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

Cuihong Fan and Elmar G. Wolfstetter

Abstract

We reconsider the justifications of the R&D subsidies of Spencer and Brander (1983), by allowing firms to form a research joint venture (RJV) and license innovations. If governments offer unconditional subsidies, an RJV is formed and the strategic benefits of R&D subsidies vanish. Nevertheless, governments subsidize their domestic firms to enhance their bargaining position in the joint venture subgame. If governments offer subsidies conditional on forming resp. not forming an RJV, the game has multiple equilibria: one that restores the Spencer and Brander result, and another in which governments induce the formation of an RJV by a combination of conditional taxes and subsidies.

KEYWORDS: patent licensing, joint ventures, industrial organization

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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 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 which, 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 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, unconditional 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. However, these subsidies play an entirely different role. Therefore, our analysis suggests an alternative justification of observed R&D subsidies.

In principle, subsidies can be made either unconditional or conditional on

[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)).

forming resp. not forming an RJV. We cover both cases. In the equilibrium under unconditional subsidies firms actually form an RJV, and governments offer subsidies that are lower than the equilibrium subsidies in the Spencer and Brander (1983) model. However, in the case of conditional subsidies, the game has two kinds of equilibria: one in which the Spencer and Brander (1983) result is restored because at least one government charges a prohibitively high tax on forming an RJV, and another in which governments induce the formation of an RJV by a combination of conditional subsidies and taxes.

There is a large literature on international R&D rivalry and R&D subsidies, as well as 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 "RJV competition", when firms pool their innovations but not their R&D investments, and "RJV cartelization", when firms pool both their R&D investments and innovations, but remain competitors in the product market, to "extended collusion", where collusion extends to the product market (see D'Aspremont and Jacquemin, 1988, Kamien, Muller, and Zang, 1992, Miyagiwa and Ohno, 2002).

The RJV mechanism proposed in the present paper covers a middle ground between the kinds of RJVs discussed in the literature. Like in the case of "RJV cartelization" we assume that firms use the RJV to coordinate and pool their R&D expenditures and share the resulting innovation, while remaining competitors in the product market. And like in the case of "extended collusion" we account for the fact that R&D cooperation tends to induce some form of collusion in the product market. However, unlike in the case of "extended collusion" we do not allow firms to directly coordinate output strategies; we only allow them to do so indirectly through output–based royalty licensing of the RJV's innovation, within the limits set by competition law.

Empirical studies have shown that output–based royalty licensing is the most commonly employed licensing scheme (see Rostoker, 1984, Anand and Khanna, 2000). This suggests that the RJV mechanism proposed in the present paper is eminently plausible, although it has been apparently ignored in the RJV literature.

We also mention that firms not only have an incentive to cooperate in R&D and license their innovation; they are often given additional incentives to do so. For example, in the European Community, several agencies support RJVs. Some of its programs, such as *EUREKA*, are financed by each firm's home government. And some programs, such as *ESPRIT* and *RACE*, require a result–sharing agreement between the cooperating firms (see Socorro (2006) and Flster (1995)).

The paper proceeds as follows. Section 2 introduces the model. Section 3 solves the game without an RJV, which serves as our benchmark model. Section 4 explains why and how we model the pooling of R&D investments combined with the licensing of the innovation. Section 5 solves the subgame–perfect equilibrium of the full game with an RJV, assuming unconditional subsidies, and compares it with that of the benchmark model. Section 6 extends the analysis to the case 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 scheme and the RJV's R&D investment. If they do not agree, they go alone and simultaneously choose the R&D investments, as in Spencer and Brander (1983) (a detailed account follows in section 4).

Stage 3 Firms observe the R&D investment(s) and the terms of the licensing mechanism 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 investments 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 $\frac{\partial}{\partial q_j}\left(P'(Q)q_i\right) < 0$, $i, j = 1, 2$, and $P'(Q) < 0$. 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 at such a level that both firms serve the market if they do not innovate, i.e., $0 \leq c < P(0)$ and the function f satisfies the Inada condition. These conditions assure interior solutions.

We rule out "drastic" innovations, i.e. we assume that the innovation subgame does not have an equilibrium that implements monopoly.

3 The Benchmark Model 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 strategy vectors $\left(q^b(x), x^b(s), s^b\right)$, where b is mnemonic for "benchmark model".

The payoff functions of the Cournot, R&D investment, and subsidy subgames are[3]

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

$$\Pi_i(x; s_i) := \pi_i\left(q^b(x); x_i\right) - (1 - s_i)x_i \tag{2}$$

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

$$\text{where} \quad \Pi_i^b(s) := \Pi_i\left(x^b(s); s_i\right). \tag{4}$$

[3]For convenience, the payoff function of the Cournot subgame excludes the net R&D expenditure which is no longer a decision variable at this stage. This convention is applied throughout the paper.

The equilibrium strategies $\left(q^b(x), x^b(s), s^b\right)$ solve the first–order conditions: $\partial\pi_i(q;x_i)/\partial q_i = 0$, $\partial\Pi_i(x;s_i)/\partial x_i = 0$, $\partial G_i^b(s)/\partial s_i = 0$, for all $i = 1,2$.

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.

Proposition 1 (Spencer and Brander (1983))**.** *In a symmetric equilibrium of the benchmark game the equilibrium subsidy rates are* $s_1^b = s_2^b = s_b$

$$s_b = \frac{\partial\Pi_i(x;s_i)}{\partial x_j} \frac{\partial x_j^b(s)/\partial s_i}{\partial x_i^b(s)/\partial s_i}\bigg|_{x=x^b(s),s=s^b} > 0. \tag{5}$$

Proof. By definition of Π_i^b and the envelope theorem one has

$$\frac{\partial\Pi_i^b(s)}{\partial s_i} = \frac{d\Pi_i(x^b(s);s_i)}{ds_i} = \frac{\partial\Pi_i(x;s_i)}{\partial x_j}\bigg|_{x=x^b(s)} \frac{\partial x_j^b(s)}{\partial s_i} + x_i^b(s). \tag{6}$$

Therefore, s^b solves the requirement

$$0 = \frac{\partial G_i^b(s)}{\partial s_i} = \frac{\partial\Pi_i(x;s_i)}{\partial x_j}\bigg|_{x=x^b(s)} \frac{\partial x_j^b(s)}{\partial s_i} - s_i \frac{\partial x_i^b(s)}{\partial s_i}. \tag{7}$$

After rearranging and noting that $\partial\Pi_i/\partial x_j < 0$, $\partial x_i^b/\partial s_i > 0$, $\partial x_j^b/\partial s_i < 0$, the assertion follows immediately. □

4 The Research Joint Venture Mechanism

Firms have an incentive to coordinate and pool their R&D investments, and to license the resulting innovation. We take this into account by including an additional stage to the base game in which firms decide whether to form an independent R&D joint venture (RJV), which may be viewed as an additional player.

In the following we assume that the RJV employs a mechanism, $\{x_r, r, t\}$, that stipulates a joint level of R&D investment, x_r; prescribes that firms pay an output–based royalty to the RJV, with royalty rates $r := (r_1, r_2)$, and in addition pass on the subsidies received from national governments; and prescribes lump–sum transfers $t := (t_1, t_2)$ from the RJV to firms.

The royalty payments serve two purposes: to finance the R&D investment, and to reduce the undesirable competition effect of the cost reduction induced by the innovation,[4] whereas the lump–sum transfers, t, serve the purpose of distributing the RJV's equilibrium income to its member firms.

In principle, royalty schemes can be used to monopolize the product market by sufficiently raising the effective marginal cost above the pre–innovation level. However, such misuse is not compatible with competition law.

Competition law typically permits RJVs provided member firms maintain a competitive relationship in the product market. This rules out that firms directly coordinate strategies in the product market; however, it does not rule out that firms indirectly influence the degree of competition through intelligent licensing of the RJV's innovation, within certain limits. Therefore, we assume that the RJV can only choose royalty rates that are not greater than the cost reduction due to its innovation.[5]

The optimal mechanism solves the allocation problem by choosing x_r and r in such a way that it maximizes the RJV surplus, defined as the sum of the firms' operating profits, π_i, plus the income of the RJV,

$$\Phi := \sum_i \left(\pi_i + (r_i q_i + s_i x_r - x_r)\right),$$

subject to the constraint that royalty rates shall not exceed the cost reduction induced by the innovation. Thereby, firms' operating profit is $\pi_i := (P(Q) - c + f(x_r) - r_i)\, q_i$.

And it solves the bargaining or distribution problem by choosing the transfers, t, to be paid from the RJV to firms, in such a way that they maximize the Nash (1950) product, $\prod_i \left(\pi_i + t_i - \Pi_i^b\right)$, subject to the RJV's budget constraint:[6] $\sum_i (r_i q_i + s_i x_r) \geq \sum_i t_i + x_r$.

The proposed mechanism covers a middle ground between the kinds of RJVs discussed in the literature, which range from "RJV competition" and "RJV cartelization" (see Kamien, Muller, and Zang, 1992) to "extended collusion" (D'Aspremont and Jacquemin, 1988). Unlike the mechanisms assumed in the literature, the proposed mechanism is optimal in the class of mechanisms that include royalty licensing, subject to the constraints set by competition law.

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[4] We mention that this elimination of the competition effect of a cost reduction can also be achieved through cross–ownership (Dick, 1993). Cross–ownership may however be restricted by competition law, although competition law typically fails to outlaw cross–ownership in non–voting shares.

[5] This constraint is also employed in the literature on patent licensing on the ground that competition authorities do not allow licensing to be misused to induce monopolization (see, for example, Giebe and Wolfstetter, 2008).

[6] Without loss of generality we assume that governments subsidize the total R&D expenditure of the RJV, x_r, and not just the part claimed to be made by the own national firm.

5 The Game with Unconditional Subsidies

We now change the benchmark model by allowing firms to form an RJV and adopt the optimal RJV mechanism. Governments offer subsidies which are independent of whether firms form an RJV or stay alone, that is why we refer to them as unconditional subsidies.

The equilibrium strategies of the Cournot and R&D investment subgames depend upon whether firms form an RJV. If they do not, the equilibrium outputs and R&D investments are the same as in the benchmark model. Therefore, we now focus on the subgames in which the RJV has been formed.

Since the RJV mechanism requires firms to pay output–based royalties for the use of its innovation, the payoff functions of the Cournot subgame are now

$$\pi_i(q; x_r, r_i) := (P(Q) - c - r_i + f(x_r))\, q_i. \tag{8}$$

With slight abuse of notation we denote the equilibrium strategies in that subgame by the vector $q(x_r, r)$ and the aggregate equilibrium output by $Q(x_r, r)$. For convenience, we write

$$\pi_i^u(x_r, r) := \pi_i\left(q(x_r, r); x_r, r_i\right). \tag{9}$$

The RJV chooses royalty rates and R&D investment in such a way that the RJV surplus is maximized, subject to the constraint that royalty rates shall not exceed the cost reduction induced by the innovation

$$\begin{aligned} \max_{x_r, r_i \le f(x_r)} \Phi(x_r, r; s) &:= \sum_i \left(\pi_i^u(x_r, r) + r_i q_i(x_r, r) + s_i x_r\right) - x_r \\ &= (P(Q(x_r, r)) - c + f(x_r))\, Q(x_r, r) - (1 - \sum_i s_i) x_r. \end{aligned} \tag{10}$$

And, given the RJV's optimal allocation decision, $(x_r(s), r(s))$, and firms' continuation play, $q(x_r(s), r(s))$, the RJV solves its bargaining problem by choosing the transfers, t, in such a way that they maximize the Nash product, subject to the RJV's budget constraint,

$$\max_t \prod_i \left(\pi_i^u(x_r(s), r(s)) + t_i - \Pi_i^b(s)\right) \tag{11}$$

$$\text{s.t.} \quad \sum_i (r_i(s) q_i(x_r(s), r(s)) + s_i x_r(s)) \ge \sum_i t_i + x_r(s), \tag{12}$$

where $(\Pi_1^b(s), \Pi_2^b(s))$ represents the disagreement point.

Proposition 2 (Joint Venture Subgame)**.** *In equilibrium, the RJV is formed and given s, the RJV mechanism,* $\{x_r(s), r(s), t(s)\}$*, is characterized as follows (for* $i, j = 1, 2, i \neq j$*):*

$$r_1(s) = r_2(s) = f(x_r(s)) \tag{13}$$

$$f'(x_r(s))2q_i^b(0) = 1 - s_1 - s_2 \tag{14}$$

$$t_i(s) = \frac{1}{2}\left(\Phi^u(s) + \Pi_i^b(s) - \Pi_j^b(s) - 2\pi_i^u(x_r(s), r(s))\right) \tag{15}$$

where $\Phi^u(s) := \Phi(x_r(s), r(s); s)$.

Proof. For the optimal x_r the surplus Φ is strictly increasing in r_i, for all $r_i \leq f(x_r)$, since Φ is strictly concave in Q and increasing r_i diminishes the equilibrium output Q closer towards the monopoly output. Therefore, it is optimal to set the highest possible royalty rates equal to $f(x_r(s))$, as stated in (13). This immediately implies $q_i(x_r(s), r(s)) = q_i^b(0)$ and thus

$$\pi_i^u(x_r(s), r(s)) = \left(P(Q^b(0) - c\right)q_i^b(0) =: \pi_u. \tag{16}$$

Equation (14) is the first–order condition of the maximization problem (10) concerning x_r.

Substituting the budget constraint into the Nash product, the Nash bargaining problem simplifies to

$$\max_{t_1} \left(\pi_u + t_1 - \Pi_1^b(s)\right)\left(\Phi^u(s) - \pi_u - t_1 - \Pi_2^b(s)\right). \tag{17}$$

Computing the first–order condition, one obtains the two equilibrium transfers (15). Thus, the total payoffs of the two member firms are

$$\begin{aligned}\Pi_i^u(s) :=& \pi_i^u(x_r(s), r(s)) + t_i(s) \\ =& \frac{1}{2}\left(\Phi^u(s) + \Pi_i^b(s) - \Pi_j^b(s)\right).\end{aligned} \tag{18}$$

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

$$\Pi_i^u(s) - \Pi_i^b(s) = \frac{1}{2}\left(\Phi^u(s) - \left(\Pi_i^b(s) + \Pi_j^b(s)\right)\right) \geq 0. \tag{19}$$

This shows that in equilibrium firms form the RJV. □

Using the equilibrium of the RJV subgames, we now solve the subsidy game played between national governments whose payoff function is $G_i^u(s) = \Pi_i^u(s) - s_i x_r(s)$.

By (18),

$$G_i^u(s) = \frac{1}{2}\left(\Phi^u(s) + \Pi_i^b(s) - \Pi_j^b(s)\right) - s_i x_r(s).$$

By the envelope theorem one has $\partial \Phi^u(s)/\partial s_i = x_r(s)$. Therefore,

$$\begin{aligned}\frac{\partial G_i^u(s)}{\partial s_i} =& \frac{1}{2}\left(\frac{\partial \Phi^u(s)}{\partial s_i} - 2x_r(s) - 2s_i \frac{\partial x_r(s)}{\partial s_i}\right) + \frac{1}{2}B(s) \\ =& \frac{1}{2}\left(B(s) - x_r(s) - 2s_i \frac{\partial x_r(s)}{\partial s_i}\right),\end{aligned} \tag{20}$$

where $B(s) := \partial \Pi_i^b(s)/\partial s_i - \partial \Pi_j^b(s)/\partial s_i$, will be referred to as "bargaining effect".

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; in fact it would tax firms' R&D expenditures, since if one ignores $B(s)$ the partial derivatives of $G_i^u(s)$ are negative at $s = 0$. This is due to the fact that the innovation developed by the RJV has the feature of a public good, and therefore each government tries to free ride. The bargaining effect counters the incentive to free ride, because by offering a subsidy governments can raise their national firm's share of the RJV profit. This suggests that governments subsidize only in order to enhance the bargaining power of their national firm.[7]

Proposition 3. *Suppose the functions $G_i^u(s)$ are concave in s_i. The equilibrium subsidy rates, s^u, are lower than in the benchmark model without RJV.*

Proof. We evaluate the partial derivatives $\partial G_i^u(s)/\partial s_i$ at the point $s^b = (s_b, s_b)$ and show that they are negative. Since these derivatives are monotonically decreasing (by the assumed concavity), the equilibrium subsidy rates,s^u, must be lower than s^b.

Notice that the term $B(s)$ in the RHS of (20) vanishes since (s_b, s_b) is an equilibrium of the game without RJV. By the first–order conditions of government i in

[7] In a linear model, one can show that equilibrium subsidies are always nonnegative. A documentation in the form of a *Mathematica* file is available from the authors upon request.

the game without RJV (where $s^b = (s_b, s_b)$),

$$\left.\frac{\partial G_1^b(s)}{\partial s_1}\right|_{s=s^b} = \left.\left(\frac{\partial \Pi_1^b(s)}{\partial s_1} - x_1^b(s) - s_b \frac{\partial x_i^b(s)}{\partial s_1}\right)\right|_{s=s^b} = 0 \tag{21}$$

$$\left.\frac{\partial G_2^b(s)}{\partial s_2}\right|_{s=s^b} = \left.\left(\frac{\partial \Pi_2^b(s)}{\partial s_2} - x_2^b(s) - s_b \frac{\partial x_2^b(s)}{\partial s_2}\right)\right|_{s=s^b} = 0. \tag{22}$$

Of course, $s = s^b$ implies $x_1^b(s) = x_2^b(s)$. By (21)–(22), $\partial \Pi_1^b(s)/\partial s_1 = \partial \Pi_2^b(s)/\partial s_2$.

Therefore, one obtains

$$\left.\frac{\partial G_i^u(s)}{\partial s_i}\right|_{s=s^b} = -\frac{1}{2}\left.\left(x_r(s) + 2s_i \frac{\partial x_r(s)}{\partial s_i}\right)\right|_{s=s^b} < 0, \tag{23}$$

as asserted. □

We conclude that subsidies are also a feature of the model with RJVs. However, they serve an entirely different purpose than in the Spencer and Brander (1983) model. When RJVs and licensing are feasible, firms are not abe to use R&D investments to gain a strategic advantage in the Cournot–market game. Therefore, governments can no longer use subsidies to enhance their domestic firm's 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.

6 Extension to Conditional Subsidies

So far we have assumed that governments offer subsidies which are independent of whether their domestic firms stay alone or form an RJV. Now we explore what happens in the probably unlikely case that governments are able to commit to offering subsidies conditional on forming resp. not forming an RJV.

In order to allow for all possibilities we assume that governments offer two subsidy rates:[8]

1. subsidies rates paid if and only if the RJV is formed (these are denoted by $s^r := (s_1^r, s_2^r)$), and

2. subsidy rates paid if and only if firms stay alone (these are denoted by $s^n := (s_1^n, s_2^n)$).

[8]This setup includes all possible subsidy schemes as a special case. In particular, $s_i^r = s_i^n \geq 0$ is the case of unconditional subsidies which were analyzed in the previous section; $s_i^r = 0, s_i^n > 0$ is the case when subsidies are paid only if no RJV is formed; and $s_i^r < 0$ is the case when firms are penalized, in the form of a linear tax, if they form an RJV.

Subsidy rates may be negative.

At the outset note that the subsidies that are conditional on not forming an RJV, s^n, have the same effect on the default payoffs, Π_i^b, and thus on the bargaining position, as unconditional subsidies; yet, they have the distinct advantage that no subsidy is actually paid if the RJV is formed. This suggests that governments should make use of these conditional subsidies, if that is feasible.

Note that s_i^r affects only the surplus, Φ, but not the default payoffs, Π_i^b, whereas s_i^n affects only the default payoffs, Π_i^b. And only the default payoffs affect the firms' bargaining position. Therefore, we now write $\Phi^c(s^r)$, $\Pi_i^b(s^n)$, where c is mnemonic for "conditional". Also, denote the sum of default payoffs by

$$\Pi^b(s^n) := \Pi_1^b(s^n) + \Pi_2^b(s^n). \tag{24}$$

Governments' payoff functions are

$$G_i^c(s^r, s^n) = \Pi_i^c(s^r, s^n) - s_i^r x_r(s^r), \tag{25}$$

where

$$\Pi_i^c(s^r, s^n) := \frac{1}{2}\left(\Phi^c(s^r) + \Pi_i^b(s^n) - \Pi_j^b(s^n)\right) \tag{26}$$

$$\Phi^c(s^r) := \Phi(x_r(s^r)), r(s^r), s^r). \tag{27}$$

Interestingly, the game can have two kinds of equilibria: one symmetric equilibrium in which the benchmark model is restored, and one asymmetric equilibrium in which the RJV is formed, governments use the subsidy rate s_i^n to maximize the bargaining position of their domestic firm, and s_i^r to tax firms for the R&D investment of the RJV.

In the benchmark model without RJV from section 3, subsidies were set at the uniform rates $s_1^b = s_2^b$. To construct an equilibrium that restores the equilibrium outcome of the benchmark model, consider strategies $(s_i^r, s_i^n = s_i^b)$, and set high tax rates $-s_i^r > 0$. Choose these tax rates so high that no RJV is formed if these strategies are played, i.e. $\Phi^c(s^r) < \Pi^b(s^b)$, so that no government can profitably induce the formation of an RJV by revising its own subsidy rates. Then, these strategies are obviously an equilibrium, by definition of s^b combined with the fact that the high tax rates, $-s^r$, prevent firms from profitably forming an RJV.

We now turn to the other kind of equilibrium in which the RJV is formed. In such an equilibrium firms are taxed if they form an RJV and subsidy rates (s^r, s^n) are chosen in such a way that firms are indifferent between forming and not forming an RJV. The entire gain of forming an RJV is appropriated by governments.

Proposition 4. *An equilibrium in which the RJV is formed, (s^r, s^n), must satisfy the following conditions:*

$$\frac{\partial \Pi^b(s^n)}{\partial s_i^n} > 0, \quad i = 1,2 \quad \textit{(monotonicity conditions)} \tag{28}$$

$$\Phi^c(s^r) = \Pi^b(s^n) \quad \textit{(surplus condition).} \tag{29}$$

In a symmetric equilibrium $s_i^r = s_r, s_i^n = s_n, i = 1,2$, one must also have $s_r < 0$, i.e. firms are taxed if they form an RJV.

Proof. The proof is by contradiction. Suppose the monotonicity conditions (28) do not hold, say because $\partial \Pi^b / \partial s_1^n \leq 0$. Then, if government 1 increases s_1^n, it thus neither increases $\Pi^b(s^n)$ nor affects $\Phi^c(s^r)$. Therefore, the RJV is maintained. However, $\Pi_1^b(s^n)$ goes up while $\Pi_2^b(s^n)$ goes down. Therefore, firm 1 benefits at no cost to government 1. But this contradicts the assumption that (s^r, s^n) is an equilibrium.

Next, suppose the surplus condition (29) does not hold. Since in the assumed equilibrium the RJV is formed, one must have $\Phi^c(s^r) > \Pi^b(s^n)$. But then, by (28) government 1 can increase s_1^n without destroying the RJV which raises its payoff as already explained above.

If the equilibrium is symmetric, suppose $s_r \geq 0$. Then, by a known fact

$$\Phi^c(s_r, s_r) \geq \Phi^c(0,0) > \Pi^b(0,0) > \Pi^b(s_n, s_n).$$

Therefore, if one does not tax the RJV the surplus condition (29) fails. □

Proposition 5. *If the monotonicity conditions* (28) *hold at $s^n = s^b$, the following subsidy rates are an equilibrium in which the RJV is formed:*

$$s_1^n = s_2^n = s_b \tag{30}$$

$$s_1^r = s_2^r = s_r < 0 \tag{31}$$

$$\Phi^c(s^r) = \Pi^b(s^b). \tag{32}$$

Proof. At the outset note that

$$\Phi^c(s^r) = \Pi^b(s^n) \quad \Rightarrow \quad G_i^c(s^r, s^n) = \Pi_i^b(s^n) - s_r x_r(s^r). \tag{33}$$

Also notice that by choosing $s_r < 0$ and sufficiently small, the surplus condition (29) can be satisfied for $s_1^n = s_2^n = s_b$.

We show that no unilateral deviation is profitable. Suppose one government, say government 2, applies the alleged equilibrium subsidies (s_r, s_b). We show that government 1 cannot increase its payoff by any unilateral deviation from its alleged equilibrium strategy.

Suppose government 1 decreases its subsidy rate s_1^n from s_b to s_b'. Then, by the monotonicity conditions (28), $\Phi^c(s^r) > \Pi^b(s_b', s_b)$; hence, the RJV is maintained. However, reducing s_1^n reduces the default payoffs of firm 1 and increases that of firm 2; hence, $\Pi_1^c(s^r, s^n)$ is reduced. Since the tax on forming an RJV is not affected, $G_1^c(s^r, s^n)$ is equally reduced.

In turn, Suppose government 1 deviates by raising s_1^n from s_b to s_b'. Then, by the monotonicity conditions (28), $\Phi^c(s^r) < \Pi^b(s_b', s_b)$. Hence, the RJV is destroyed, and the government's payoff is changed from $G_1^c(s^r, s^b)$ to $G_1^b(s_b', s_b)$ by the amount

$$\begin{aligned} G_1^b(s_b', s_b) - G_1^c(s^r, s^b) &= G_1^b(s_b', s_b) - \left(G_1^b(s^b) + s_b x_1^b(s^b) - s_r x_r(s^r)\right) \\ &< G_1^b(s_b', s_b) - G_1^b(s^b) \quad \text{since} \quad s_b > 0, s_r < 0 \\ &\leq 0, \end{aligned}$$

where the last inequality follows from the fact that s^b is an equilibrium of the game when no RJV is formed.

Similarly, if government 1 deviates by reducing s_1^r from s_r to s_r', it reduces $\Phi^c(s^r)$ and leaves $\Pi^b(s^b)$ unchanged. Hence, $\Phi^c(s_r', s_r) < \Pi^b(s^b)$, and the RJV is destroyed. The government's payoff is changed by the amount

$$\begin{aligned} G_1^b(s^b) - G_1^c(s^r, s^b) &= -s_b x_1^b(s^b) + s_r x_r(s^r) \quad \text{by (33)} \\ &< 0 \quad \text{since } s_b > 0, s_r < 0, \end{aligned}$$

because now the subsidies have to be paid and the tax from the RJV is no longer collected.

In turn, if government 1 increases s_1^r from s_r to s_r', it thus increases $\Phi^c(s^r)$ and leaves $\Pi^b(s^b)$ unchanged. Hence, $\Phi^c(s_r', s_r) > \Pi^b(s^b)$, and the RJV is maintained. In that case, one finds, using the envelope theorem and the fact that $x_r(s^r)$ is increasing in s_i^r:[9]

$$\frac{\partial G_1^c(s^r, s^n)}{\partial s_1^r} = -\frac{1}{2}\left(x_r(s^r) + 2 s_1^r \frac{\partial x_r(s^r)}{\partial s_1^r}\right) < 0. \tag{34}$$

Therefore, increasing s_1^r is not profitable either. □

If the monotonicity conditions (28) assumed in Proposition 4 do not hold at $s_i^n = s_b$, an equilibrium can be constructed by uniformly raising the subsidy rates

[9] Note, this derivative applies only as long as the RJV is formed, which is why it only applies to upwards deviations in the choice of s_1^r. Hence, it should be viewed as a right hand derivative.

s^n. As we show in the Appendix, the monotonicity conditions (28) hold if the subsidy rates s_i^n are equal *and* sufficiently high. High subsidy rates s_i^n also assure that it does not pay for a government to unilaterally raise s_i^n, and thus destroy the RJV, because in that case it has to pay the high subsidy based on s_i^n. Similar to the argument in the proof of Proposition 5 it never pays to reduce s_i^n nor to change s_i^r.

7 Conclusion

The present paper has reconsidered the justification of R&D subsidies by Spencer and Brander (1983) and others by allowing firms to pool R&D investments and license the resulting innovations. This modification has drastic implications. If unconditional subsidies are offered, in equilibrium firms form an RJV and apply an optimal royalty scheme that neutralizes the competition effect of their innovation within the constraints set by competition law. Like in Spencer and Brander (1983), governments subsidize their firms; but unlike in Spencer and Brander they do this only to enhance the bargaining power of their domestic firm and not to gain a strategic advantage in the market game. Therefore the justification of R&D subsidies proposed by Spencer and Brander (1983) no longer holds and an alternative explanation of subsidies is made available.

However, if governments offer subsidies conditional on forming and on not forming an RJV, the game has two kinds of equilibria: one in which the Spencer and Brander (1983) result is restored because at least one government sets a prohibitively high tax on forming an RJV that chokes off the formation of an RJV; and another in which the RJV is formed. In the latter equilibrium governments use conditional subsidies on not forming an RJV to enhance the bargaining position of their firm. Since these subsidies are not paid as long as the RJV is maintained, governments always gain from raising this subsidy. However, the RJV is also taxed to such an extent that this incentive to enhance the bargaining position is kept at bay.

It is not clear which of these two equilibria is more plausible. The equilibrium in which the RJV is formed is appealing on the ground that it is payoff–dominant; however, the other equilibrium is more appealing on the ground that the subsidies are actually paid.

Altogether we doubt that governments are actually able to commit to conditional subsidies. Therefore, we feel that our analysis of unconditional subsidies is the most relevant case as far as positive theory is concerned.

Appendix: Supplement to Proposition 5

In the discussion of Proposition 5 we invoked a result concerning the monotonicity conditions (28) which we now elaborate in detail.

Let $\hat{\Pi}_i^b(s^n) := \Pi_i^b(s^n) + (1-s_i^n)x_i^b(s^n)$ and $\hat{\Pi}^b(s^n) := \hat{\Pi}_1^b(s^n) + \hat{\Pi}_2^b(s^n)$.

We proceed as follows: we first show that $\partial\hat{\Pi}^b/\partial c_i < 0$, which immediately entails $\partial\hat{\Pi}^b/\partial x_i > 0$; and then show that this implies $\partial\hat{\Pi}^b/\partial s_i^n > 0$.

Lemma 1. *If $s_1^n = s_2^n$ the sum of equilibrium default profits $\hat{\Pi}^b(s^n)$ is strictly monotone increasing in s_1^n and s_2^n, i.e.,*

$$s_1^n = s_2^n \quad \Rightarrow \quad \frac{\partial\hat{\Pi}^b(s^n)}{\partial s_i^n} > 0, \quad i = 1,2. \tag{35}$$

Proof. Denote firms' unit costs by c_1, c_2.

The assumed $s_1^n = s_2^n$ induces the same cost reduction in the event when no RJV is formed. Denote the resulting unit cost by $c_1 = c_2 = c'$.

By the envelope theorem one has for $c_1 = c_2 = c'$

$$\begin{aligned} \frac{\partial\hat{\Pi}^b}{\partial c_i} &= \frac{\partial\hat{\Pi}_i^b}{\partial q_j^b}\frac{\partial q_j^b}{\partial c_i} + \frac{\partial\hat{\Pi}_i^b}{\partial c_i} + \frac{\partial\hat{\Pi}_j^b}{\partial q_i^b}\frac{\partial q_i^b}{\partial c_i} \\ &= q_i^b\left(P'(Q^b)\frac{\partial Q^b}{\partial c_i} - 1\right). \end{aligned} \tag{36}$$

By the equilibrium conditions for an asymmetric Cournot duopoly one has

$$P'(Q^b)Q^b + 2P(Q^b) \equiv c_i + c_j \tag{37}$$

$$\text{hence} \quad \frac{\partial Q^b}{\partial c_i} < 0. \tag{38}$$

By partially differentiating identity (37) w.r.t. c_i one obtains for $c_i = c_j$

$$3P'(Q^b)\frac{\partial Q^b}{\partial c_i} + P''(Q^b)\frac{\partial Q^b}{\partial c_i}Q^b \equiv 1. \tag{39}$$

Substituting (39) into (36) gives, for $c_i = c_j = c'$,

$$\frac{\partial\hat{\Pi}^b}{\partial c_i} = -\left(P''(Q^b)Q^b + 2P'(Q^b)\right)\frac{\partial Q^b}{\partial c_i} < 0, \tag{40}$$

which immediately implies $\partial\hat{\Pi}^b/\partial x_i > 0, i = 1,2$, and hence

$$\frac{\partial\hat{\Pi}^b}{\partial s_i} > 0, \quad i = 1,2. \tag{41}$$

□

By definition of $\hat{\Pi}^b$ and Π^b, one has

$$\frac{\partial \Pi^b}{\partial s_i^n} = \left(\frac{\partial \hat{\Pi}^b}{\partial s_i^n} + x_i^b \right) - \left((1 - s_i^n) \frac{\partial x_i^b}{\partial s_i^n} + (1 - s_j^n) \frac{\partial x_j^b}{\partial s_i^n} \right) \tag{42}$$

Therefore, the monotonicity conditions (28) are always satisfied if the subsidy rates s_1^n, s_2^n are equal *and* sufficiently high.

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