, x_L, should maximize the sum total of firms' net profits.
2. The license fee should be based on a royalty rate per output unit, r_L, 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, $c - f(x_L) + r_L = c$.

[3] The full documentation of the example plus a supplementary *Mathematica* file are available for download at `http://www2.wiwi.hu-berlin.de/institute/wt1/papers/`

3. The transfers to the member firms should solve the Nash bargaining game between the members of the RJV subject to budget and participation constraints (see the exact statement in (13) to (15)).

The choice of royalty rate is rationalized as follows. If firms pay no royalties their unit costs are reduced 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 royalty licensing with a royalty rate r_L equal to the cost reduction caused by the innovation, i.e., $r_L = f(x_L)$. This way, the effective unit cost, i.e. the unit cost after the innovation plus royalty rate, is equal to the unit cost before the innovation. This completely neutralizes the undesirable competition effect of the innovation.[4]

If the RJV were free to set any royalty rate, it would obviously set a royalty rate — e.g. $r = (1 - c + f(x_L))/4$ — that effectively raises the marginal cost of its member firms and implement the monopoly solution. It is reasonable to assume that the competition authority does not allow the RJV to raise the marginal cost of its member firms above the level prior to the innovation. Therefore, the best the RJV can do is to set the royalty rate equal to the cost reduction that is due to its innovation.

We mention that setting the royalty rate equal to the cost reduction can be optimal even if there are more than two firms, and not all of them join the RJV. In order to see this, one must analyze an asymmetric oligopoly with $n > 2$ firms, among which $k \leq n$ join the RJV and set up a royalty scheme with royalty rate $r \leq f(x_L)$. If one computes the smallest k for which $r = f(x_L)$ is optimal, one finds that it is generally less than n. Using our example and setting $c = 0.25$, $f(x_L) = 0.05$, $n \in \{5, 10\}$, it turns out that $r = f(x_L)$ is optimal if at least 70% of all firms join the RJV.[5]

4 THE BENCHMARK CASE WITHOUT RJV

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

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:

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

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

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

[4]We mention that royalty licensing is quite commonly used in industry (see Rostoker, 1984, Anand and Khanna, 2000).

[5]This is similar to the well-known result that at least 80% of all firms have to merge in order to make a merger profitable (see Salant, Switzer, and Reynolds, 1983).

where

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

The equilibrium strategies σ satisfy the following conditions 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.[6]

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 our downloadable example we state necessary and sufficient conditions for the existence of a symmetric equilibrium with and without subsidies, and for drastic and non-drastic innovations.

5 Solution of the Game with Unconditional Subsidies

We now characterize the joint–venture and subsequent Cournot subgames for arbitrarily given nonnegative subsidy rates s. These subsidies are made independent of whether firms join an RJV.

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

[6] 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.

operating profit plus transfer payment, $\pi_i(q) + t_i$, by choosing their own output q_i, where the operating profit π_i is a function of q as follows:

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

Obviously, the maximizer of $\pi_i(q) + t_i$ equals that of $\pi_i(q)$. Therefore,

PROPOSITION 2 (COURNOT SUBGAMES) *The equilibrium strategies of the Cournot subgames, $q^L(x)$, are*

$$q_i^L(x) = \begin{cases} q_i^N(0) & \textit{if the RJV was formed,} \\ q_i^N(x) & \textit{otherwise,} \end{cases} \tag{10}$$

where $q_1^N(0) = q_2^N(0) = q_0^N$ is the symmetric equilibrium output in the benchmark case for $x = 0$ (see (5)). And the associated equilibrium operating profit if an RJV is formed is

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

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,

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

(where π^L and q_0^N are independent of x_L), and solve the following Nash bargaining problem (subject to budget (14) and participation constraints (15)):

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

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

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

where $\left(\Pi_1^{N*}(s), \Pi_2^{N*}(s)\right)$ represents the disagreement point.

PROPOSITION 3 (JOINT VENTURE SUBGAME) *In equilibrium the RJV is formed and given s, the equilibrium RJV contract, $\{r_L(s), x_L^*(s), t(s)\}$, is characterized as follows (for $i, j = 1, 2, i \neq j$):*

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

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

$$\Pi_i^L(s) := \pi^L + t_i(s) = \frac{1}{2}\left(\Phi^L(s) + \Pi_i^{N*}(s) - \Pi_j^{N*}(s)\right) \tag{18}$$

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

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 of the RJV, $x_L^*(s)$. 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 simplifies 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, one obtains the two equilibrium transfers and thus the total payoffs of the two member firms as stated in (18), (19).

Next, computing the difference $\Pi_i^L(s) - \Pi_i^{N^*}(s)$, for $i, j = 1, 2, i \neq j$, 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 not binding and the RJV is formed. □

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

The first–order conditions of government i are: $\partial G_i^L(s)/\partial s_i \leq 0$, $s_i \partial G_i^L(s)/\partial s_i = 0$. By the envelope theorem one has $\partial \Phi^L(s)/\partial s_i = x_L^*(s)$. Therefore,

$$\begin{aligned} \frac{\partial G_i^L(s)}{\partial s_i} &= \frac{1}{2}\left(\frac{\partial \Phi^L(s)}{\partial s_i} - 2x_L^*(s) - 2s_i \frac{\partial x_L^*(s)}{\partial s_i}\right) + \frac{1}{2}B(s) \\ &= \frac{1}{2}\left(B(s) - x_L^*(s) - 2s_i \frac{\partial x_L^*(s)}{\partial s_i}\right) \end{aligned} \tag{22}$$

$$B(s) := \frac{\partial \Pi_1^{N^*}(s)}{\partial s_i} - \frac{\partial \Pi_2^{N^*}(s)}{\partial s_i}, \tag{23}$$

where $B(s)$, will be referred to as "bargaining effect."

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: First, we show that, because of the bargaining effect, the governments have incentives to subsidize R&D investment. Obviously, the bargaining effect, $B(s)$, is positive since a higher s_i not only boosts the profit of firm i but also lowers the profit of the rival firm and both effects raise firm i's share in the surplus generated by the RJV. If there were no bargaining effect, the governments would not subsidize the RJV because the innovation developed by the RJV has the feature of a public good, and therefore each government tends to free ride. However, to gain a larger share of the total surplus of the RJV, the governments still have incentives to subsidize if the RJV's R&D investment is not very large.

To prove the second part of Proposition 4, we evaluate the partial derivatives $\partial G_i^L(s)/\partial s_i$ at the point $s = (s_N, s_N)$ and show that they are negative. Since these derivatives are monotonically decreasing (by the assumed concavity), the equilibrium subsidy rate s_L must be lower than s_N.

Notice that the term $B(s)$ in 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 $s^N = (s_N, s_N)$),

$$\left.\frac{\partial G_1^N(s)}{\partial s_1}\right|_{s=s^N} = \left.\left(\frac{\partial \Pi_1^{N*}(s)}{\partial s_1} - x_1^N(s) - s_N \frac{\partial x_i^N(s)}{\partial s_1}\right)\right|_{s=s^N} = 0 \qquad (24)$$

$$\left.\frac{\partial G_2^N(s)}{\partial s_2}\right|_{s=s^N} = \left.\left(\frac{\partial \Pi_2^{N*}(s)}{\partial s_2} - x_2^N(s) - s_N \frac{\partial x_2^N(s)}{\partial s_2}\right)\right|_{s=s^N} = 0. \qquad (25)$$

Of course, $s = s^N$ implies $x_1^N(s) = x_2^N(s)$. By (24)–(25), $\partial \Pi_1^{N*}(s)/\partial s_1 = \partial \Pi_2^{N*}(s)/\partial s_2$.

Therefore, one obtains

$$\left.\frac{\partial G_i^L(s)}{\partial s_i}\right|_{s=s^N} = -\frac{1}{2}\left.\left(x_L^*(s) + 2s_N \frac{\partial x_L^*(s)}{\partial s_i}\right)\right|_{s=s^N} < 0, \qquad (26)$$

as asserted. □

We illustrate the results with our example in Table 1. It states the symmetric equilibrium outcomes, the subsidy rates and the R&D investments and profits, for different values of the efficiency parameter γ for the games with and without licensing.[7]

It shows that all these variables, except Π_i^{N*}, are monotonically increasing in R&D efficiency (measured by a decreasing γ). Only Π_i^{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.

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

	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	≈ 0
x_L	.125	.074	.051	.038	.030	.024	.020	.016	.012	≈ 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

The subsidy rates s_L are positive if $\gamma \in (1, 2.62)$, and reach zero for all $\gamma \geq 2.62$, while s_N is positive and approaches zero only as γ approaches 17 (from below).

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 show in the downloadable documentation of the example.

6 EXTENSION TO CONDITIONAL SUBSIDIES

So far we have assumed that governments offer subsidies independent of whether their domestic firms stay alone or form an RJV. We now explore what happens if governments are able to offer conditional subsidies. In order to allow for all possible contingent subsidies, we assume that each government offers a menu of subsidies:

$$\{s_1^r, s_1^n\}, \quad \text{resp.} \quad \{s_2^r, s_2^n\}, \tag{27}$$

where s_i^r is paid if and only if firms form an RJV, and s_i^n if and only if firm i stays alone.

If $s_i^r = s_i^n$, the subsidy scheme is equivalent to an unconditional subsidy (analyzed in the previous section). If $s_i^r = 0, s_i^n > 0$ a subsidy is paid only if no RJV is formed, and if $s_i^r > 0, s_i^n = 0$ a subsidy is paid only if the RJV is formed. Therefore, the assumed menu of subsidies includes all possible subsidy schemes as a special case.

For convenience of notation let $s := (s^r, s^n)$ with $s^r := (s_1^r, s_2^r)$ and $s^n := (s_1^n, s_2^n)$. Note that Φ is only a function of s^r and firms' default payoffs are only a function of s^n. Therefore,

$$\Pi_i^L(s) := \frac{1}{2}\left(\Phi^L(s^r) + \Pi_i^{N*}(s^n) - \Pi_j^{N*}(s^n)\right) \tag{28}$$

$$\Phi^L(s^r) := \Phi(x_L^*(s^r), s^r) \tag{29}$$

$$G_i^L(s) = \Pi_i^L(s) - s_i^r x_L^*(s^r). \tag{30}$$

PROPOSITION 5 *Suppose conditional subsidies are feasible. In equilibrium $s^r = (0,0)$, i.e. subsidies conditional on forming an RJV are not offered. Hence, unconditional subsidies are not part of the equilibrium.*

PROOF: A subsidy that is conditional on forming an RJV matters only when the RJV forms. Therefore, the equilibrium subsidies (s_1^r, s_2^r) must be maximizers of governments' payoffs G^L, and one obtains, using the envelope theorem and the fact that $x_L^*(s^r)$ is increasing in s_i^r:

$$\frac{\partial G_i^L(s)}{\partial s_i^r} = -\frac{1}{2}\left(x_L^*(s^r) + 2s_i^r \frac{\partial x_L^*(s^r)}{\partial s_i^r}\right) < 0. \tag{31}$$

Therefore, in equilibrium one has $s^r = (0,0)$.

Since unconditional subsidies are the special case where $s_i^n = s_i^r > 0$, it follows immediately that unconditional subsidies are not an equilibrium.

□

This result reflects the fact that the RJV's R&D is a public good; therefore, each government wishes to free ride on the subsidy provided by the other government.

In the following we pay no more attention to s^r and characterize the equilibrium strategies s^n.

If both governments only offer subsidies conditional on not forming an RJV, one may conjecture that the Spencer and Brander (1983) equilibrium in which both governments subsidize at the same rate and both firms compete in R&D investment will be restored. However, this is not the case.

PROPOSITION 6 *Setting $s^n = s^N$ and not forming an RJV is not part of the equilibrium.*

PROOF: If the assertion were not true, one would have $s^n = s^N$ and the RJV were not formed. The latter implies $\Pi_i^{N*}(s^N) > \Pi_i^L(s^N) = (\Phi^L(0,0) + \Pi_i^{N*}(s^N) - \Pi_j^{N*}(s^N))/2$ and hence, $\Pi_1^{N*}(s^N) + \Pi_2^{N*}(s^N) > \Phi^L(0,0)$. However, this contradicts the fact that

$$\begin{aligned}\Pi^{N*}(s^n) :&= \Pi_1^{N*}(s^N) + \Pi_2^{N*}(s^N) \\ &< \Pi_1^{N*}(0,0) + \Pi_2^{N*}(0,0) \\ &< \Phi^L(0,0).\end{aligned} \tag{32}$$

□

To prepare the characterization of the equilibrium subsidy rates s^n, implicitly define $\tilde{s}(s_2^n)$ as the subsidy rate that solves the equation (where $\Pi^{N*}(s^n)$ denotes the sum of default payoffs):

$$\Pi^{N*}\left(\tilde{s}(s_2^n), s_2^n\right) = \Phi^L(0,0). \tag{33}$$

In other words, $\tilde{s}(s_2^n)$ denotes the subsidy rate s_1^n of government 1 that keeps firms indifferent between forming and not forming the RJV.

LEMMA 1 *$\tilde{s}$ has the following properties: 1) $\tilde{s}$ is defined for all $s_2^n \in (0,1)$, 2) $\tilde{s}(s_2^n) > s_2^n$.*

PROOF: The RJV is formed if and only if $\Pi^{N*}(s^n) \leq \Phi^L(0,0)$. In order to prove 1) and 2) we need to show that for each given s_2^n there exists a value of s_1^n for which this inequality is satisfied with equality, and that $\tilde{s}(s_2^n) > s_2^n$.

The proof is in three steps.

a) By a known property of an asymmetric Cournot duopoly, the direct effect of a cost reduction on the own profit is greater in absolute amount than the indirect effect on the other firm's profit. Every increase in x_i induces a reduction in unit cost. Since the partial derivative of Π_1^N with respect to x_1^N is positive and that of Π_2^N is negative, it follows that

$$\frac{\partial \Pi_1^N(x^N(s^n), s_1^n)}{\partial x_1^N} > -\frac{\partial \Pi_2^N(x^N(s^n), s_2^n)}{\partial x_1^N} > 0. \tag{34}$$

Hence, by the envelope theorem together with (34) and $z_i := (x^N(s^n), s_i^n)$

$$\begin{aligned}
\frac{\partial \Pi^{N*}(s^n)}{\partial s_1^n} &= \frac{\partial \Pi_1^N(z_1)}{\partial x_2^N}\frac{\partial x_2^N(s^n)}{\partial s_1^n} + x_1^N(s^n) + \frac{\partial \Pi_2^N(z_2)}{\partial x_1^N}\frac{\partial x_1^N(s^n)}{\partial s_1^n} \\
&> \frac{\partial \Pi_1^N(z_1)}{\partial x_2^N}\frac{\partial x_2^N(s^n)}{\partial s_1^n} + x_1^N(s^n) - \frac{\partial \Pi_1^N(z_1)}{\partial x_1^N}\frac{\partial x_1^N(s^n)}{\partial s_1^n} \\
&= \frac{\partial \Pi_1^N(z_1)}{\partial x_2^N}\frac{\partial x_2^N(s^n)}{\partial s_1^n} + x_1^N(s^n) > 0.
\end{aligned} \tag{35}$$

This proves that the sum of profits, $\Pi^{N*}(s^n)$, is a strictly increasing function of s_1^n.

b) By (32) we know that

$$\Pi_1^{N*}\left(s_1^n, s_2^n\right) + \Pi_2^{N*}\left(s_1^n, s_2^n\right) < \Phi^L\left(0,0\right). \tag{36}$$

Therefore, for $s_1^n \leq s_2^n$, $\Pi^{N*}(s^n) < \Phi^L(0,0)$.

c) If s_1^n is sufficiently high relative to s_2^n, the profit of firm 1 can be made arbitrarily high, whereas the profit of firm 2 cannot become negative. Hence, there exists a s_1^n for which $\Pi^{N*}(s^n) > \Phi^L(0,0)$. While this is obvious if one allows for $s_1 > 1$, it can also be shown for $s_1 \leq 1$. A sufficient condition is spelled out in the Appendix.

Combining a), b), and c) it follows that for each s_2^n there is a unique map $\tilde{s}(s_2^n)$ which exhibits $\tilde{s}(s_2^n) > s_2^n$. □

Proposition 7 *Suppose conditional subsidies are feasible, the equilibrium strategies s^n are asymmetric. Government 1 offers the (higher) subsidy rate $s_1^n = \tilde{s}(s_2^n)$, and government 2 the (lower) rate $s_2^n > 0$, the RJV is formed, and no subsidy is paid out.*

Proof: We construct a subsidy rate s_2^n to which $s_1^n = \tilde{s}(s_2^n)$ is a best reply, and *vice versa*.

1) For all $s_2^n, s_1^n = \tilde{s}(s_2^n)$, the following holds true: Suppose government 1 unilaterally deviates and offers a lower conditional subsidy rate, $s_1 < s_1^n$. Then, the partnership is maintained and no subsidy is paid (recall, Π^{N*} is increasing in s_1). However, the government's payoff diminishes since its domestic firm's default payoff goes down and that of the rival goes up.

Similarly, one can show that government 2 cannot benefit from unilaterally lowering its subsidy rate.

2) Now consider "upward" deviations to $s_1 > s_1^n$, resp. $s_2 > s_2^n$. By the monotonicity of Π^{N*} (see (35)), these deviations destroy the RJV. Therefore, the deviating government's payoff jumps down discontinuously due to the fact that now the promised subsidy has to be paid. For example, if government 2 deviates to $s_2 > s_2^n$ its payoff jumps from $G_2^L(s^n) = \Pi_2^L(s^n) = \Pi_2^{N*}(s_1^n, s_2^n)$ (represented by the dashed line in Figure 1) down to $G_2^N(s_1^n, s_2) = \Pi_2^{N*}(s_1^n, s_2) - s_2 x_2^N(s_1^n, s_2)$ (represented by the solid curve in Figure 1).[8] Therefore, locally, these deviations do not pay. However, to assure that this extends also to large deviations, we now construct a value of s_2^n for which the discontinuous jumps occur to the nonincreasing part of the G_i^N functions.

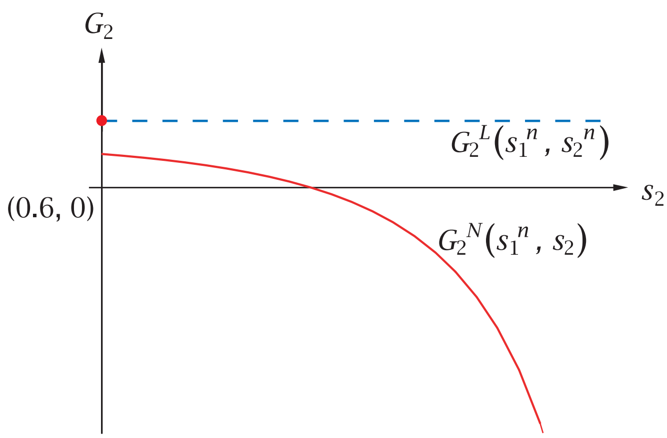

Figure 1: Payoff of government 2 for $s_2 \geq s_2^n = 0.6$

For this purpose, denote the reaction function of government 2 in the benchmark model by $R(s_1)$. That function is strict monotone decreasing (see

[8]This graph is based on the example spelled out in the downloadable documentation of our example.

Spencer and Brander, 1983); therefore, for all s_1 one has $R(s_1) \leq R(0)$. Now set $(s_2^n = R(0), s_1^n = \tilde{s}(s_2^n))$. Then, s_2^n is not smaller than the maximizer over s_2 of $G_2^N(\tilde{s}(s_2^n), s_2)$, and hence

$$\frac{\partial G_2(\tilde{s}(s_2^n), s_2)}{\partial s_2} \leq 0, \quad \forall s_2 \geq s_2^n. \tag{37}$$

And since $s_1^n = \tilde{s}(s_2^n) > s_2^n \geq R(0)$, it follows that s_1^n is greater than the maximizer of G_1^N and hence

$$\frac{\partial G_1(s_1, s_2^n)}{\partial s_1} \leq 0, \quad \forall s_1 \geq \tilde{s}(s_2^n). \tag{38}$$

This proves that upward deviations give rise to a downward jump of the governments' payoff from $G_i^L(s^n) = \Pi_i^{N*}(s^n)$ to the declining part of the function $G_i^N(s) = \Pi_i^{N*}(s) - s_i x_i^N(s)$. Therefore, it does not pay to unilaterally raise s_1 resp. s_2. □

The equilibrium that we constructed in the proof of Proposition 7 is not unique. There are other equilibria for other values of s_2^n, each combined with $s_1^n = \tilde{s}(s_2^n)$. This multiplicity and the properties of these equilibria are illustrated in detail in the following Table 2 which is based on our example for $\gamma = \sqrt{40}/3$.

Table 2 summarizes a sample of equilibrium subsidies, associated payoffs, G_i^*, Π_i^*, and cost reductions f_i^*. The first two columns state equilibrium subsidy rates, column 3 and 4 state the equilibrium cost reduction, and columns 5 and 6 state the associated equilibrium payoffs of governments and firms. As s_2 is increased, the equilibrium subsidy rate of government 1 goes up, and so does the profit of firm 1.

s_2^n	$s_1^n = \tilde{s}(s_2^n)$	f_1^*	f_2^*	$G_1^* = \Pi_1^*$	$G_2^* = \Pi_2^*$
0.3	0.813	0.553	0.037	0.221	0.026
0.4	0.816	0.567	0.043	0.222	0.025
0.5	0.819	0.586	0.052	0.223	0.024
0.6	0.824	0.615	0.064	0.225	0.022
0.7	0.831	0.664	0.084	0.228	0.019
0.8	0.842	0.759	0.120	0.234	0.013

Table 2: Sample of equilibrium strategies (s_1^n, s_2^n), and payoffs

Altogether, we conclude that no matter whether conditional subsidies are feasible, licensing eliminates the strategic motive of R&D investments, and subsidies only serve the purpose to raise firms' share in the surplus generated by the RJV.

7 CONCLUSION

The present paper has reconsidered the explanation of R&D subsidies by Spencer and Brander (1983) and others. We enrich their model by allowing firms to pool R&D investments and license the innovation of the RJV. This modification has drastic implications. In equilibrium, firms form an RJV and write an 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 justification of R&D subsidies proposed by Spencer and Brander (1983) no longer holds. Nevertheless, governments still subsidize R&D investments, but only in order to improve their domestic firm's bargaining position in RJV subgame.

Remarkably, our result is independent of whether governments offer unconditional subsidies or are able to commit to offer a menu of conditional subsidies. In this regard, the only difference is that unconditional subsidies must be paid whereas conditional subsidies are never paid out and therefore their benefit comes at no cost.

Altogether, one may debate whether governments can commit to conditional subsidies. However, regardless of whether conditional or unconditional subsidies are more meaningful, the main message remains the same.

APPENDIX: SUPPLEMENT TO THE PROOF OF LEMMA 1

Here we supplement part c) of the proof of Lemma 1. Denote the unit cost after innovation by c_1 resp. c_2 and write the equilibrium profits of the Cournot subgame without RJV by $\Pi_i^N(c_1, c_2)$. Also denote the lowest unit cost that can be achieved by $\underline{c}$, i.e., $\underline{c} := \inf\{c_i \geq 0 \mid c_i = c - f(x_i), x_i \geq 0\}$.

The following assumption assures that for each given s_2^n the sum of equilibrium profits, $\Pi^{N^*}(s^n)$ exceeds $\Phi^L(0,0)$ for some s_1^n

ASSUMPTION 1

$$\Pi_1^N(\underline{c}, \underline{c}) + \Pi_2^N(\underline{c}, c) > \Phi^L(0,0). \tag{39}$$

PROOF: For $s_1 = 1$ it is optimal for firm 1 to lower the unit cost to the level $\underline{c}$, regardless of the cost reduction chosen by firm 2. Suppose government 1 sets $s_1 = 1$ and denote the best reply of government 2 by s_2, and denote the optimal unit cost of firm 2 by c_2. Then, using the assumption and the fact that c_2 is an optimal unit cost, one obtains:

$$\begin{aligned}
\Pi^{N*}(s_1, s_2) &= \Pi_1^N(\underline{c}, c_2) + \Pi_2^N(\underline{c}, c_2) - (1 - s_2)x_2^N(s) \\
&\geq \Pi_1^N(\underline{c}, c_2) + \Pi_2^N(\underline{c}, c) \quad \text{(by definition of a maximum)} \\
&\geq \Pi_1^N(\underline{c}, \underline{c}) + \Pi_2^N(\underline{c}, c) \quad \text{(by the monotonicity of } \Pi_1^N \text{ in } c_2\text{)} \\
&> \Phi^L(0, 0) \quad \text{(by Assumption 1)}.
\end{aligned}$$

It follows that there exists also some $s_1 < 1$ that assures existence of a s_1^n that satisfies the inequality $\Pi^{N*}(s^n) > \Phi^L(0, 0)$. □

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