

R&D LEADERSHIP AND RESEARCH JOINT VENTURES

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Abstract

This paper examines the effect of R&D leadership on Research Joint Venture formation. If firms compete in R&D, there is a first (second)-mover advantage, when spillovers are relatively low (high). RJV profits exceed those of R&D leadership, except for a very narrow range of low unit R&D costs and spillovers. For a leader, preventing follower activity is only profitable if unit R&D costs and spillovers are relatively low. If unit R&D costs are sufficiently low, preventing the follower from becoming active may be welfare dominant but not profit maximizing, possibly justifying a role for government policy to subsidise R&D investment.

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1. Introduction

Throughout history, individual firms, countries and, more recently, international economic regions have sought to improve their technological capabilities. A well-developed economy may try to innovate, by moving up the 'value-chain', in order to improve its competitiveness vis-à-vis its economic competitors. On the other hand, both well and less-developed economies have often sought technological progress in order to 'catch-up' with more advanced economies and possibly break into export markets. Consequently, many governments worldwide have offered various forms of support in order to encourage greater levels of innovation and technological progress.

Innovation often bears the hallmark of a public good as the knowledge generated by any specific research and development (R&D) project may become available, via some form of spillovers, to more than those that have undertaken such a project. This can serve to reduce the private incentive to undertake R&D if innovators cannot fully appropriate the benefits of their success, despite such innovation often having social benefits in excess of any private returns. As well as this, many major R&D projects may be very expensive and the likelihood of success very uncertain, again dampening any private incentive.

Public solutions to the private innovation problem include patents and R&D subsidies, the later either directly or via favourable taxation policy. One possible private solution is for innovators to *co-operate* in R&D by forming a Research Joint Venture (RJV), where innovation is undertaken to maximise the sum of joint profits of all RJV members. Also, innovators can decide on the level of information sharing within the RJV, so that effective spillover levels become endogenous, and can also co-ordinate their innovation efforts to avoid any duplication. One downside to such arrangements is that they may be continued to the output market in contravention of antitrust laws. Another is that such ventures are undertaken by a subset of firms in an industry, thereby possibly giving these firms a competitive advantage over their rivals and dampening effective competition in the final market. Consequently, whether such ventures are socially beneficial will depend on the relative size of these effects.

While firms can undertake R&D in order to improve the quality of their product (product innovation) or reduce marginal production costs (process innovation), much of the literature, and this paper, focusses on the latter. The existing literature is generally favourable towards such ventures as they often lead to greater incentives to undertake R&D, higher total industry profits and, possibly, greater welfare. A seminal contribution to the literature on RJV formation in the presence of exogenous R&D spillovers is by D'Aspremont and Jacquemin

(1988), where profit maximising firms either *compete* or *co-operate* (form RJV) in R&D.¹ From the firms' perspective, RJV formation is weakly preferred to R&D competition.² From a welfare perspective, however, the desirability of RJV formation is not clear-cut. If all output is exported, welfare is simply measured by total industry profits and RJV formation is weakly welfare-dominant for all spillovers.³ If output is consumed domestically, however, RJV formation should only be encouraged if spillover levels are relatively high.

A feature of the D'Aspremont and Jacquemin model is that effective spillovers remain exogenous under RJV formation. Poyago-Theotoky (1999) showed that firms will fully share information when forming a RJV so that spillovers are endogenised. Kamien, Muller and Zang (1992) conclude that RJV 'cartelisation' is most desirable as R&D investment and profits are highest, while output prices are lowest.⁴

Salant and Shaffer (1998) note that, for a particular range of exogenous spillover parameter and unit R&D costs, asymmetric R&D investment within a RJV can increase both total industry profits and welfare. With a convex R&D cost function, asymmetric investment may increase total R&D costs at the innovation stage, but this will be offset by higher profits in the output market so that overall profits and, consequently, welfare, will be higher, even in the case where there are no exogenous R&D spillovers.

One characteristic that is shared by all of the above papers is that firms simultaneously undertake their R&D investment. A sizable literature has analysed the effects of a firm having a first-mover advantage, either as an incumbent monopolist (Dixit (1980)), or as a duopolist (Spencer & Brander (1992)). Many of these papers focus on the case of output leadership, but also extend their models to 'capacity' leadership, where capacity can be interpreted as, for example, production facilities, advertising expenditure or R&D investment. More importantly, however, much of this literature papers assumes that only one firm has the first-mover advantage.

Rossell and Walker (1999), using the D'Aspremont & Jacquemin framework, look at the effect of incumbent R&D leadership in the presence of potential entry when there are R&D spillovers. While noting the standard outcomes of blockaded entry, entry accommodation and entry deterrence, they also argue that for relatively high spillovers, the incumbent may choose its R&D in order to solicit entry into the industry. In particular, the higher are fixed costs, the more likely it is that entry will be blockaded, though the incumbent will prefer accommodation in order to benefit from the effect of relatively high spillovers. In

¹ Earlier related papers include Dasgupta & Stiglitz (1980), Katz (1986) and Spence (1988). Several

² RJV profits are always greater, except for spillovers of $\frac{1}{2}$ when the two cases are identical.

³ This point was noted by, among others, Neary and O'Sullivan (1999).

⁴ KMZ define a RJV as a situation where firms fully share information between themselves, while 'cartelisation' refers to when the firms choose their R&D investment in order to maximise joint profits. Despite the taxonomy of R&D organisation, their results are identical to those of D'Aspremont and Jacquemin.

this case, the incumbent may choose some R&D level that makes entry profitable. In this paper, however, there is no co-operative behaviour, nor is there any welfare analysis.

Looking at empirical evidence regarding RJV formation, Hernan, Marin and Siotis (2003) analyse European data and find that industry concentration, firm size, technological spillovers and R&D intensity increase the likelihood of forming a RJV while patent effectiveness reduces it. These findings lead them to argue that "...knowledge diffusion is central to our understanding of RJV formation".⁵ Roller, Tombak and Siebert (2007) analyse US data and find that firms that are similar in size, have already participated in other RJV's and produce complementary products are more likely to form RJV's.⁶

This paper combines the models of Brander and Spencer (1992) and D'Aspremont and Jacquemin (1988) to analyse the incentives for firms to form a RJV when one firm has a first-mover ability in undertaking R&D investment but each firm receives an exogenous R&D spillover from its rival. While the effect of having a first-mover ability is well understood in relation to setting capacity, output and prices, its effect on R&D investment, especially when there are R&D spillovers between the firms and firms can make co-operative agreements, is much less so.

The paper analyses a one-shot game where two, ex-ante symmetric, output-setting firms produce a homogenous good and remain rivals in the output market. At the R&D stage, the firms may either compete against, or co-operate (form RJV) with, each other. In the former case, the firms choose their R&D to maximise own profits while the latter implies R&D investment to maximise joint profits. In both cases, backward induction is used to solve for the subgame perfect Nash equilibrium outcome.

It is assumed that both firms have costlessly entered the industry by, for example, receiving a licence from the government or a regulatory authority. The important point is that one firm has an exogenously given first-mover advantage in R&D. In choosing its R&D, the 'leader' firm may choose to 'accommodate' the 'follower' by simply choosing its R&D investment to maximise its own profits, or it may seek to prevent the follower from becoming 'active' in the industry by choosing its R&D to ensure that the producing a positive output level is unprofitable for the follower.^{7, 8}

In the *entry accommodation* case, there are four stages. Firstly, the firms decide whether to form a RJV or not. Secondly, the leader chooses its R&D, taking the R&D

⁵ R. Hernan, P. Marin & G. Siotis, 2003, 'An empirical evaluation of the determinants of research joint venture formation', *Journal of Industrial Economics*, vol. 51 (1), p87.

⁶ The authors also provide theoretical evidence that large firms will not form RJV's with smaller firms.

⁷ Intuitively, the latter is equivalent to entry deterrence in the absence of fixed entry costs, given that the follower has already entered the industry.

⁸ While the main focus of this chapter is on RJV formation, the issue of activity prevention is analysed given sequential R&D choices. While the assumption of costless entry limits any overview of 'activity prevention' incentives, it should be possible get an idea of how positive fixed entry costs affect an incumbent firm's investment incentives when faced with potential entry.

reaction function of the follower into account. Thirdly, the follower chooses its R&D level. Finally, the firms simultaneously choose their profit maximising output levels.

Conversely, in the *activity prevention* case, there are two stages. In the first stage, the leader chooses its R&D to ensure that activity is unprofitable for the follower. Secondly, given that the follower will decide not to become active, the leader chooses its profit maximising monopoly output level.

The main issue in this paper is: will a leader's profits when the firms compete in R&D exceed its profits when they form a RJV? Other interesting questions include: do the leader's profits always exceed those of the follower? Will a leader accommodate the follower or prevent it from becoming active? Will accommodation and/or activity prevention increase profits relative to the simultaneous R&D case? Given the public-good nature of R&D, it is quite conceivable that a follower may 'free-ride' on the decision of a 'leader' and be better off than when the firms simultaneously undertake their R&D investment. Also, and perhaps more interestingly, the follower may be better off than the leader under certain circumstances.

Section two of the paper introduces the model. Section three analyses the basic two-stage game where two firms simultaneously choose R&D and output levels in each stage. Section four looks at R&D competition and RJV formation in the context of R&D leadership. Section five compares the simultaneous and sequential R&D cases when the leader accommodates the follower. Section six looks at where the leader prevents the follower from becoming active, while Section seven compares accommodation to 'activity prevention'. Section eight simulates the model to facilitate comparison. Section nine concludes.

2. The model

It is assumed that the firms face a linear inverse demand function of the form

$$p(Q) = a - bQ \quad (1)$$

where $Q = q + q^*$ is total industry output. Marginal production costs are a linear function of own and rival R&D and are

$$c(x, x^*) = A - \theta(x + \beta x^*) \geq 0 \quad c^*(x, x^*) = A - \theta^*(\beta^* x + x^*) \geq 0 \quad (2)$$

where $0 \leq \beta, \beta^* \leq 1$ are the exogenous R&D spillover parameters of the respective firms.⁹ In (2), $\theta, \theta^* > 0$ denote the firms' efficiency in reducing marginal production costs through R&D so that $\theta\beta$ and $\theta^*\beta^*$ are the *effective* R&D spillovers of the respective firms. It is assumed that that $0 < A < a$ and $Q \leq a/b$. R&D costs are strictly increasing and convex in R&D, thereby exhibiting diminishing returns, and are given by $\gamma x^2/2$ and $\gamma x^{*2}/2$ for the respective firms, where $\gamma > 0$ is a measure of unit R&D costs.

⁹ In what follows, the non-representative firm is denoted by *.

In what follows, N denotes R&D competition (non co-operation), C denotes R&D co-operation (RJV formation), D denotes activity prevention, L represents the leader and F denotes the follower. For example, FC refers to the case of the follower when the firms co-operate in R&D, while LD refers to the leader when it prevents activity by the follower.

3. Simultaneous R&D

This two-stage game is identical to D'Aspremont and Jacquemin where, firstly, the firms simultaneously choose their R&D levels and either compete or co-operate in R&D. Secondly, the firms simultaneously choose their profit maximising output levels.

3.1 – output stage

The objective function of the representative firm is

$$\max_q \pi(q, q^*) = [p(Q) - c]q - \frac{\gamma x^2}{2} \quad (3)$$

so that the firm's first-order output condition is

$$\pi_q = a - 2bq - bq^* - c = 0 \Rightarrow p(Q) - c = bq \quad (4)$$

Given (1), (2) and (4), profit maximising output levels are

$$\begin{bmatrix} q \\ q^* \end{bmatrix} = \frac{1}{3b} \begin{bmatrix} \alpha + (2\theta - \theta^* \beta^*)x + (2\theta\beta - \theta^*)x^* \\ \alpha + (2\theta^* \beta^* - \theta)x + (2\theta^* - \theta\beta)x^* \end{bmatrix} \quad (5)$$

where $\alpha = a - A > 0$. For the representative firm, own R&D positively (negatively) affects own output if the rival's effective spillover is sufficiently low (high), i.e. if $\theta^* \beta^* < (>) 2\theta$. On the other hand, the effect of rival R&D on own output is positive (negative) if own effective spillover is sufficiently high (low), i.e. if $\theta\beta > (<) \frac{\theta^*}{2}$.¹⁰ The expressions in (5) are relevant for all cases where both firms undertake R&D.

From (3) and (4), profit for the representative firm can be expressed as

$$\pi = bq^2 - \frac{\gamma x^2}{2} \quad (6)$$

Welfare is the sum of consumer surplus and total industry profits that, given (1) and (6), is

$$W = \frac{bQ^2}{2} + bq^2 - \frac{\gamma x^2}{2} + bq^{*2} - \frac{\gamma x^{*2}}{2} \quad (7)$$

where the first term on the right hand side of (7) is a measure of consumer surplus from (1).

¹⁰ Similar conditions hold for the other firm.

3.2 - R&D competition

In this game, each firm chooses its R&D in order to maximise its *own* profits, though as the firms remain rivals in the output market, there will be strategic considerations to each firm's R&D investment. The representative firm's first-order R&D condition is

$$\frac{d\pi}{dx} = \underbrace{\frac{\partial\pi}{\partial x}}_{\text{direct effect}} + \underbrace{\frac{\partial\pi}{\partial q^*} \cdot \frac{\partial q^*}{\partial x}}_{\text{strategic effect}} = 0 \quad (8)$$

The *direct* R&D effect is the marginal benefit of R&D, the reduction in own marginal production costs, less marginal R&D cost. The *strategic* R&D effect is the change in rival output due to a unit change in own R&D times the change in own profits due to a unit change in rival output. Using (1), (2), (3) and (5) in (8) implies

$$\left[\frac{2(2\theta - \theta^* \beta^*)}{3} \right] q^N = \mu^N q^N = \gamma x^N \quad (9)$$

where μ^N is the marginal return to R&D per unit of output if the firms compete in R&D. From (1), (2), (3) and (8), non-strategic R&D investment implies $\mu^N = \theta$ so that the representative firm will over (under) invest in R&D when $\theta^* \beta^* < (>) \theta/2$.¹¹ The more efficient is each firm in reducing its own marginal production costs through R&D, given any efficiency of its rival, the greater the effective R&D spillover range of its rival at which each firm over-invests in R&D in order to profit-shift from its rival. As firms become less efficient, then they will seek to under-invest in R&D for greater effective spillover levels of its rival in order to 'free-ride' on the now relatively more efficient rival. Given ex-ante symmetric firms, ex-post symmetry implies $\theta = \theta^*$ and $\beta = \beta^*$ so that the firms will over (under) invest in R&D when $\beta < (>) 1/2$.¹² Given (5) and incumbent symmetry, profit maximising R&D levels are

$$x^N = x^{*N} = \frac{2\alpha\theta(2-\beta)}{9b\gamma - 2\theta^2(2-\beta)(1+\beta)} \quad (10)$$

which are decreasing in the spillover parameter because as firms increasingly benefit from rival R&D, each firm's incentive to undertake R&D is reduced.¹³

Solving for output levels in (5) and substituting into (6), we can derive profit levels

¹¹ Over-investment in R&D refers to where a firm chooses its R&D where the marginal private benefit of R&D is less than the marginal private cost in order to profit-shift from its rival and increase output market profits in the next stage, thereby increasing total profits. Conversely, under-investment in R&D has the same effect but now the firms invest in R&D where their marginal private benefit exceeds marginal private cost in order to free-ride on rival R&D.

¹² The firms' R&D levels are strategic substitutes (complements) when $\beta < (>) 1/2$. Consequently, their R&D reaction functions are downward (upward) sloping in R&D space.

¹³ Each firm's second-order R&D condition requires $9b\gamma - 2\theta^2(2-\beta)^2 > 0$. To ensure analysis for all spillover levels, this implies that $b\gamma$ is large enough to satisfy $9b\gamma - 2\theta^2(2-\beta)(1+\beta) > 0$.

$$\pi^N = \pi^{*N} = \frac{\gamma\alpha^2[9b\gamma - 2\theta^2(2-\beta)^2]}{[9b\gamma - 2\theta^2(2-\beta)(1+\beta)]^2} \quad (11)$$

Profits are increasing in a firm's effective spillover due to the benefits from rival R&D and lower own R&D costs, except when $b\gamma < \frac{2\theta^2(2-\beta)^3}{27(1-\beta)}$, that, given the stability conditions, can only occur when $\beta > 1/2$. In this spillover range, relatively effective R&D (low γ) increases the total R&D investment and, consequently, R&D costs, to an extent that is not offset by the benefit of lower marginal production costs given a rival's spillover benefit.¹⁴

Solving for welfare implies

$$W^N = \frac{2\gamma\alpha^2[18b\gamma - 2\theta^2(2-\beta)^2]}{[9b\gamma - 2\theta^2(2-\beta)(1+\beta)]^2} \quad (12)$$

that is increasing in the spillover, except when $b\gamma < \frac{2\theta^2(2-\beta)^3}{9(4-5\beta)}$ that can only occur if $\beta < 1/2$.

At these spillovers, lower profits offset any increased consumer surplus as a result of higher R&D expenditure so that welfare decreases.

3.3 - RJV formation (R&D co-operation)

In this game, the firms choose their R&D to maximise the sum of *joint* profits, taking into account the effect of their own R&D on RJV partner profits. Despite this, there will still be some degree of strategic R&D investment given the firms' output market rivalry. The representative firm's first-order R&D condition is now

$$\frac{d(\pi + \pi^*)}{dx} = \left\{ \frac{\partial \pi}{\partial x} + \frac{\partial \pi}{\partial q^*} \cdot \frac{\partial q^*}{\partial x} \right\} + \left\{ \frac{\partial \pi^*}{\partial x} + \frac{\partial \pi^*}{\partial q} \cdot \frac{\partial q}{\partial x} \right\} = 0 \quad (13)$$

so that the marginal benefit of an individual firm's R&D is now the *sum* of the reductions in marginal production costs of all RJV members.

Using (1), (2) and (5), we can re-write (13) as

$$\left[\frac{2(2\theta - \theta^*\beta^*)}{3} \right] q + \left[\frac{2(2\theta^*\beta^* - \theta)}{3} \right] q^* = \mu^c q + \mu^{*c} q^* = \gamma x^c \quad (14)$$

Non-strategic R&D investment now implies $\mu^c + \mu^{*c} = \theta + \theta^*\beta^*$ so the representative firm over (under) invests in R&D if $\mu^c + \mu^{*c} > (<) \theta + \theta^*\beta^*$.¹⁵ This reduces to the condition of over (under) investment in R&D if $\theta^*\beta^* < (>) -\theta < 0$, which given $\theta, \theta^* > 0$ and $\beta^* \geq 0$

¹⁴ Leahy & Neary (1996) define $\eta = \theta^2/b\gamma$ as the relative effectiveness of R&D, in that R&D is more effective in increasing profits the lower are unit R&D costs (γ) or the more efficient firms are in reducing marginal production costs through R&D (higher θ).

¹⁵ Non-strategic R&D investment now requires firms to invest in R&D to the point where the marginal social return to R&D per unit output (equal to the sum of marginal private returns) is equal to the marginal social cost (equal to marginal private cost).

implies that the firm will under-invest in R&D for any effective R&D spillover received by its rival. The fact that the firms remain rivals in the output market implies that each firm has an incentive to ‘free-ride’ on its RJV partner’s R&D in order to increase output market profits.

Given ex-post symmetry, $\theta = \theta^*$ and $\beta = \beta^*$ so that substituting (5) into (14) implies

$$x^C = x^{*C} = \frac{2\alpha\theta(1+\beta)}{9b\gamma - 2\theta^2(1+\beta)^2} \quad (15)$$

In contrast to the competitive R&D case, R&D levels are now *increasing* in the effective spillover as the firms are internalising the spillover.¹⁶ When $\beta < 1/2$, the own-profit effect of R&D dominates the cross-profit effect so that greater R&D increases joint profits. On the other hand, when $\beta > 1/2$, cross-profit effects are positive as R&D is a strategic complement at these spillover levels and, hence, the greater the incentive to undertake R&D.

Solving for profits, we can derive

$$\pi^C = \pi^{*C} = \frac{\gamma\alpha^2}{9b\gamma - 2\theta^2(1+\beta)^2} \quad (16)$$

Profits are increasing in the spillover for all R&D costs, as lower marginal production costs from own and RJV partner R&D offset higher direct R&D costs. Welfare is

$$W^C = \frac{2\gamma\alpha^2[18b\gamma - 2\theta^2(1+\beta)^2]}{[9b\gamma - 2\theta^2(1+\beta)^2]^2} \quad (17)$$

and is also increasing in spillovers for all R&D costs. As firms’ profits are rising, so is consumer surplus as higher R&D reduces marginal production costs and raises output, thereby reducing price.

3.4 - R&D competition v RJV formation

Comparing R&D levels in (10) and (15), it can be shown that

$$x^N \begin{cases} > \\ = \\ < \end{cases} x^C \text{ when } \beta \begin{cases} < \\ = \\ > \end{cases} \frac{1}{2} \quad (18)$$

For low spillovers ($\beta < 1/2$), over-investment in R&D due to profit-shifting when the firms compete in R&D dominates under-investment due to free-riding when the firms co-operate in R&D. For high spillovers ($\beta > 1/2$), however, R&D co-operation gives a greater incentive to undertake R&D due to the effects internalisation of spillovers on joint profits.

Comparing profit levels in (11) and (16), we find that

$$\pi^C \begin{cases} > \\ = \end{cases} \pi^N \text{ when } \beta \begin{cases} \neq \\ = \end{cases} \frac{1}{2} \quad (19)$$

¹⁶ Each firm’s second-order R&D condition requires $9b\gamma - 2\theta^2(1+\beta)^2 > 0$.

Firms will weakly prefer to form a RJV as it is at least as profitable as R&D competition for any spillover level, and will strictly prefer it when $\beta \neq \frac{1}{2}$.

Perhaps the most interesting question is how the formation of a RJV will affect welfare. Given stability conditions, comparing (12) and (17) implies

$$W^N \begin{cases} > \\ = \\ < \end{cases} W^C \text{ for } \beta \begin{cases} < \\ = \\ > \end{cases} \frac{1}{2} \quad (20)$$

At low spillovers ($\beta < \frac{1}{2}$), R&D competition implies over-investment in R&D and higher absolute R&D levels than in the co-operative case. This leads to lower marginal production costs and, consequently, higher output and lower prices that raise consumer surplus. This higher consumer surplus offsets the higher profits effect of R&D co-operation and so overall welfare is higher. The opposite holds for high spillovers ($\beta > \frac{1}{2}$) as the internalisation of spillovers effect dominates and R&D, profits and consumer surplus are higher when the firms co-operate in R&D. Hence, a RJV will only raise welfare for high spillovers ($\beta > \frac{1}{2}$).

4. R&D leadership (sequential R&D)

This section looks at the effect of one firm being a R&D leader. When accommodating the follower firm, the leader can either compete or co-operate in R&D with the follower. If, however, the leader seeks to prevent the follower from becoming active in the industry, it just competes in R&D with the follower and specifically chooses its R&D level to ensure that becoming active is unprofitable for the follower firm. In both cases, the leader takes the follower's R&D reaction function into account when choosing its own R&D level. In what follows, the leader and follower are denoted by L and F, respectively.

The interesting question is: will a leader's profit when competing in R&D exceed that of where the firms, in both the simultaneous and sequential R&D games, form a RJV. If so, a leader will not wish to form a RJV, in contrast to its incentives in a simultaneous R&D game.

The inverse demand curve and marginal production costs are similar to (1) and (2), respectively, but are now described by

$$p = a - b(q^L + q^F) \quad , \quad c^L = A - \theta^L(x^L + \beta^L x^F) \quad , \quad c^F = A - \theta^F(x^F + \beta^F x^L) \quad (21)$$

while R&D costs are $\frac{\gamma(x^L)^2}{2}$ and $\frac{\gamma(x^F)^2}{2}$ for the leader and follower, respectively.¹⁷

¹⁷ As (21) is identical to (2) if the representative firm is denoted as the leader and the other firm (*) as the follower, it can be argued that there is no need to introduce new notation. While this would be true if the simultaneous and sequential R&D cases are looked at in isolation, it will be easier to compare the two cases if the notation for each game is different. It may also be argued that unit R&D costs should be different for the two firms, as in Muniagurria and Singh (1997). In this chapter, however, it is assumed that there is no learning between R&D periods. As the benefits of R&D spillovers accrue

Given (21), profits can now be expressed as

$$\pi^i = [p(q^i, q^j) - c^i(x^i, x^j)]q^i - \frac{\gamma x^{i2}}{2}, (i, j=L, F, i \neq j) \quad (22)$$

while welfare is

$$W = \frac{b(q^L + q^F)^2}{2} + \pi^L + \pi^F \quad (23)$$

4.1 - Profitable activity: Accommodation & R&D competition ¹⁸

There are four stages to this game. Firstly, the firms decide whether or not to form a RJV. Secondly, the leader firm chooses its profit maximising R&D level. Thirdly, the follower firm, given the leader's R&D choice, chooses its profit maximising R&D level. Finally, both firms simultaneously choose their profit maximising output levels.

4.1.1 – Output

The output stage is as in the simultaneous R&D game but (5) is amended to

$$\begin{bmatrix} q^L \\ q^F \end{bmatrix} = \frac{1}{3b} \begin{bmatrix} \alpha + (2\theta^L - \theta^F \beta^F)x^L + (2\theta^L \beta^L - \theta^F)x^F \\ \alpha + (2\theta^F \beta^F - \theta^L)x^L + (2\theta^F - \theta^L \beta^L)x^F \end{bmatrix} \quad (24)$$

4.1.2 - Follower R&D

When the firms compete in R&D, the follower's first-order R&D condition is

$$\frac{d\pi^F}{dx^F} = \frac{\partial \pi^F}{\partial x^F} + \frac{\partial \pi^F}{\partial q^L} \cdot \frac{\partial q^L}{\partial x^F} = 0 \quad (25)$$

that, given (21), (22) and (24), can be expressed as

$$\left[\frac{2(2\theta^F - \theta^L \beta^L)}{3} \right] q^F - \gamma x^F = \mu^F q^F - \gamma x^F = 0 \quad (26)$$

where μ^F is the follower's marginal return to R&D per unit of output under R&D competition.

Non-strategic R&D investment requires $\mu^F = \theta^F$ so that the entrant over (under) invests in

R&D if $\theta^L \beta^L < (>) \frac{\theta^F}{2}$.¹⁹ Using (24) in (26), the follower's R&D reaction function is

through lower marginal production costs, each firm benefits from its rival's R&D to an equal extent given that outputs are chosen after both firms have undertaken their R&D investment.

¹⁸ This case is identical to that of Rossell and Walker (1996), except that entry is costless.

¹⁹ This is similar to simultaneous R&D game condition in Section 3 where the intuition for this result is given.

$$x^{FN}(x^{LN}) = \frac{2(2\theta^F - \theta^L \beta^L) \{ \alpha + (2\theta^F \beta^F - \theta^L) x^{LN} \}}{9b\gamma - 2(2\theta^F - \theta^L \beta^L)^2} \quad (27)$$

so that the leader's R&D is a strategic substitute (complement) for the follower's R&D when $(2\theta^F - \theta^L \beta^L)(2\theta^F \beta^F - \theta^L) < (>) 0$ as the firms' R&D reaction functions are downward (upward) sloping in R&D space.²⁰

4.1.3 - Leader R&D

The leader firm chooses its R&D to maximise its own profits, but as it is now a Stackelberg leader in R&D, its R&D investment is undertaken subject to the follower's R&D reaction function. Consequently, its first-order R&D condition is

$$\frac{d\pi^L}{dx^L} = \frac{\partial \pi^L}{\partial x^L} + \frac{\partial \pi^L}{\partial q^F} \cdot \frac{\partial q^F}{\partial x^L} + \frac{\partial \pi^L}{\partial x^F} \cdot \frac{\partial x^F}{\partial x^L} + \frac{\partial \pi^L}{\partial q^F} \cdot \frac{\partial q^F}{\partial x^F} \cdot \frac{\partial x^F}{\partial x^L} = 0 \quad (28)$$

The leader's R&D directly affects the follower's R&D choice and, indirectly, its output level, and both then affect the leader's profits. Given (21), (24) and (27), (28) can be expressed as

$$\mu^{LN} q^{LN} = \left\{ \frac{2(2\theta^L - \theta^F \beta^F) [9b\gamma - 2(2\theta^F - \theta^L \beta^L)^2] + 4(2\theta^L \beta^L - \theta^F)(2\theta^F - \theta^L \beta^L)(2\theta^F \beta^F - \theta^L)}{3[9b\gamma - 2(2\theta^F - \theta^L \beta^L)^2]} \right\} q^{LN} = \gamma x^{LN} \quad (29)$$

where μ^{LN} is the leader's marginal return to R&D per unit of output when the firms compete in R&D. Non-strategic R&D investment implies $\mu^{LN} = \theta^L$. From (29), it can be shown that if

$\theta^F < \frac{\theta^L}{2\beta^F}$, the leader will over (under) invest in R&D if $b\gamma > (<) \frac{2\theta^L \beta^L (2\theta^F - \theta^L \beta^L)}{3}$.²¹ If,

simultaneously, $\theta^F < \frac{\theta^L \beta^L}{2}$, the leader always over-invests in R&D. On the other hand, if

$\frac{\theta^L \beta^L}{2} < \theta^F < \frac{\theta^L}{2\beta^F}$, the leader over (under) invests in R&D if unit R&D costs are sufficiently

high (low).

Conversely, when $\theta^F > \frac{\theta^L}{2\beta^F}$, the leader will over (under) invest in R&D if

$b\gamma < (>) \frac{2\theta^L \beta^L (2\theta^F - \theta^L \beta^L)}{3}$. If, simultaneously, $\theta^F > \frac{\theta^L \beta^L}{2}$, the leader over (under) invests

in R&D if unit R&D costs are sufficiently low (high). On the other hand, when

$\frac{\theta^L}{2\beta^F} < \theta^F < \frac{\theta^L \beta^L}{2}$, the leader under-invests in R&D for all unit R&D costs.

²⁰ The follower's second-order R&D condition requires $9b\gamma - 2(2\theta^F - \theta^L \beta^L)^2 > 0$.

²¹ The leader's second-order R&D condition requires

$9b\gamma [9b\gamma - 2(2\theta^F - \theta^L \beta^L)^2] - 2(2\theta^L - \theta^F \beta^F) [9b\gamma - 2(2\theta^F - \theta^L \beta^L)^2] + 2(2\theta^L \beta^L - \theta^F)(2\theta^F - \theta^L \beta^L)(2\theta^F \beta^F - \theta^L)^2 > 0$.

Ex-post symmetry implies that $\theta^L = \theta^F \equiv \theta \geq 0$ and $0 \leq \beta^L = \beta^F \equiv \beta \leq 1$. Applying these conditions to the investment incentives that follow from (27), the leader's R&D is a strategic substitute (complement) for follower R&D when $\beta < (>) \frac{1}{2}$. When $\beta < \frac{1}{2}$, then from (29), the leader will over (under) invest in R&D if $b\gamma > (<) \frac{2\theta^2 \beta(2-\beta)}{3}$. Given the stability conditions, however, this can be reduced to the condition that the leader will always over-invest in R&D when $\beta < \frac{1}{2}$. Similarly, if $\beta > \frac{1}{2}$, the leader will over (under) invest in R&D if $b\gamma < (>) \frac{2\theta^2 \beta(2-\beta)}{3}$. Except for a range of unit R&D costs where the leader's second order condition is satisfied and $b\gamma < \frac{2\theta^2 \beta(2-\beta)}{3}$, the leader will under-invest in R&D.²²

Solving for the leader's R&D level gives

$$x^{LN} = \frac{2\alpha\theta(2-\beta)[9b\gamma - 6\theta^2(1-\beta^2)][9b\gamma - 6\theta^2(2-\beta)(1-\beta)]}{9b\gamma[9b\gamma - 2\theta^2(2-\beta)^2] - 2\theta^2(2-\beta)^2[9b\gamma - 6\theta^2(1-\beta^2)]^2} \quad (30)$$

To derive the follower's R&D level, substituting (30) into (27) implies

$$x^{FN} = \frac{2\alpha\theta(2-\beta)\{9b\gamma[9b\gamma - 2\theta^2(2-\beta)^2] - 6\theta^2(2-\beta)(1-\beta)[9b\gamma - 6\theta^2(1-\beta^2)]\}}{9b\gamma[9b\gamma - 2\theta^2(2-\beta)^2] - 2\theta^2(2-\beta)^2[9b\gamma - 6\theta^2(1-\beta^2)]^2} \quad (31)$$

From (30) and (31),

$$x^{LN} \begin{pmatrix} > \\ = \\ < \end{pmatrix} x^{FN} \text{ when } \beta \begin{pmatrix} \neq \\ = \\ < \end{pmatrix} \frac{1}{2} \quad (32)$$

The leader uses its position to ensure that its R&D is at least as great as the follower's. Given this, the leader's marginal production costs will never be greater, and its direct R&D costs never lower, than those of the follower. It may seem surprising that the leader's R&D will not strictly exceed that of the follower for all spillovers. This is because the firms' R&D are neither strategic substitutes nor complements when $\beta = \frac{1}{2}$, so that in R&D space, the Cournot-Nash and Stackelberg points coincide.

The firms' profit levels are

$$\pi^{LN} = \frac{\gamma\alpha^2[9b\gamma - 6\theta^2(2-\beta)(1-\beta)]^2}{9b\gamma[9b\gamma - 2\theta^2(2-\beta)^2] - 2\theta^2(2-\beta)^2[9b\gamma - 6\theta^2(1-\beta^2)]^2} \quad (33)$$

$$\pi^{FN} = \frac{\gamma\alpha^2[9b\gamma - 2\theta^2(2-\beta)^2]\{9b\gamma[9b\gamma - 2\theta^2(2-\beta)^2] - 6\theta^2(2-\beta)(1-\beta)[9b\gamma - 6\theta^2(1-\beta^2)]\}^2}{[9b\gamma[9b\gamma - 2\theta^2(2-\beta)^2] - 2\theta^2(2-\beta)^2[9b\gamma - 6\theta^2(1-\beta^2)]^2]^2} \quad (34)$$

for the leader and follower, respectively, which implies that

²² Even though the leader's R&D is a strategic complement for that of the follower when $\beta > \frac{1}{2}$, it is in the leader's interests, if unit R&D costs are sufficiently low, to over-invest in R&D in order to profit-shift from the follower, despite the relatively large spillover to the follower. As unit R&D costs increase, this incentive to over-invest is eliminated as profit-shifting becomes prohibitively expensive.

$$\pi^{\text{LN}} \begin{cases} > \\ = \\ < \end{cases} \pi^{\text{FN}} \text{ when } \eta \equiv (2\beta - 1)^3 \left[9b^2\gamma^2 - b\gamma\theta^2(2 - \beta)(11 - 10\beta) + 6\theta^4(2 - \beta)(1 - \beta)^2 \right] \begin{cases} < \\ = \\ > \end{cases} 0 \quad (35)$$

Given the second-order conditions, the [.] term in η in (35) is positive when $\beta = 0$ and increasing over all spillovers. Given this, we can conclude that profits are identical when $\beta = \frac{1}{2}$ and that the leader makes greater profits than the follower when $\beta < \frac{1}{2}$. When $\beta > \frac{1}{2}$, however, the follower's profits exceed those of the leader and there is a *second-mover advantage*. At these spillovers, the follower benefits from the leader's relatively high R&D without having to incur the expense of such R&D. By using (30) and (31) to solve for output levels in (24), and by substituting these output levels, (33) and (34) into (21), we can derive the welfare level. Unfortunately, this leads to an extremely complicated equation from which no definitive conclusions can be drawn and so it is omitted from the analysis.²³

4.2 – Profitable activity: Accommodation & RJV formation²⁴

Stage four is as in the competitive R&D case as the firms remain rivals in the output market. Given this, the expressions in (26) remain valid. As there is no threat of further market entry, it is assumed that there is no endogenous information sharing within the RJV so that the effect of joint profit maximisation can be looked at in isolation.²⁵

4.2.1 - Follower R&D

When the firms co-operate in R&D, the follower's first-order R&D condition is now

$$\frac{d(\pi^L + \pi^F)}{dx^F} = \left\{ \frac{\partial \pi^L}{\partial x^F} + \frac{\partial \pi^L}{\partial q^F} \cdot \frac{\partial q^F}{\partial x^F} \right\} + \left\{ \frac{\partial \pi^F}{\partial x^F} + \frac{\partial \pi^F}{\partial q^L} \cdot \frac{\partial q^L}{\partial x^F} \right\} = 0 \quad (36)$$

As the follower's strategic incentives vis-à-vis the leader are identical to those it faces in the simultaneous R&D case, the follower will under-invest in R&D for all spillovers. Given (21), (22) and (24), the follower's co-operative R&D reaction function is

$$x^{FC}(x^{LC}) = \frac{2\alpha(\theta^L\beta^L + \theta^F) + 2[(2\theta^L\beta^L - \theta^F)(2\theta^L - \theta^F\beta^F) + (2\theta^F - \theta^L\beta^L)(2\theta^F\beta^F - \theta^L)]x^{LC}}{9b\gamma - 2(2\theta^L\beta^L - \theta^F)^2 - 2(2\theta^F - \theta^L\beta^L)^2} \quad (37)$$

²³ To overcome this, certain values will be imposed on the parameters of the model in order to facilitate comparison of the welfare levels of the various games. This will be done in Section 8.

²⁴ This game may be more difficult to sustain given the sequential nature of the game. Given complete and perfect information, however, it is assumed that a legal agreement binds both parties to acting in a manner that maximises joint profits once they agree to form a RJV.

²⁵ This will also facilitate a direct comparison with the D'Aspremont & Jacquemin model.

where firms' R&D are strategic substitutes (complements) if $\beta^L < (>) \frac{\theta^F (4\theta^L - 5\theta^F \beta^F)}{\theta^L (5\theta^L - 4\theta^F \beta^F)}$.²⁶

4.2.2 - Leader R&D

The leader firm's first-order condition is now given by

$$\frac{d(\pi^L + \pi^F)}{dx^L} = \frac{d\pi^L}{dx^L} + \left\{ \frac{\partial \pi^F}{\partial x^L} + \frac{\partial \pi^F}{\partial q^L} \cdot \frac{\partial q^L}{\partial x^L} + \frac{\partial \pi^F}{\partial x^F} \cdot \frac{\partial q^L}{\partial x^F} \cdot \frac{\partial x^F}{\partial x^L} + \frac{\partial \pi^F}{\partial x^F} \cdot \frac{\partial x^F}{\partial x^L} \right\} = 0 \quad (38)$$

where the effect of leader R&D on own profit is given by (28). Using this, we can re-write (38) as

$$\frac{d(\pi^L + \pi^F)}{dx^L} = \left\{ \frac{\partial \pi^L}{\partial x^L} + \frac{\partial \pi^L}{\partial q^F} \cdot \frac{\partial q^F}{\partial x^L} + \frac{\partial \pi^F}{\partial x^L} + \frac{\partial \pi^F}{\partial q^L} \cdot \frac{\partial q^L}{\partial x^L} \right\} + \underbrace{\left\{ \frac{\partial \pi^L}{\partial x^F} + \frac{\partial \pi^L}{\partial q^F} \cdot \frac{\partial q^F}{\partial x^F} + \frac{\partial \pi^F}{\partial x^F} + \frac{\partial \pi^F}{\partial q^L} \cdot \frac{\partial q^L}{\partial x^F} \right\}}_{(=0)} \frac{\partial x^F}{\partial x^L} = 0 \quad (39)$$

where the first part of the R&D reaction function term in (39) is identical to the follower's first-order R&D condition in (36). Given this, the expression in (39) is identical to the representative firm's first-order condition in the simultaneous R&D game so that when the firms form a RJV (co-operate in R&D), there is *no first-mover R&D advantage* and the game is *identical* to that where the firms simultaneously choose their R&D levels given no explicit information sharing within the RJV. This is due to the fact that when the firms form a RJV, the shape of firms' iso-profit curves ensures that the highest profit that the leader can attain, subject to the follower's R&D reaction function, is at the Cournot-Nash equilibrium (see Figure 1). As there is no first-mover advantage, R&D, profit and welfare levels are given by (15), (16) and (17), respectively, and the firms under-invest in R&D for all spillover levels.

5. Profitable activity & Accommodation: Simultaneous v sequential R&D

5.1 – R&D competition

Looking firstly at R&D levels, it can be shown from (10), (30) and (31) that

$$\beta \begin{cases} < \\ = \\ > \end{cases} \frac{1}{2} \Rightarrow \begin{cases} x^{LN} > x^N > x^{FN} \\ x^{LN} = x^N = x^{FN} \\ x^{LN} > x^{FN} > x^N \end{cases} \quad (40)$$

Being a R&D leader ensures at least as high a R&D level as simultaneously choosing R&D while being a follower leads to lower (higher) R&D than the simultaneous game when $\beta < (>) \frac{1}{2}$. Comparing profit levels in (11), (33) and (34), and using (35), it is found that

²⁶ The follower's second-order R&D condition requires $9b\gamma - 2(2\theta^L\beta^L - \theta^F)^2 - 2(2\theta^F - \theta^L\beta^L)^2 > 0$.

$$\beta \begin{cases} < \\ = \\ > \end{cases} \frac{1}{2} \Rightarrow \begin{cases} \pi^{LN} > \pi^N > \pi^{FN} \\ \pi^{LN} = \pi^N = \pi^{FN} \\ \pi^{FN} > \pi^{LN} > \pi^N \end{cases} \quad (41)$$

When $\beta < 1/2$, a follower is worse off relative to the simultaneous R&D game due to over-investment in R&D by the leader. When $\beta = 1/2$, R&D is neither a strategic substitute nor strategic complement and the simultaneous and sequential cases are identical and all firms make identical profits. If $\beta > 1/2$, however, being a R&D leader is always better than simultaneously choosing R&D levels, but being a follower is even better.

It can be shown that $q^L + q^F \begin{cases} > \\ = \\ < \end{cases} 2q^N$ when $b\gamma \begin{cases} > \\ = \\ < \end{cases} \frac{2\theta^2(2-\beta)(1-\beta)}{3}$. Given the second-

order R&D conditions, total output in the sequential R&D game exceeds that of the simultaneous game when $\beta > 1/2$. As total industry profits are also higher in the sequential R&D game when $\beta > 1/2$ (see (41)), consumers gain from lower prices so that total welfare is higher when the firms sequentially choose their R&D levels.²⁷

For $\beta < 1/2$, a comparison between total industry profit levels leads to a complicated result from which no simple conclusion can be drawn and, hence, it is omitted from the analysis, as is a welfare comparison between the two cases.²⁸

5.2 - Compete in R&D or form RJV?

As the simultaneous and sequential R&D games are identical under RJV formation, and RJV formation is at least as profitable as R&D competition when the firms simultaneously choose their R&D, the only comparison to make here is that between where the firms form a RJV and when they compete in R&D and *sequentially* choose their R&D.

From (30) and (15),

$$x^{LN} \begin{cases} > \\ = \\ < \end{cases} x^{LC} = x^C \text{ when } \phi \equiv (2\beta - 1) \left\{ 81b^2\gamma^2 - 36b\gamma\theta^2(2-\beta)^2 + 4\theta^4(2-\beta)(1+\beta)[7\beta^2 - 13\beta + 7] \right\} \begin{cases} < \\ = \\ > \end{cases} 0 \quad (42)$$

²⁷ An interesting implication of (41) is that if *both* firms could choose the timing of their R&D investment, then the firms would face a ‘Prisoner’s Dilemma’ situation when $\beta > 1/2$. As both firms would prefer to be a follower at these spillover levels, they will ‘wait’ and simultaneously invest in R&D. By doing so, both be worse off than when the firms sequentially undertake their R&D investment. Given this, it would be in the firms’, and society’s, interests to sequentially choose their R&D levels and for a leader to compensate a follower with a ‘side-payment’ equal to half the difference between the leader and follower’s profits. Of course, such an explicit profit-sharing agreement could be in breach of antitrust legislation.

²⁸ Welfare levels will be simulated in Section 8 when restrictions are imposed on the model parameters.

From (18) and (40), $x^{LN} > x^{LC}$ when $\beta < 1/2$. Given the second-order conditions, the $\{.\}$ term in (42) is positive for all $\beta \geq 1/2$ so that $x^{LN} < x^C$ when $\beta > 1/2$. Given this, we can state that

$$x^{LN} \begin{cases} > \\ = \\ < \end{cases} x^{LC} \text{ when } \beta \begin{cases} < \\ = \\ > \end{cases} 1/2 \quad (43)$$

Similarly, we can compare the follower's R&D to that of the RJV game. From (18) and (40), it can be shown that

$$x^{FN} \begin{cases} > \\ = \\ < \end{cases} x^{FC} = x^C \text{ when } \psi \equiv (2\beta - 1) \left[9b\gamma - 2\theta^2(2 - \beta)(1 + \beta) \right] \left[9b\gamma - 2\theta^2(2 - \beta)(4 - 5\beta) \right] \begin{cases} < \\ = \\ > \end{cases} 0 \quad (44)$$

Given the second-order conditions, $[9b\gamma - 2\theta^2(2 - \beta)(1 + \beta)] > 0$ when $\beta < 1/2$ so that $x^{FN} > x^{FC}$ at these spillovers, except for a narrow range of relative R&D effectiveness where $\frac{\theta^2}{b\gamma} > \frac{9}{2(2 - \beta)(4 - 5\beta)}$. The lower are unit R&D costs and the spillover parameter, the greater

the leader's R&D level and the lower is the follower's when the firms compete in R&D. If β and γ are low enough, the leader's R&D choice pushes the follower's R&D level below that of what will be chosen in a RJV. Conversely, from (40) and (43), $x^{FC} > x^{FN}$ when $\beta > 1/2$.

The most interesting aspect of this comparison is how profit levels compare as this determines the firms' incentives to form a RJV. From (18) and (34),

$$\pi^{LN} \begin{cases} > \\ = \\ < \end{cases} \pi^{LC} \text{ when } \rho \equiv (2\beta - 1)^2 \left[9b\gamma - 2\theta^2(2 - \beta)(4 - 5\beta) \right] \begin{cases} < \\ = \\ > \end{cases} 0 \quad (45)$$

so that profits are equalised at $\beta = 1/2$ when R&D is neither a strategic substitute nor strategic complement. From (45) and the stability conditions, it can be shown that when $\beta < 1/2$, $\pi^{LC} > \pi^{LN}$, *except for a narrow range of relative R&D effectiveness where $b\gamma < \frac{2\theta^2(2 - \beta)(4 - 5\beta)}{9}$*

(see Figure 2, where $\theta = 1$). Over this range, the leader's greater R&D in the competitive R&D case reduces its marginal production costs below the level that occurs when the firms form a RJV. This offsets the higher direct R&D costs so that profits are higher for the leader. Hence, if β and γ are low enough, a leader will not form a RJV as doing so leads to a lower level of profits than competing in R&D. This result contrasts with the D'Aspremont and Jacquemin result that firms will always prefer to form a RJV than compete in R&D.

When $\beta > 1/2$, $\pi^{LC} > \pi^{LN}$ for all spillovers and relative R&D effectiveness and the leader will always prefer to form a RJV as the gain to the follower implies that R&D competition is not as profitable as RJV formation. As unit R&D costs increase, forming a RJV becomes more profitable for all spillovers as a leader's R&D expenditure when

competing in R&D is too large relative to any benefit that accrues from having lower marginal production costs.²⁹

Comparing the profits of the follower in the competitive and co-operative R&D cases, we can deduce from (19) and (41) that $\pi^{FC} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \pi^{FN}$ when $\beta \begin{pmatrix} < \\ = \\ > \end{pmatrix} 1/2$. For $\beta > 1/2$, comparison of (16) and (34) shows that

$$\pi^{FN} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \pi^{FC} \text{ if } \begin{cases} 9b^2\gamma^2[81b^2\gamma^2 - 72b\gamma\theta^2(2-\beta)^2 + 4\theta^4(2-\beta)(14\beta^3 - 51\beta + 44)] \\ -8\theta^6(2-\beta)^2 \begin{bmatrix} b\gamma(-36\beta^4 + 96\beta^3 - 54\beta^2 - 54\beta + 51) \\ -2\theta^2(1-\beta^2)^2(5\beta^2 - 8\beta + 5) \end{bmatrix} \end{cases} \begin{pmatrix} < \\ = \\ > \end{pmatrix} 0 \quad (46)$$

Given the second-order conditions, it can be shown that the expression in (46) is positive so that $\pi^{FC} > \pi^{FN}$ at these spillovers. At these spillovers, therefore, a follower will weakly prefer to form RJV when R&D levels are chosen sequentially as it benefits from the fact that, relative to the competitive R&D case, the leader's R&D is lower when $\beta < 1/2$ and the follower gains to a large degree from the leader when $\beta > 1/2$.

If it is the case that $\pi^{LN} + \pi^{FN} > 2\pi^C$, total industry profits when the firms sequentially choose competitive R&D levels will exceed those of co-operative R&D. In such a scenario, it is again in the firms' interests not to form a RJV but to agree to sequentially choose R&D and equally share total industry profits. Given our expressions in (45) and (46), this outcome may only be possible at very low values of $b\gamma$ and β .

An equally important question is how do welfare levels compare? Given the complexity of the individual welfare expressions, however, no firm conclusions can be drawn from a comparison and, hence, it is also omitted from the analysis.³⁰

6. Activity prevention

While the main emphasis of this paper is on RJV formation under R&D leadership and accommodating the follower, another possibility is that the leader will attempt to prevent the follower from becoming active in the industry. In this case, the firms are assumed to just compete in R&D as RJV formation is irrational. The output and follower R&D stages are as in the entry accommodation case, given that the follower's strategic incentive vis-à-vis the leader is unchanged and the firms remain rivals in the output market.

6.1 - Leader R&D

²⁹ In Figure 3.2, when $\beta = 1/2$, profits are identical in the two cases, as noted previously.

³⁰ Such a comparison will be possible in Section 8 when certain restrictions are imposed on the parameters of the model.

To ensure that it is unprofitable for the follower to become active in the industry, the leader chooses its R&D level so that the follower optimally chooses not to produce any output. The leader is able to determine this R&D level from (24) and (27). There is no first-order condition for the leader as its R&D choice may not be ex-post profit maximising but it does ensure that becoming active in the market is unprofitable for the follower. The leader does not choose its R&D to ensure that the follower chooses not to undertake R&D, as it may then still be possible for the follower to become active in the industry if autonomous marginal production costs (A) are low, or if the follower's effective spillover ($\theta^F\beta^F$) is relatively high.

In choosing its R&D level, the leader substitutes the follower's R&D reaction function in (27) into (24) so that output levels are now solely a function of the leader's R&D choice. Ex-post symmetry implies that $\theta^L = \theta^F \equiv \theta$ and $\beta^L = \beta^F \equiv \beta$, so that to ensure that the follower chooses not to produce any output ($q^{FD} = 0$), the leader chooses

$$x^{LD} = \frac{\alpha}{\theta(1-2\beta)} \quad (47)$$

which is undefined for $\beta > 1/2$. Intuitively, for relatively high spillovers ($\beta > 1/2$), the firms' R&D are strategic complements and the leader is unable to prevent follower activity. To derive the follower's optimal R&D choice, substituting (47) into (27) gives $x^{FD} = 0$. Interestingly, the leader's R&D choice is not a function of relative R&D ineffectiveness ($b\gamma$). As a certain, relatively large, level of R&D must be undertaken to ensure that the follower never becomes active in the industry. Also, output levels in (24) are not directly affected by unit R&D costs so that if the follower's R&D is zero, the leader's R&D will also not be a function of unit R&D costs. From (47), the leader's R&D level is increasing in the spillover. As the spillover increases, the follower's benefit from the leader is increasing and the leader must undertake greater R&D investment to ensure that the absolute cost difference between the firms is maintained and becoming active is unprofitable for the follower.

Substituting (47) into (24) implies that the leader's output level³¹ is

$$q^{LD} = \frac{\alpha(1-\beta)}{b(1-2\beta)} \quad (48)$$

From (22), (47) and (48), the leader's profit is

$$\pi^{LD} = \frac{\alpha^2 [2\theta^2(1-\beta)^2 - b\gamma]}{2b\theta^2(1-2\beta)^2} \quad (49)$$

which is increasing (decreasing) in the spillover when $b\gamma < (>) \theta^2(1-\beta)$. The more effective is R&D (i.e. lower is $b\gamma$), then as spillovers increase, the increased R&D expenditure required to

³¹ This can also be derived by substituting (47) into monopoly output level $q^{LD} = \frac{a-c^L}{2b} = \frac{\alpha + \theta x^{LD}}{2}$.

prevent activity will be more than offset by the benefit of lower marginal production costs so that the leader's profits increase.

From (49), it is the case that

$$\pi^{LD} \begin{cases} > \\ = \\ < \end{cases} 0 \text{ when } b\gamma \begin{cases} < \\ = \\ > \end{cases} 2\theta^2(1-\beta)^2 \quad (50)$$

Given this, and the fact that the leader's R&D choice is undefined for $\beta \geq \frac{1}{2}$, inducing the follower not to become active is a profitable strategy only if R&D is highly effective, i.e. $b\gamma$ is low (see Figure 3 where $\theta = 1$). At these levels of $b\gamma$, the leader's relatively high, but relatively inexpensive, R&D level will reduce marginal production costs to such an extent that offsets higher R&D costs and leads to positive profits. From (50), preventing the follower from becoming active will never be profitable when $b\gamma \geq 2\theta^2(1-\beta)^2$, as the relatively large R&D costs required to prevent activity by the follower will offset any higher operating profit from having sole control of the market. The threshold level of relative R&D ineffectiveness is decreasing in the spillover as the required R&D expenditure of the leader must increase which makes such a strategy less profitable. Even if preventing activity is profitable, whether the leader undertakes this action will depend on how profits from this strategy compare to those when accommodating the follower.

From a welfare point of view, we can derive the condition that

$$W^D \begin{cases} > \\ = \\ < \end{cases} 0 \text{ when } b\gamma \begin{cases} < \\ = \\ > \end{cases} 3\theta^2(1-\beta)^2 \quad (51)$$

As with profits, welfare will tend to be non-positive, except when spillovers are relatively low and R&D is highly effective. From (50) and (51), there will, for some levels of R&D effectiveness, be a positive welfare level even when preventing the follower from becoming active is not profitable as a positive output level will ensure some degree of consumer surplus.

7. Accommodate or prevent follower activity?

Even though preventing the follower from becoming active is profitable at certain combinations of spillover and R&D effectiveness, the benefits to becoming a monopolist in the output market may be offset by the higher R&D expenditure required to prevent follower activity so that the leader will prefer to accommodate the follower. We know from (45) that a

leader will form a RJV if accommodating entry when $b\gamma > \frac{2\theta^2(2-\beta)(4-5\beta)}{9}$. Comparing

(16) and (51), and given the second-order conditions, it can be shown that

$$\pi^{LC} \begin{cases} > \\ = \\ < \end{cases} \pi^{LD} \text{ when } \lambda \equiv 9b^2\gamma^2 - 6b\gamma\theta^2(2\beta^2 - 4\beta + 3) + 4\theta^4(1 - \beta^2)^2 \begin{cases} > \\ = \\ < \end{cases} 0 \quad (52)$$

Conversely, when $b\gamma < \frac{2\theta^2(2-\beta)(4-5\beta)}{9}$, a leader prefers to compete in R&D rather than form a RJV. Comparing (11) and (49), and again given the second-order conditions, then

$$\pi^{LN} \begin{cases} > \\ = \\ < \end{cases} \pi^{LD} \text{ when } \tau \equiv 2b\gamma\theta^2(1-2\beta)^2 [9b\gamma - 6\theta^2(2-\beta)(1-\beta)]^2 - [2\theta^2(1-\beta)^2 - b\gamma] \left\{ 9b\gamma [9b\gamma - 2\theta^2(2-\beta)^2]^2 - 2\theta^2(2-\beta)^2 [9b\gamma - 6\theta^2(1-\beta^2)]^2 \right\} \begin{cases} > \\ = \\ < \end{cases} 0 \quad (53)$$

Given the complexity of the expressions in (52) and (53), no simple conclusion can be drawn and an analysis of this comparison between profit levels is left to the next section where restrictions are imposed on the model parameters of the model in order to facilitate simulation of the models.

8. Results

This section compares the various cases and attempts to draw conclusions about the effects of R&D leadership on Research Joint Venture formation. To facilitate this, it is necessary to simulate the models by imposing restrictions on the parameters of the model. In particular, α , b and θ are normalised to unity, while β and γ are taken as exogenous parameters.³² For given levels of β and γ , we can analyse profit and welfare levels.

8.1 Profits

Given the parameter restrictions above, we can simulate the expressions in (52) and (53) and compare leader profits when preventing follower activity to those of accommodation. When $\gamma > \frac{2(2-\beta)(4-5\beta)}{9}$, RJV formation is more profitable than R&D competition when there is accommodation (see Figure 2). Given this, comparing RJV formation under accommodation to activity prevention, it can be seen from Figure 4, where $\gamma = 2$, that because λ is positive, profits will be greater when the leader accommodates the follower and the firms form a RJV (see (52)).³³ Even though the leader is a monopolist when preventing follower activity, the greater R&D expenditure required to ensure this outcome is

³² As $b = 1$, the relative level of R&D effectiveness is equivalent to the inverse of unit R&D costs.

³³ A similar result is satisfied for other admissible values of γ . Also, note that the comparison is only valid when $\beta < \frac{1}{2}$.

attained is not offset by the increased output market profits that accrue to a monopolist and, hence, accommodation is more profitable.

When $\gamma < \frac{2(2-\beta)(4-5\beta)}{9}$, a comparison between preventing follower activity and

sequential R&D competition is often not possible as the second-order conditions are not satisfied at these levels of unit R&D cost. For given spillover levels, however, it can be shown that there is a very narrow range of unit R&D costs at which profits are greater when the leader accommodates the follower.³⁴ Again, the benefit of being a monopolist is more than offset by the increased R&D expenditure required to ensure this.

We can conclude, therefore, that if a firm can undertake its R&D before a rival that has costlessly entered the industry, it will forego the opportunity to prevent the follower from becoming active in the industry and will instead either form a RJV or compete in R&D with its rival depending on unit R&D costs and spillovers. Given this result, however, the combination of spillovers and unit R&D cost at which R&D competition is more profitable than RJV formation only satisfy the second-order R&D conditions for very narrow combinations of spillover and unit R&D cost so that accommodation and RJV formation is usually the most profitable outcome for a R&D leader.

8.2 Welfare: output exported

If all output is exported, there are no consumer welfare considerations and welfare is given by total industry profits. From the previous section, we know that a leader will always accommodate a follower as it is more profitable to do so, and will usually form a RJV, except for a relatively narrow range of spillovers and unit R&D costs at which it will compete in R&D. In such a case, a follower will make at least zero profits so that total industry profits and, consequently, welfare are higher when the leader accommodates the follower.

8.3 Welfare: domestic consumption

While a R&D leader will usually prefer to accommodate the follower and form a RJV, the interesting question is whether this action will lead to the highest level of welfare when all output is consumed domestically. Looking firstly at Figure 5 where $\gamma = 2$, when $\beta < \frac{1}{2}$, welfare is highest when the firms sequentially choose their R&D and compete in R&D.³⁵

³⁴ A diagram to show this result would require an exceptionally fine grid over very narrow ranges of spillovers and unit R&D costs.

³⁵ In Figures 3.6 and 3.7, ‘sim comp’ refers to the case where the firms simultaneously choose R&D levels and compete in R&D. Similarly, ‘seq RJV’ refers to when R&D levels are chosen sequentially and the firms form a RJV.

The higher total R&D compared to the simultaneous R&D game reduces marginal production costs to an extent that total output is higher and, hence, prices are lower so that consumer welfare also increases. On the other hand, when $\beta > \frac{1}{2}$, welfare is highest when the firms form a RJV, irrespective of whether they simultaneously or sequentially undertake their R&D investment. At these spillovers, the benefit to internalising the R&D spillover dominates R&D leadership advantage given the relatively large spillover gains to each firm.

On the other hand, when $\gamma = 1$, it can be seen from Figure 6 that when $\beta < 0.4$ (approx), welfare is highest when a leader prevents follower activity. At these spillovers, low unit R&D costs reduce the expenditure required to achieve this and this relatively lower expenditure is more than offset by the profits derived from being a monopolist so that leader profits are relatively high. As well as this, the high level of R&D will reduce marginal production costs, leading to lower prices and increase consumer welfare. The combination of these two effects will imply that welfare is highest when the leader undertakes an anti-competitive R&D investment strategy. For policymakers, however, the problem is that what is welfare-dominant is not the most profitable action for the leader. From Figure 2 and Section 8.1, we know that accommodation, either by means of R&D competition when $\beta \leq 0.25$ (approx) or RJV formation when $0.25 < \beta < 0.4$, is what is most profitable for the leader. In such a situation, there may be a role for government to subsidise R&D investment in order to make activity prevention more profitable, given the relatively high R&D investment that is undertaken in this case.

On the other hand, when $0.4 < \beta < 0.5$ (approx), welfare is highest when R&D is undertaken sequentially and the firms compete in R&D, though RJV formation is most profitable.³⁶ In this case, government policy may seek to prevent RJV formation. When $\beta > 0.5$, welfare is again highest when the firms form a RJV, and this is also the most profitable strategy for the leader.

9. Summary and conclusions

This chapter examines the effects of R&D leadership on Research Joint Venture formation in an industry where two, symmetric, output-setting firms that can produce a homogenous good may either compete or co-operate in R&D. It is assumed that both firms have entered the industry, but have yet to become active in the market. One of the firms is assumed to have an exogenously determined first-mover advantage in R&D investment.

³⁶ The intuition for the welfare result is given in the previous paragraph.

If R&D levels are chosen simultaneously, the firms will weakly prefer to form a RJV. On the other hand, for relatively low spillovers, welfare is highest when the firms compete in R&D, while RJV formation leads to higher welfare when spillovers are relatively high.

The main question of this chapter is how does the exogenously given ability of one firm to undertake its R&D investment before its rival affect the incentive to form a RJV? Certain other questions arise. Will the leader accommodate the follower or try to prevent it from becoming active in the industry? Will the leader's profit always exceed that of the follower?

Regarding the incentive to form a RJV when sequentially choosing R&D levels, RJV profits exceed those of leadership, except for a very narrow range of low unit R&D costs and spillovers. At these R&D cost and spillover levels, a leader will prefer to compete in R&D, thereby contradicting the D'Aspremont and Jacquemin result that co-operation is always at least as profitable as R&D competition. Conversely, a follower always prefers RJV formation.

Looking at the entry accommodation case, there is no first-mover advantage if the firms form a RJV. If the firms compete in R&D, then there is a first-mover advantage, both in relation to the follower and the simultaneous R&D case. For relatively high spillovers, however, there is a second-mover advantage as the follower's profits exceed those of the leader, though the leader increases its own profit relative to the simultaneous R&D game.

For the leader, preventing follower activity is only profitable if unit R&D costs and spillovers are relatively low, with the threshold value of unit R&D costs at which it remains profitable decreasing in the spillover. As the leader must undertake a large level of R&D to ensure that becoming active is unprofitable for the follower, this strategy is only profitable for the leader if R&D is relatively inexpensive and spillovers are relatively low. Even when preventing the follower from becoming active is profitable, however, it will never be as profitable as accommodating entry, despite it ensuring that the leader is a monopolist in the product market.

When the good is consumed domestically and spillovers are relatively low, welfare tends to be highest when the firms sequentially choose competitive R&D levels, while for relatively high spillovers, RJV formation dominates. It is possible, however, that if unit R&D costs are sufficiently low, preventing the follower from becoming active may be welfare dominant relative to accommodation, due to the effect of large R&D investment on consumer welfare. In such a case, however, preventing follower activity may not be most profitable for the leader, possibly justifying a role for government policy to subsidise R&D investment.

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Figure 1 R&D reaction functions ($\beta < \frac{1}{2}$)





