

RESEARCH JOINT VENTURES: A BARRIER TO ENTRY?

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Abstract

This paper examines a one-shot game where two symmetric incumbents are faced with possible entry into an industry, where firms may differ in the efficiency of R&D in reducing marginal production costs. The decision facing the incumbents is whether to compete at the R&D stage or to form a RJV. R&D competition may imply that remaining in the market is not viable for the incumbents and the entrant is a monopolist. Conversely, RJV formation may make entry unprofitable and, possibly, increase welfare. The effect on welfare will depend on whether output is exported in its entirety or consumed domestically.

JEL Classification: D2, L2, L4

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1. Introduction

The importance of innovation to improve or maintain the competitiveness of not just individual good and service providers, but also individual economies and economic regions, has become much more apparent in recent years. The main objective of the Lisbon Strategy, for example, was to encourage innovation in the EU in order to ‘catch up’ with the US and Asian economies. Similarly, the Europe 2020 Strategy requires research and innovation to drive the ‘Smart Growth’ aspect of the programme. As well as these, there exists a ‘block exemption’ for Joint Ventures from EU competition law. In recent years, relatively well developed economies have placed greater emphasis on their indigenous industries ‘moving up the value chain’ or entering the ‘smart economy’ by investing in innovation capabilities, increasing their ability to absorb technological advances developed elsewhere and encouraging multinational companies to locate a greater share of their research and development (R&D) facilities in the domestic economy.

A well-known problem of the innovation process is that the knowledge generated has the properties of a public good as it can ‘spill over’ to rivals who may benefit from the innovator’s effort without incurring similar costs. This reduces the private incentive to undertake R&D as innovators cannot fully appropriate the benefits of their innovation. Classic examples of public solutions to this problem are the introduction of patents and R&D subsidies. Other problems associated with private innovation are that the outcome of any innovation process may be uncertain and/or the financial investment required may be relatively large. There is also the possibility that innovating firms are duplicating the innovation efforts of its rivals, which is socially wasteful.

A private solution to such problems is for innovators to *co-operate* in R&D by forming a Research Joint Venture (RJV), where innovation can be undertaken to maximise the sum of joint profits of all RJV members. As well as this, innovators can decide on the level of information sharing within the RJV, so that effective spillover levels become endogenous. RJV members may also co-ordinate their innovation efforts in order to eliminate any possibility of duplication. In this way, the private innovation incentive is increased as each member takes into account the effect of its innovation on not only its own profits, but also those of its RJV partners.

A possible problem of RJVs is that co-operation at the innovation stage may be extended, implicitly, to the final output stage, thereby increasing market power. Another problem is that RJV’s may be formed by a subset of firms in order to attain, or increase, a competitive advantage over non-RJV firms. This may induce the exit of non-RJV firms, again leading to increased market power. Still another possibility is that RJV’s may be used to prevent entry into an industry in order to increase or maintain existing levels of market power

that would be reduced in the absence of RJV formation. Against these, RJV formation may induce greater consumer welfare if the effect of any increased innovation is to reduce marginal production costs and, consequently, final output prices. This, however, may only be a temporary outcome as, in the longer term, prices may increase if non-RJV firms are forced to exit the industry and/or potential entrants are faced with greater barriers to entry. Consequently, the social desirability of RJV formation should be analysed on a case-by-case basis as it will depend on structural factors such as the nature of competition between firms, the possibility of economies of scale or learning-by-doing effects and the ease of entry into, and exit from, the industry in question.

While firms can undertake R&D in order to improve the quality of their product (product innovation) or reduce marginal production costs (process innovation), this paper focuses on the latter. In general, the existing literature is favourable towards RJV as they often lead to greater incentives to undertake R&D, greater total industry profits and, possibly, greater welfare. The starting point for much of the theoretical literature on RJV formation in the presence of exogenous R&D spillovers is the D'Aspremont and Jacquemin (1988) paper, where firms can either *compete* in R&D, by simultaneously choosing their R&D levels to maximise own profits, or *co-operate* in R&D (form a RJV), where the firms simultaneously choose their R&D to maximise the sum of joint profits.¹ On the other hand, the firms always remain rivals in the output market.

From the firms' perspective, RJV formation is weakly preferred to R&D competition.² From a welfare perspective, however, the desirability of RJV formation depends on whether output is entirely exported or consumed domestically. In the former case, welfare is measured by total industry profits and RJV formation is weakly welfare-enhancing for all spillovers.³ If all output is consumed domestically, RJV formation should only be encouraged if spillover levels are relatively high. When the firms compete in R&D and spillovers are relatively low, over-investment in R&D leads to greater output and higher consumer welfare and this dominates the spillover internalisation effect of RJV formation. At relatively high spillovers, RJV formation is welfare-enhancing due to lower prices and higher profits.⁴

One aspect of the D'Aspremont and Jacquemin model is that under RJV formation, effective spillovers remain exogenous. Poyago-Theotoky (1999) showed that firms will fully

¹ Earlier related papers include Dasgupta & Stiglitz (1980), Katz (1986) and Spence (1988). A number of papers extend the D'Aspremont & Jacquemin framework without fundamentally adding to their analysis. Such papers include, among others, Suzumura (1992), Vonortas (1994), Ziss (1995) and Steurs (1995). For a general overview of the relationship between spillovers and innovation, see De Bondt (1996).

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 A similar point was made by Motta (1992) in the context of a vertical product differentiation model where firms engage in product innovation. In this case, the threshold spillover was not identical due to a different demand specification.

share information when co-operating in R&D. Kamien, Muller and Zang (1992) provide a classification of R&D organisations that depend on whether the firms maximise joint profits and/or fully share information. The authors conclude that RJV cartelisation is most desirable as R&D investment and profits are highest, while output prices are lowest.⁵ Despite their taxonomy, their results are identical to those of D'Aspremont and Jacquemin.

Poyago-Theotoky (1995) looked at the effect of a subset of firms forming a RJV and fully sharing information with RJV partners. One interesting result was that for a given range of exogenous R&D spillovers, which depended on RJV size, the R&D of any RJV firm was a strategic substitute for that of the non-RJV firms but a strategic complement for that of its RJV partners.⁶ In the absence of complete exogenous spillovers, RJV members increased their profits relative to non-RJV members and total industry profits generally increased, though this depended on the extent of exogenous R&D spillovers. The profits of an individual RJV firm initially increases, and then decreases, in the RJV size, suggesting that existing RJV firms will not seek extra partners once the RJV size attains a certain threshold. Poyago-Theotoky also finds that equilibrium RJV size is sub-optimal so that government policy should seek to encourage industry-wide RJV formation.

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 increases both total industry profits and welfare. The convexity of the R&D cost function implies that for any given level of total R&D investment, asymmetric investment increases R&D costs at the pre-output stage, but this is offset by higher profits at the production stage so that overall profits and, consequently, welfare, will be higher, even if no exogenous R&D spillovers.

While the existing literature concentrates on the formation of RJV's by all or a subset of existing firms in an industry, very little attention has been paid to the idea of RJV formation between existing firms for the purpose of increasing the entry barrier into an industry. An exception is Soberman (1999) who looks at where two incumbent firms undertake R&D to gain a competitive advantage over an entrant that cannot undertake R&D, possibly making entry unprofitable. In contrast to other papers, there are no exogenous R&D spillovers and co-operation takes the form of sharing R&D costs and knowledge rather than maximising the joint profits of RJV members.

A growing number of papers examine the empirical evidence regarding RJV formation. Hernan, Marin and Siotis (2003) look at 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. The authors argue that "...knowledge

⁵ 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.

⁶ The analysis of RJV formation is incomplete in that it is mostly limited to the case where six out of ten firms form a RJV.

diffusion is central to our understanding of RJV formation".⁷ 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.⁸

This paper seeks to fill a gap in the existing literature. From a theoretical and policy perspective, a RJV where members fully share information may induce a competitive advantage that blockades entry, despite entry being profitable in the absence of a RJV, thereby preventing increased competition in the output market, possibly leading to lower welfare.⁹

The structure of this paper is as follows: Section 2 introduces the model and outlines the game-theoretic structure. Section 3 describes the output production and R&D investment incentives of the firms in a general demand framework. Section 4 looks at a linear demand and quadratic R&D cost case so that R&D, profit and welfare levels can be derived, while Section 5 simulates the model by imposing restrictions on the parameters of the model in order to compare the various games. Section 6 concludes.

2. The Model

This paper builds on the framework of D'Aspremont & Jacquemin (1988) by examining a one-shot game where two, symmetric, incumbent firms are faced with the possible entry of a new firm into an homogenous good industry currently characterised by a Cournot duopoly. Each firm can undertake process R&D and all firms are assumed to face an identical convex R&D cost function that exhibits diminishing returns to R&D. Each firm also receives an exogenous spillover from the R&D of rival firms. The entrant's efficiency in reducing marginal production costs through R&D may differ from that of the incumbents.¹⁰ All firms are profit maximisers and are assumed to have complete information regarding demand, own and rival marginal production and R&D cost functions, spillovers, etc.

If there is entry into the industry, any fixed cost must be incurred before any R&D or output decision is made. An example would be an application for, and receipt of, a licence

⁷ 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.

⁸ The authors also provide theoretical evidence that large firms will not form RJV's with smaller firms.

⁹ There are two possible entry prevention scenarios. Firstly, *blockaded* entry refers to when the incumbent firms' joint profit maximising actions make entry unprofitable. Secondly, *strategic* entry deterrence refers to when the incumbents specifically choose their R&D investment to ensure that entry is unprofitable for the entrant. In such a case, the incumbents would not have a first-order condition at the R&D stage. This paper focuses on the former case.

¹⁰ The entrant may have developed R&D capability in other industries. For example, Microsoft and Sony entered the video games industry by applying expertise developed in their original businesses of developing computer operating systems and hi-fi equipment, respectively.

that permits an undertaking to produce for the output market.¹¹ Irrespective of the number of active firms in the industry, all firms simultaneously choose their R&D and output levels and remain rivals at the output stage. All production takes place in one economy, while output may be consumed domestically or exported in its entirety to another economy.

The decision facing the incumbents is whether to remain competitive at the R&D stage or to form a full information-sharing RJV.¹² The interesting question is: if entry is profitable when all firms compete in R&D, will the formation of a RJV make entry unprofitable and restrict competition in the output market? This will have implications for national welfare if output is consumed domestically, as output may be lower and prices higher than if no RJV is formed. On the other hand, total industry profits may be higher if entry is blockaded.

The game played between the firms consists of four stages. Firstly, the incumbents commit themselves to competing in R&D or forming a RJV. Secondly, the entrant makes its entry decision and incurs any fixed cost if entering the market.¹³ Thirdly, active firms simultaneously choose their R&D levels, taking the R&D of the other firms as given. Finally, active firms simultaneously choose their output levels, taking the output of rivals as given. At each stage of a game, each firm takes into account the effect of its actions on future choices. The model is solved by backward induction leading to a subgame perfect Nash equilibrium in R&D and output levels.

The inverse demand function faced by the firms is

$$p(Q) \quad \text{where} \quad p'(Q) = -b, \quad p''(Q)Q/p' \equiv r \quad (1)$$

where b is the slope of the inverse demand function (not necessarily constant), r is a measure of the concavity of demand and total industry output ($Q = q + q^* + q^e$) depends on the number of active firms in the industry.¹⁴ Each firm has an identical, convex, R&D cost function of $\Gamma(x)$, $\Gamma^*(x^*)$ and $\Gamma^e(x^e)$, respectively, where x denotes the level of R&D, $\Gamma'(\cdot) > 0$ and $\Gamma''(\cdot) > 0$. For simplicity, it is assumed that fixed entry costs are zero.¹⁵

The benefits of R&D occur through the firms' marginal production cost functions, which are assumed to be linear functions of all R&D levels with the following properties:

¹¹ This ensures that an entrant cannot decide to enter the market and produce final output having observed the R&D of the incumbent firms. Of course, the entrant, having made its entry decision, may decide to produce final output without having undertaken any R&D investment.

¹² Competitive R&D refers to when firms choose their R&D levels non co-operatively in order to maximise their own profits. It does not refer to the level of competition at the R&D or output stage.

¹³ Given the assumption of complete information, the incumbents can decide whether or not to commit themselves to forming a RJV. Having made this decision, the entrant then decides whether or not to enter the industry.

¹⁴ In differentiating between the firms, the non-representative incumbent is denoted by $*$, while the entrant is denoted by e .

¹⁵ The emphasis in this paper is on analysing the effect of RJV formation on entry, especially if entry is profitable when all firms compete in R&D. To isolate this effect, entry is assumed to be costless.

$$\begin{aligned}
c = c(x, x^*, x^e) \geq 0 & & c_x = -\theta & & c_{x^*} = -\theta\beta & & c_{x^e} = -\theta\beta \\
c^* = c^*(x, x^*, x^e) \geq 0 & & c^*_x = -\theta^* \beta^* & & c^*_{x^*} = -\theta^* & & c^*_{x^e} = -\theta^* \beta^* \\
c^e = c^e(x, x^*, x^e) \geq 0 & & c^e_x = -\theta^e \beta^e & & c^e_{x^*} = -\theta^e \beta^e & & c^e_{x^e} = -\theta^e
\end{aligned} \tag{2}$$

where $\theta, \theta^*, \theta^e > 0$ denote the effectiveness of R&D in reducing marginal production costs for the respective firms. On the other hand, $0 \leq \beta, \beta^*, \beta^e \leq 1$ are exogenous R&D spillover parameters that, in the absence of any R&D co-operation, determine the *effective* R&D spillover received by each firm from its rivals. If the incumbent firms form a RJV and fully share information between them, then $c_{x^*} = -\theta$ and $c^*_{x^*} = -\theta^*$.

Given R&D and output levels, the representative incumbent's profit is

$$\pi = [p(Q) - c(x, x^*, x^e)]q - \Gamma(x) \tag{3}$$

while the entrant's profit, given zero entry costs, is

$$\pi^e = [p(Q) - c^e(x, x^*, x^e)]q^e - \Gamma^e(x^e) \tag{4}$$

Welfare is the sum of consumer surplus and firm profits and is given by

$$W = \omega(Q) + \pi + \pi^* + \pi^e \tag{5}$$

where $\omega(Q)$ is a measure of consumer surplus in the producing country. If all output is exported, then $\omega(Q)$ is zero and welfare is equal to total industry profits.

Two cases are considered:

(i) Game N: All firms *compete* in R&D. Each firm chooses its own profit maximising R&D, taking rivals' R&D as given.

(ii) Game C: The incumbent firms *co-operate* in R&D (form a RJV). The incumbents choose their R&D to maximise the sum of their *joint* profits, again taking other firms' R&D as given, and fully share information. The entrant again competes in R&D vis-à-vis the incumbents by choosing its R&D to maximise its own profits, taking the incumbents' R&D as given.

In moving from game N to C, there are two separate effects of RJV formation. Firstly, there is the joint profit maximising (internalisation of spillovers) effect and, secondly, the effect of full information sharing between the incumbents.

3. Output production and R&D investment

3.1 Stage 4: output

Profit maximisation for the representative incumbent, from (3), implies

$$\frac{d\pi}{dq} = p(Q) - c(x, x^*, x^e) + p'(Q)q = \pi_q(q, q^*, q^e, x, x^*, x^e) = 0 \tag{6}$$

Totally differentiating (6),

$$\pi_{qq}dq + \pi_{qq^*}dq^* + \pi_{qq^e}dq^e + \pi_{qx}dx + \pi_{qx^*}dx^* + \pi_{qx^e}dx^e = 0 \quad (7)$$

Similar conditions for the other firms imply that, given (2), (6) and (7),

$$\begin{bmatrix} \pi_{qq} & \pi_{qq^*} & \pi_{qq^e} \\ \pi_{q^*q}^* & \pi_{q^*q^*}^* & \pi_{q^*q^e}^* \\ \pi_{q^eq}^e & \pi_{q^eq^*}^e & \pi_{q^eq^e}^e \end{bmatrix} \begin{bmatrix} dq \\ dq^* \\ dq^e \end{bmatrix} = - \begin{bmatrix} \theta \\ \theta^* \beta^* \\ \theta^e \beta^e \end{bmatrix} dx - \begin{bmatrix} \theta\beta \\ \theta^* \beta^* \\ \theta^e \beta^e \end{bmatrix} dx^* - \begin{bmatrix} \theta\beta \\ \theta^* \beta^* \\ \theta^e \beta^e \end{bmatrix} dx^e \quad (8)$$

As the firms' outputs are homogenous, the matrix of second derivatives on the left-hand side of (8) must be negative-definite which is satisfied if demand is not 'too' convex.¹⁶

If entry is unprofitable and the incumbents act as duopolists, then (8) is reduced to

$$\begin{bmatrix} \pi_{qq} & \pi_{qq^*} \\ \pi_{q^*q}^* & \pi_{q^*q^*}^* \end{bmatrix} \begin{bmatrix} dq \\ dq^* \end{bmatrix} = - \begin{bmatrix} \theta \\ \theta^* \beta^* \end{bmatrix} dx - \begin{bmatrix} \theta\beta \\ \theta^* \beta^* \end{bmatrix} dx^* \quad (9)$$

If entry leads to the incumbents making a loss, the output market is a monopoly and total differentiation of the entrant's first-order condition implies that profit maximisation requires

$$\pi_{q^eq^e}^e dq^e = -\theta^e dx^e \quad (10)$$

3.2 Stage 3: Profitable entry - R&D competition

Using the envelope theorem, the representative incumbent's first-order R&D condition is

$$\frac{d\pi}{dx} = \underbrace{\frac{\partial\pi}{\partial x}}_{\text{direct effect}} + \underbrace{\frac{\partial\pi}{\partial q^*} \cdot \frac{\partial q^*}{\partial x} + \frac{\partial\pi}{\partial q^e} \cdot \frac{\partial q^e}{\partial x}}_{\text{strategic effects}} = 0 \quad (11)$$

where the direct effect of R&D is the marginal benefit of R&D, the reduction in variable production costs, less the marginal cost of the investment. Each firm's R&D, however, affects its rivals' output that will have a subsequent effect on own profits. Strategic effects, therefore, may be non-zero as firms may have an incentive to over or under-invest in R&D.¹⁷ From (1), (2) and (3), (11) can be expressed as

$$\frac{d\pi}{dx} = \left[\theta - b \frac{\partial q^*}{\partial x} - b \frac{\partial q^e}{\partial x} \right] q - \Gamma'(x) = \mu^N q - \Gamma'(x) = 0 \quad (12)$$

¹⁶ From (1), (2) and (6), $\pi_{qq} = -b(2 + \sigma r)$ and $\pi_{qq^*} = \pi_{qq^e} = -b(1 + \sigma r)$, where σ is the market share of the representative incumbent. Similarly, $\pi_{q^*q^*}^* = -b(2 + \sigma^* r)$, $\pi_{q^*q^e}^* = \pi_{q^*q^e}^* = -b(1 + \sigma^* r)$ and $\pi_{q^eq^e}^e = -b(2 + \sigma^e r)$, $\pi_{q^eq^*}^e = \pi_{q^eq^e}^e = -b(1 + \sigma^e r)$. To satisfy the firms' second-order conditions, these expressions must be negative. As the own marginal profitability effect must dominate the cross-effect, this is satisfied if $r > -1/\sigma$. Similar conditions hold for the other firms so that $r > -1/\sigma^*$ and $r > -1/\sigma^e$.

¹⁷ Over (under) investment in R&D occurs when firms invest in R&D where the marginal private benefit of R&D is less (greater) than the marginal private cost. While not profit maximising at the R&D stage, the firms increase output market profit in the second stage, so total profit is maximised.

where μ^N is the representative incumbent's marginal return to R&D per unit of output.¹⁸ Given ex-ante symmetry, the incumbent firms will be ex-post symmetric so that $\theta = \theta^*$ and $\beta = \beta^*$.¹⁹ Non-strategic R&D investment requires $\mu^N = \theta$, so that using the relevant partial derivatives in (8), and given that the determinant of the matrix of second derivatives on the left hand side of (8) is negative, the incumbents over (under) invest in R&D (see Appendix) if

$$\beta < (>) \frac{2+r(\sigma+\sigma^e)}{2+\sigma} - \frac{\theta^e \beta^e}{\theta} \equiv \bar{\beta}(\beta^e) \quad (13)$$

When $\beta < \bar{\beta}$, over-investment in R&D seeks to profit-shift from rivals. Conversely, if $\beta > \bar{\beta}$, each incumbent's benefit from rival R&D is relatively large so they under-invest in R&D to 'free-ride' on rival investment.^{20,21} From (13), the threshold spillover parameter is decreasing in the effective spillover of the entrant, as increasing gains to the entrant from incumbent R&D reduces the incentive of the incumbents to over-invest in R&D in order to profit-shift from the entrant. The greater the relative efficiency of the incumbents (higher θ or lower θ^e), the higher the threshold spillover parameter of the incumbents at which they cease to profit-shift from the entrant by over-investing in R&D.

The entrant's first-order R&D condition is similar to (11) and is given by

$$\frac{d\pi^e}{dx^e} = \frac{\partial \pi^e}{\partial x^e} + \frac{\partial \pi^e}{\partial q} \cdot \frac{\partial q}{\partial x^e} + \frac{\partial \pi^e}{\partial q^*} \cdot \frac{\partial q^*}{\partial x^e} = 0 \quad (14)$$

Given (1), (2) and (3), (14) can be expressed as

$$\frac{d\pi^e}{dx^e} = \left[\theta^e - b \frac{\partial q}{\partial x^e} - b \frac{\partial q^*}{\partial x^e} \right] q^e - \Gamma^{e'}(x^e) = \mu^{eN} q^e - \Gamma^{e'}(x^e) = 0 \quad (15)$$

where μ^{eN} is the entrant's marginal return to R&D per unit of output.²² Ex-post incumbent symmetry implies that $\theta = \theta^*$ and $\beta = \beta^*$. Non-strategic R&D investment requires $\mu^{eN} = \theta^e$ so that using the relevant partial derivatives from (8), and given that the determinant of the

¹⁸ The representative incumbent's second-order condition requires $\Gamma^{//}(x) - \mu^N \frac{\partial q}{\partial x} - q \frac{\partial \mu^N}{\partial x} > 0$.

¹⁹ Incumbent symmetry implies equal incumbent market shares ($\sigma = \sigma^*$) so that $\pi_{qq} = \pi^*_{q^*q^*} = -b(2+\sigma)$ and $\pi_{qq^*} = \pi_{q^*q} = \pi^*_{q^*q} = \pi^*_{q^*q^*} = -b(1+\sigma)$.

²⁰ If demand is linear ($r = 0$), the incumbent firms over (under) invest in R&D if $\beta < (>) \bar{\beta}(\beta^e) = \frac{\theta - \theta^e \beta^e}{\theta}$. This is consistent with D'Aspremont and Jacquemin (1988) and others, where

$\theta = \theta^e = 1$, $\beta = \beta^e$ and the firms over-invest in R&D when $\beta < 1/2$ and under-invest in R&D when $\beta > 1/2$.

²¹ A firm's R&D is a strategic substitute (complement) when an increase in its R&D investment reduces (increases) the marginal profitability of its rival's R&D investment. If R&D is a strategic substitute (complement), R&D reaction functions are downward (upward) sloping in R&D space. It can be shown that the incumbents' R&D are strategic substitutes (complements) for the entrant's R&D if

$$2 \left\{ -b \left[q^e \frac{\partial^2 q}{\partial x^e \partial x} + \frac{\partial q}{\partial x^e} \cdot \frac{\partial q^e}{\partial x} \right] + p^{//}(Q) \frac{\partial q}{\partial x^e} \left[\frac{\partial q}{\partial x} + \frac{\partial q^*}{\partial x} + q^e \frac{\partial q^e}{\partial x} \right] \right\} + \theta^e \frac{\partial q^e}{\partial x} < (>) 0.$$

²² The entrant's second-order R&D condition requires $\Gamma^{e//}(x^e) - \mu^{eN} \frac{\partial q^e}{\partial x^e} - q^e \frac{\partial \mu^{eN}}{\partial x^e} > 0$.

matrix of second derivatives on the left hand side of (8) is negative, the entrant will over (under) invest in R&D (see Appendix) if

$$\beta < (>) \frac{\theta^e (1 + \sigma r)}{\theta(2 + \sigma^e r)} \equiv \tilde{\beta} \quad (16)$$

As the entrant's relative efficiency increases (θ^e increases or θ decreases), the higher the incumbents' spillover parameter at which the entrant over-invests in R&D in order to profit-shift from the incumbents.²³ Conversely, the more relatively inefficient is the entrant, the more it under-invests in R&D to 'free-ride' on the R&D of the incumbent firms. This is consistent with earlier reasoning for the incumbents.²⁴

To compare the investment incentives of the firms when demand is linear ($r = 0$), suppose that the entrant is sufficiently less efficient than the incumbents ($\theta^e < 2\theta/3$) so that $\tilde{\beta} < \bar{\beta}$. If $\beta < \tilde{\beta}$, all firms over-invest in R&D as the spillover benefits to rivals are relatively low. On the other hand, all firms under-invest in R&D if $\beta > \bar{\beta}$ as spillover gains are relatively high. In the intermediate case, where $\tilde{\beta} < \beta < \bar{\beta}$, the incumbent firms over-invest in R&D to profit-shift from the relatively inefficient entrant. Conversely, the entrant under-invests in R&D to free-ride on the relatively more efficient incumbents so that incumbent R&D is higher at these spillover levels.²⁵ The greater the degree of over-investment in R&D by the incumbent firms, the lower are marginal production costs, the higher is output and lower is price. If output is consumed domestically, the beneficial effects on consumers may ensure that welfare is higher relative to when firms invest non-strategically or under-invest in R&D.

3.3 Stage 3: Profitable entry - RJV formation (R&D co-operation)

The incumbent firms form a RJV by maximising the sum of their joint profits and fully share information so that $c_x = c_{x^*} = -\theta$ and $c_x^* = c_{x^*}^* = -\theta^*$. The representative incumbent's first-order R&D condition is

²³ The entrant's R&D is a strategic substitute (complement) for the incumbents' R&D if $\left\{ -b \left[\frac{\partial^2 q^*}{\partial x \partial x^e} + \frac{\partial q^*}{\partial x^e} \cdot \frac{\partial q^e}{\partial x} \right] + p''(Q) \left[\frac{\partial q^*}{\partial x^e} + \frac{\partial q^e}{\partial x^e} \right] \left[\frac{\partial q^*}{\partial x} + \frac{\partial q^e}{\partial x} \right] \right\} q + \left\{ [-b + p''(Q)q] \left[\frac{\partial q^*}{\partial x} + \frac{\partial q^e}{\partial x} \right] + \theta \right\} \frac{\partial q}{\partial x^e} < (>) 0$.

²⁴ If demand is linear ($r = 0$), the entrant over (under) invests in R&D if $\beta < (>) \frac{\theta^e}{2\theta} = \tilde{\beta}$. This reduces to the D'Aspremont and Jacquemin condition when $\theta^e = \theta$.

²⁵ Similar reasoning applies when $\theta^e > 2\theta$ so that $\tilde{\beta} > \bar{\beta}$. In this case, all firms over-invest in R&D if $\beta < \tilde{\beta}$ and under-invest in R&D if $\beta > \tilde{\beta}$. If $\bar{\beta} < \beta < \tilde{\beta}$, the incumbent firms under-invest in R&D while the relatively efficient entrant over-invests in R&D.

$$\frac{d(\pi + \pi^*)}{dx} = \left\{ \frac{\partial \pi}{\partial x} + \frac{\partial \pi}{\partial q^*} \cdot \frac{\partial q^*}{\partial x} + \frac{\partial \pi}{\partial q^e} \cdot \frac{\partial q^e}{\partial x} \right\} + \left\{ \frac{\partial \pi^*}{\partial x} + \frac{\partial \pi^*}{\partial q} \cdot \frac{\partial q}{\partial x} + \frac{\partial \pi^*}{\partial q^e} \cdot \frac{\partial q^e}{\partial x} \right\} = 0 \quad (17)$$

that, from (1) and (2), can be re-written as

$$\frac{d(\pi + \pi^*)}{dx} = \left\{ \theta q - \Gamma'(x) - bq \frac{\partial q^*}{\partial x} - bq \frac{\partial q^e}{\partial x} \right\} + \left\{ \theta^* q^* - bq^* \frac{\partial q}{\partial x} - bq^* \frac{\partial q^e}{\partial x} \right\} = 0 \quad (18)$$

The marginal benefit of an incumbent's R&D is now the *sum* of the reduction in variable production costs of the RJV members.²⁶ Ex-post incumbent symmetry implies $\theta = \theta^*$, $\beta = \beta^*$ and $q = q^*$ so that (18) reduces to

$$\frac{d(\pi + \pi^*)}{dx} = 2 \left[\theta - b \frac{\partial q}{\partial x} - b \frac{\partial q^e}{\partial x} \right] q - \Gamma'(x) = \mu^C q - \Gamma'(x) = 0 \quad (19)$$

where μ^C is the sum of the RJV members' marginal return to R&D per unit output.²⁷ Non-strategic R&D investment requires $\mu^C = 2\theta$, so that from (8) and (19), the incumbents over (under) invest in R&D (see Appendix) if

$$\beta^e < (>) \frac{\theta \sigma^e r}{\theta^e (1 + \sigma r)} \equiv \hat{\beta} \quad (20)$$

From (20), the threshold spillover parameter of the entrant at which the incumbents begin to under-invest in R&D is increasing in their relative efficiency level.²⁸ As they become more efficient, and particularly for low spillover parameters, the incumbent firms increasingly over-invest in R&D as the incentive to shift profits from a relatively inefficient entrant dominates the benefits of free-riding on a RJV partner.²⁹ As the entrant remains in R&D competition vis-à-vis the incumbents, its first-order R&D condition is again given by (14) and its investment incentive by (16). The rationale for the entrant's investment decision is given in Section 3.2.

²⁶ The direct marginal net benefit of R&D for RJV members is $\frac{\partial(\pi + \pi^*)}{\partial x} = \theta q + \theta^* q^* - \Gamma'(x) = 2\theta q - \Gamma'(x)$ given incumbent symmetry and full information sharing.

²⁷ This implies that $\frac{\partial q}{\partial x} = \frac{\partial q^*}{\partial x} = \frac{\partial q}{\partial x^*} = \frac{\partial q^*}{\partial x^*}$. The representative incumbent's second-order R&D condition requires $\Gamma''(x) - \mu^C \frac{\partial q}{\partial x} - q \frac{\partial \mu^C}{\partial x} > 0$.

²⁸ The entrant's R&D is a strategic substitute (complement) for incumbent R&D when $\left[p''(Q) \left(2 \frac{\partial q}{\partial x} + \frac{\partial q^e}{\partial x^e} \right) - b \frac{\partial q}{\partial x^e} \right] \left[\frac{\partial q}{\partial x} + \frac{\partial q^e}{\partial x} \right] - b \left[\frac{\partial^2 q}{\partial x \partial x^e} + \frac{\partial^2 q^e}{\partial x \partial x^e} \right] + \theta \frac{\partial q}{\partial x^e} < (>) 0$. As the entrant's incentives are identical to the competitive R&D case, an identical condition to that game holds for the strategic substitutability and complementarity of incumbent R&D for entrant R&D (see footnote 22).

²⁹ If demand is linear ($r = 0$), the incumbents under-invest in R&D for all $\beta^e > 0$, irrespective of the entrant's relative efficiency level, as the spillover internalisation effect offsets any strategic motives against the entrant.

3.4 Unprofitable entry or loss-making incumbents

If entry is unprofitable and the incumbent firms find it most profitable to act as duopolists at the R&D stage, they will over (under) invest in R&D if $\beta < (>) \frac{1}{2}$ if competing in R&D, and always under-invest in R&D when forming a full information-sharing RJV. On the other hand, if profitable entry implies a loss for the incumbents and the entrant finds it more profitable to act as a monopolist at the R&D stage, the absence of market rivals negates any strategic investment incentive.

4. The Linear Demand – Quadratic R&D Cost case

In this section, certain functional forms are imposed on the behavioural functions in order to facilitate simulation of these models so as to enable a comparison between them.

The firms are assumed to face the linear inverse demand function

$$p(Q) = a - bQ = a - b(q + q^* + q^e) \quad (21)$$

where $Q \leq a/b$. Marginal production costs are linear in own and rival R&D and are

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

$$c^e(x, x^*, x^e) = A - \theta^e(\beta^e x + \beta^e x^* + x^e) \geq 0 \quad (22)$$

for the incumbent and entrant firms, respectively. It is assumed that $0 < A < a$ so that firms will produce positive output levels. Finally, the firms' quadratic R&D cost functions, with common unit R&D cost $\gamma > 0$, are

$$\Gamma(x) = \gamma x^2/2, \quad \Gamma^*(x^*) = \gamma x^{*2}/2, \quad \text{and} \quad \Gamma^e(x^e) = \gamma x^{e2}/2 \quad (23)$$

From (21), consumer surplus is $\omega(Q) = \frac{bQ^2}{2}$. In what follows, N denotes R&D competition (or non co-operation) while C denotes RJV formation (R&D co-operation).

Using (21), (22) and (23) in (3), profit maximisation for the representative incumbent implies

$$\pi_q = p(Q) - c - bq = 0 \quad (24)$$

$$\Rightarrow q = [a - bq^* - bq^e - c]/2b$$

Similar conditions exist for the other firms so that if entry is profitable, output levels are

$$\begin{bmatrix} q \\ q^* \\ q^e \end{bmatrix} = \frac{1}{4b} \begin{bmatrix} a - 3c + c^* + c^e \\ a + c - 3c^* + c^e \\ a + c + c^* - 3c^e \end{bmatrix} \quad (25)$$

If entry is unprofitable and the incumbents act as duopolists in the output market, their output expressions are

$$\begin{bmatrix} q \\ q^* \end{bmatrix} = \frac{1}{3b} \begin{bmatrix} a-2c+c^* \\ a+c-2c^* \end{bmatrix} \quad (26)$$

while if entry makes the incumbents unprofitable, the entrant's monopoly output is

$$q^e = \frac{a-c^e}{2b} \quad (26a)$$

Using the first-order condition in (24) in (3), and similarly for other firms, profit levels are

$$\begin{bmatrix} \pi \\ \pi^* \\ \pi^e \end{bmatrix} = \begin{bmatrix} bq^2 - \frac{\gamma x^2}{2} \\ bq^{*2} - \frac{\gamma x^{*2}}{2} \\ bq^{e2} - \frac{\gamma x^{e2}}{2} \end{bmatrix} \quad (27)$$

irrespective of whether entry occurs or not, while welfare is

$$W = \frac{bQ^2}{2} + bq^2 - \frac{\gamma x^2}{2} + bq^{*2} - \frac{\gamma x^{*2}}{2} + bq^{e2} - \frac{\gamma x^{e2}}{2} \quad (28)$$

4.1 Profitable entry: R&D competition

Using (22) in (25), output levels can be expressed in terms of R&D levels so that

$$\begin{bmatrix} q \\ q^* \\ q^e \end{bmatrix} = \frac{1}{4b} \begin{bmatrix} \alpha + (3\theta - \theta^* \beta^* - \theta^e \beta^e)x + (3\theta\beta - \theta^* \beta^* - \theta^e \beta^e)x^* + (3\theta\beta - \theta^* \beta^* - \theta^e \beta^e)x^e \\ \alpha + (3\theta^* \beta^* - \theta - \theta^e \beta^e)x + (3\theta^* \beta^* - \theta - \theta^e \beta^e)x^* + (3\theta^* \beta^* - \theta - \theta^e \beta^e)x^e \\ \alpha + (3\theta^e \beta^e - \theta - \theta^* \beta^*)x + (3\theta^e \beta^e - \theta - \theta^* \beta^*)x^* + (3\theta^e \beta^e - \theta - \theta^* \beta^*)x^e \end{bmatrix} \quad (29)$$

where $\alpha = a-A > 0$. Given (23) and (29), the representative incumbent's first-order R&D condition in (11) is

$$\frac{d\pi}{dx} = \left[\theta - \left(\frac{3\theta^* \beta^* - \theta - \theta^e \beta^e}{4} \right) - \left(\frac{3\theta^e \beta^e - \theta - \theta^* \beta^*}{4} \right) \right] q - \gamma x = 0 \Rightarrow x = \left[\frac{3\theta - \theta^* \beta^* - \theta^e \beta^e}{2\gamma} \right] q \quad (30)$$

Similarly, the entrant's first-order R&D condition in (14) can be re-written as

$$\frac{d\pi^e}{dx^e} = \left[\theta^e - \left(\frac{3\theta\beta - \theta^* \beta^* - \theta^e}{4} \right) - \left(\frac{3\theta^* \beta^* - \theta\beta - \theta^e}{4} \right) \right] q^e - \gamma x^e = 0 \Rightarrow x^e = \left[\frac{3\theta^e - \theta\beta - \theta^* \beta^*}{2\gamma} \right] q^e \quad (31)$$

Ex-post incumbent symmetry implies that $\theta = \theta^*$, $\beta = \beta^*$, $x = x^*$ and $q = q^*$ so using the relevant output expression from (29) in (30) and (31) to solve for R&D levels implies

$$\begin{bmatrix} x^N = x^{*N} \\ x^{eN} \end{bmatrix} = \frac{\alpha}{\Phi} \begin{bmatrix} [\theta(3-\beta) - \theta^e \beta^e][8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)] \\ (3\theta^e - 2\theta\beta)\{8b\gamma - 4[\theta(3-\beta) - \theta^e \beta^e][\theta(1+\beta) - 2\theta^e \beta^e]\} \end{bmatrix} \quad (32)$$

where $\Phi = \{8b\gamma - (3\theta^e - 2\theta\beta)^2\} \{8b\gamma - 2[\theta(1+\beta) - \theta^e \beta^e][\theta(3-\beta) - \theta^e \beta^e]\} - 2(2\theta\beta - \theta^e)(3\theta^e - 2\theta\beta)[3\theta^e \beta^e - \theta(1+\beta)][\theta(3-\beta) - \theta^e \beta^e]$.³⁰ If all firms are symmetric ($\theta = \theta^e$ and $\beta = \beta^e$), R&D levels are

³⁰ The entrant's R&D is a strategic substitute (complement) for that of the incumbents if $(2\theta\beta - \theta^e)[\theta(3-\beta) - \theta^e \beta^e] < (>) 0$, that reduces to $\beta < (>) \frac{1}{2}$ if all firms are symmetric. On the other

identical, while if asymmetric, which R&D level dominates depends on the firms' effective spillovers and their relative efficiency in reducing marginal production costs through R&D.³¹

Substituting R&D levels from (32) into (29) to derive output levels, and substituting these output and R&D levels into (27), profits are

$$\begin{bmatrix} \pi^N = \pi^{*N} \\ \pi^{eN} \end{bmatrix} = \frac{\gamma\alpha^2}{2\Phi^2} \begin{bmatrix} [8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)]^2 [8b\gamma - [\theta(3 - \beta) - \theta^e\beta^e]^2] \\ [8b\gamma - (3\theta^e - 2\theta\beta)^2] \{8b\gamma - 4[\theta(3 - \beta) - \theta^e\beta^e][\theta(1 + \beta) - 2\theta^e\beta^e]\}^2 \end{bmatrix} > 0 \quad (33)$$

which are identical if all firms are symmetric ($\theta = \theta^e$, $\beta = \beta^e$) given zero entry costs.

If all output is exported, welfare is $W_{EX}^N = 2\pi^N + \pi^{eN}$.³² On the other hand, if output is consumed domestically, welfare is

$$W_D^N = \frac{\gamma\alpha^2}{2\Phi^2} \left\{ \begin{array}{l} 2 \left\{ 16b\gamma - [\theta(3 - \beta) - \theta^e\beta^e]^2 \right\} [8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)]^2 \\ + 16b\gamma [8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)] \{8b\gamma - 4[\theta(3 - \beta) - \theta^e\beta^e][\theta(1 + \beta) - 2\theta^e\beta^e]\} \\ [12b\gamma - (3\theta^e - 2\theta\beta)^2] \{8b\gamma - 4[\theta(3 - \beta) - \theta^e\beta^e][\theta(1 + \beta) - 2\theta^e\beta^e]\}^2 \end{array} \right\} \quad (34)$$

The expressions in (32), (33) and (34) are expressed in terms of spillovers (β , β^e), unit R&D costs (γ), the absolute slope of the inverse demand curve (b) and the firms' efficiency in reducing marginal production costs through R&D (θ , θ^e).³³ Comparing R&D, profit and welfare levels within and between the various games will require simulation of the models. This is attempted in Section 5 when restrictions are imposed on the model parameters.

4.2 Profitable entry: RJV formation (R&D co-operation)

The formation of a RJV with full information-sharing implies that output levels, in terms of own and rival R&D, are

$$\begin{bmatrix} q \\ q^* \\ q^e \end{bmatrix} = \frac{1}{4b} \begin{bmatrix} \alpha + [3\theta - \theta^* - \theta^e\beta^e]x + [3\theta - \theta^* - \theta^e\beta^e]x^* + (3\theta\beta - \theta^*\beta^* - \theta^e)x^e \\ \alpha + [3\theta^* - \theta - \theta^e\beta^e]x + [3\theta^* - \theta - \theta^e\beta^e]x^* + (3\theta^*\beta^* - \theta\beta - \theta^e)x^e \\ \alpha + [3\theta^e\beta^e - \theta - \theta^*]x + [3\theta^e\beta^e - \theta - \theta^*]x^* + (3\theta^e - \theta\beta - \theta^*\beta^*)x^e \end{bmatrix} \quad (35)$$

Given (22) and (35), the representative incumbent's first-order R&D condition in (17) is

hand, the incumbents' R&D is a strategic substitute (complement) for that of the entrant if $(3\theta^e - 2\theta\beta)[3\theta^e\beta^e - \theta(1 + \beta)] < (>) 0$. This also reduces to $\beta < (>) 1/2$ if all firms are symmetric.

³¹ The incumbents' second-order R&D conditions require $8b\gamma - [\theta(3 - \beta) - \theta^e\beta^e]^2 > 0$ while the entrant's requires $8b\gamma - (3\theta^e - 2\theta\beta)^2 > 0$. Also, if the R&D expressions in (32) are negative, the correct output and profit expressions are found by setting R&D levels equal to zero and using (25) and (27) to derive outputs and profits, respectively.

³² Welfare when output is exported or consumed domestically is denoted by subscripts EX and D, respectively.

³³ Leahy and Neary (1996) define $\eta = \theta^2/b\gamma$ as the relative effectiveness of R&D, as R&D is more effective in increasing profits the more efficient is the firm in reducing marginal production costs through R&D (higher θ) and the lower are unit R&D costs (γ). It would be easy to include such a parameter here if all firms were symmetric. In this chapter, however, it would complicate the analysis as the asymmetry of the firms implies that we would have to have such a parameter for each firm.

$$\frac{d(\pi + \pi^*)}{dx} = \left[\theta - \left(\frac{3\theta^* - \theta - \theta^e \beta^e}{4} \right) - \left(\frac{3\theta^e \beta^e - \theta - \theta^*}{4} \right) \right] q + \left[\theta^* - \left(\frac{3\theta - \theta^* - \theta^e \beta^e}{4} \right) - \left(\frac{3\theta^e \beta^e - \theta - \theta^*}{4} \right) \right] q^* - \gamma x = 0 \quad (36)$$

that, given ex-post incumbent symmetry ($\theta = \theta^*$ and $\beta = \beta^*$), implies that

$$x = x^* = \frac{2(2\theta - \theta^e \beta^e)}{2\gamma} q \quad (37)$$

The entrant's first-order R&D condition is given in (14), which given (4), (22), (23), (37) and ex-post incumbent symmetry, can be expressed as

$$\frac{d\pi^e}{dx^e} = \left[\theta^e - \left(\frac{3\theta\beta - \theta^* \beta^* - \theta^*}{4} \right) - \left(\frac{3\theta^* \beta^* - \theta\beta - \theta^e}{4} \right) \right] q^e - \gamma x^e = 0 \Rightarrow x^e = \frac{3\theta^e - 2\theta\beta}{2\gamma} q^e \quad (38)$$

Using the relevant output expressions from (35) in (37) and (38) to solve for R&D levels implies

$$\begin{bmatrix} x^C = x^{*C} \\ x^{eC} \end{bmatrix} = \frac{\alpha}{\Omega} \begin{bmatrix} 2(2\theta - \theta^e \beta^e)[8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)] \\ (3\theta^e - 2\theta\beta)[8b\gamma - 16(2\theta - \theta^e \beta^e)(\theta - \theta^e \beta^e)] \end{bmatrix} \quad (39)$$

where $\Omega = \{8b\gamma - 4(2\theta - \theta^e \beta^e)^2\} \{8b\gamma - (3\theta^e - 2\theta\beta)^2\} - 4(2\theta - \theta^e \beta^e)(2\theta\beta - \theta^e)(3\theta^e \beta^e - 2\theta)(3\theta^e - 2\theta\beta)$.³⁴

If all firms are symmetric ($\theta^e = \theta$ and $\beta = \beta^e$), RJV R&D exceeds entrant R&D for all spillovers given positive unit R&D costs due to the effect of joint profit maximisation and full information-sharing. This result may hold even if the entrant is relatively more efficient than the incumbents ($\theta^e > \theta$), depending on the firms' effective spillovers.

Substituting R&D levels from (39) into (37) and (38) to determine output levels, and substituting these and R&D levels into (27) implies that profits are

$$\begin{bmatrix} \pi^C = \pi^{*C} \\ \pi^{eC} \end{bmatrix} = \frac{\gamma\alpha^2}{2\Omega^2} \begin{bmatrix} \{8b\gamma - 4(2\theta - \theta^e \beta^e)^2\} \{8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)\}^2 \\ \{8b\gamma - (3\theta^e - 2\theta\beta)^2\} \{8b\gamma - 16(2\theta - \theta^e \beta^e)(\theta - \theta^e \beta^e)\}^2 \end{bmatrix} \quad (40)$$

When all firms are symmetric ($\theta = \theta^e$) and exogenous spillovers are complete ($\beta = \beta^e = 1$), the entrant's profits exceed those of the RJV members so that there is an advantage to not being a RJV member.^{35, 36, 37} This result may also hold if spillovers are less than complete ($\beta, \beta^e < 1$)

³⁴ The incumbents' second-order R&D condition requires $8b\gamma - 2(2\theta - \theta^e \beta^e)^2 > 0$, while the entrant's requires $8b\gamma - (3\theta^e - 2\theta\beta)^2 > 0$.

³⁵ That is not to say that being a RJV member is a disadvantage relative to R&D competition. Being a RJV member may be more profitable than competing in R&D, but not being a member may be even more so.

³⁶ Again, the profit expressions in (40) are only relevant if the R&D expressions in (39) and corresponding output levels from (35) are non-negative. If R&D levels are negative, they are set to zero and the correct output and profit levels are then derived through (35) and (27), respectively.

³⁷ The entrant's R&D is a strategic substitute (complement) for that of the incumbents if $(2\theta\beta - \theta^e)(2\theta - \theta^e \beta^e) < (>) 0$ which reduces to $\beta < (>) 1/2$ if all firms are symmetric. On the other hand, the incumbents' R&D is a strategic substitute (complement) for that of the entrant if $(3\theta^e - 2\theta\beta)(3\theta^e \beta^e - 2\theta) < (>) 0$ that reduces to $\beta < (>) 2/3$ if all firms are symmetric. The difference in threshold spillovers is due to the fact that full information sharing within the RJV facilitates profit

and the entrant is relatively inefficient ($\theta^e < \theta$). This is because the entrant benefits from the higher R&D of the RJV firms, without incurring the consequent higher R&D costs, to such an extent that not being a RJV member leads to higher profits.

When all output is exported, welfare is given by $W_{EX}^C = 2\pi^C + \pi^{eC}$. On the other hand, if output is consumed domestically, welfare is

$$W_D^C = \frac{\gamma\alpha^2}{2\Omega^2} \left\{ \begin{aligned} &4[8b\gamma - 2(2\theta - \theta^e\beta^e)^2][8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)]^2 \\ &+ 16b\gamma[8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)][8b\gamma - 16(2\theta - \theta^e\beta^e)(\theta - \theta^e\beta^e)] \\ &+ [12b\gamma - (3\theta^e - 2\theta\beta)^2][8b\gamma - 16(2\theta - \theta^e\beta^e)(\theta - \theta^e\beta^e)]^2 \end{aligned} \right\} \quad (41)$$

that again depends on spillovers, unit R&D costs, the slope of the inverse demand curve and the firms' R&D efficiency.

4.3 Profitable entry: R&D competition v RJV formation

In comparing R&D competition to RJV formation, the interesting question is how the R&D and profits of the incumbent firms differ between the two cases.

Comparing R&D levels in (32) and (39), it can be shown that for the incumbents

$$x^N \begin{pmatrix} > \\ = \\ < \end{pmatrix} x^C \text{ if } \alpha[8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)] \left\{ [\theta(3 - \beta) - \theta^e\beta^e]\Omega - 2(2\theta - \theta^e\beta^e)\Phi \right\} \begin{pmatrix} > \\ = \\ < \end{pmatrix} 0 \quad (42)$$

while for the entrant

$$x^{eN} \begin{pmatrix} > \\ = \\ < \end{pmatrix} x^{eC} \text{ if } \alpha(3\theta^e - 2\theta\beta) \left\{ [8b\gamma - 4[\theta(3 - \beta) - \theta^e\beta^e][\theta(1 + \beta) - 2\theta^e\beta^e]]\Omega - [8b\gamma - 16(2\theta - \theta^e\beta^e)(\theta - \theta^e\beta^e)]\Phi \right\} \begin{pmatrix} > \\ = \\ < \end{pmatrix} 0 \quad (43)$$

Similarly, comparing profit levels in (33) and (40) imply that for the incumbent firms

$$\pi^N \begin{pmatrix} > \\ = \\ < \end{pmatrix} \pi^C \text{ if } [8b\gamma - [\theta(3 - \beta) - \theta^e\beta^e]]^2\Omega^2 - [8b\gamma - 4(2\theta - \theta^e\beta^e)^2]\Phi^2 \begin{pmatrix} > \\ = \\ < \end{pmatrix} 0 \quad (44)$$

while for the entrant

$$\pi^{eN} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \pi^{eC} \text{ if } [8b\gamma - 4[\theta(3 - \beta) - \theta^e\beta^e][\theta(1 + \beta) - 2\theta^e\beta^e]]^2\Omega^2 - [8b\gamma - 16(2\theta - \theta^e\beta^e)(\theta - \theta^e\beta^e)]^2\Phi^2 \begin{pmatrix} > \\ = \\ < \end{pmatrix} 0 \quad (45)$$

Given the complexity of the expressions in (42)-(45), it is difficult to draw any firm conclusions about relative R&D and profit levels, even if it is assumed that all firms are symmetric.³⁸ To overcome this, it is necessary to impose restrictions on the parameters of the model so that they can be simulated and compared. This is attempted in Section 5.

shifting from the entrant at higher levels of spillovers than in the R&D competition case. A similar point was made by Poyago-Theotoky (1995).

³⁸ The same is true for any welfare comparison

4.4 Unprofitable entry

If, given non-negative R&D and output levels by all firms, the entrant makes a loss, it will not enter the industry and the output market remains a duopoly. This is a case of *blockaded* entry. In this case, however, R&D levels may be chosen on the basis of there being two or three firms in the industry. While the latter may make entry unprofitable, it does not follow that the incumbents initially act as if the market is a duopoly as, by doing so, the entrant may find it profitable to produce output without having been active at the R&D stage, especially if entry costs are low and spillovers are relatively high. Also, it may be more profitable for the incumbent firms to act as a duopoly in the R&D stage, even if this ensures that entry is profitable. In this case, the output expressions in (35) are relevant. On the other hand, if such R&D levels still make entry unprofitable, the incumbents choose duopoly output levels in (26). For comparison purposes, therefore, the main results of the D'Aspremont and Jacquemin paper are presented below.

When the incumbent firms compete in R&D, their R&D levels are

$$x^N = x^{*N} = \frac{2\alpha\theta(2-\beta)}{9b\gamma - 2\theta^2(2-\beta)(1+\beta)} \quad (46)$$

while profits are

$$\pi^N = \pi^{*N} = \frac{\gamma\alpha^2[9b\gamma - 2\theta^2(2-\beta)^2]}{[9b\gamma - 2\theta^2(2-\beta)(1+\beta)]^2} \quad (47)$$

and welfare is

$$W^N = \frac{2\gamma\alpha^2[18b\gamma - 2\theta^2(2-\beta)^2]}{[9b\gamma - 2\theta^2(2-\beta)(1+\beta)]^2} \quad (48)$$

In contrast to D'Aspremont and Jacquemin, this paper assumes that when incumbent firms form a RJV, they fully share information so that the equivalent R&D levels are

$$x^C = x^{*C} = \frac{4\alpha\theta}{9b\gamma - 8\theta^2} \quad (49)$$

which are independent of exogenous spillovers.³⁹ As the entrant will not enter the industry and spillovers are complete within the RJV, the incumbents are not concerned about spillovers to non-RJV firms and so their R&D is constant for any given levels of demand, unit R&D costs and R&D efficiency. Given (49), the incumbents' profits are

$$\pi^C = \pi^{*C} = \frac{\gamma\alpha^2}{[9b\gamma - 8\theta^2]} \quad (50)$$

and welfare is

³⁹ The results in (49) – (51) are equivalent to those of D'Aspremont & Jacquemin when $\beta = 1$.

$$W^c = \frac{2\gamma\alpha^2[18b\gamma - 8\theta^2]}{[9b\gamma - 8\theta^2]^2} \quad (51)$$

4.5 Unprofitable incumbents

If, given non-negative R&D and output levels by all three firms, the incumbents make a loss, they will not be active in the industry and the entrant will be a monopolist in the output market. In this case, the entrant's marginal production cost function is $c^e = A - \theta^e x^e$, where its R&D level is given by (32), which makes the incumbents unprofitable, or its monopoly R&D level. The entrant may not act as a R&D monopolist as it may then be profitable for the incumbents to produce positive output levels in the final stage. Also, the entrant may, given its R&D choice, choose its output based on three firms being active (see (26)) or its monopoly level, depending on which is most profitable.⁴⁰

If acting as a monopolist at the R&D stage is most profitable for the entrant, it invests in R&D until the marginal benefit of R&D equals its marginal cost, so its R&D level⁴¹ is

$$x^{eM} = \frac{\alpha\theta^e}{2b\gamma - \theta^{e2}} \quad (52)$$

that is independent of the spillover parameter. If being active is unprofitable for the incumbents, then given (52) and (26a), the entrant's profit is

$$\pi^{eM} = \frac{\gamma\alpha^2}{2[2b\gamma - \theta^{e2}]} \quad (53)$$

leading to welfare level

$$W^{eM} = \frac{\gamma\alpha^2[3b\gamma - \theta^{e2}]}{2[2b\gamma - \theta^{e2}]^2} \quad (54)$$

On the other hand, if the incumbents can profitably produce output given the entrant's monopoly R&D, the relevant output expressions are given by (29), with incumbent R&D levels equal to zero and the entrant's R&D given by (52).

5. Results

This section simulates the results of the previous section in order to compare the various scenarios described above. It is assumed that $\theta^e = \varepsilon\theta$, so that $\varepsilon \geq 0$ reflects the

⁴⁰ For the entrant, choosing its monopoly output may not be most profitable if its R&D choice is based on three firms being active.

⁴¹ In what follows, M denotes monopoly level of R&D, profits etc.

entrant's relative R&D efficiency. Also, the exogenous spillover parameter is assumed to be identical for each firm so that $\beta = \beta^e$ and relative *effective* spillovers depend only on ε .⁴²

For simulation purposes, α , b and θ are normalised to unity, while ε , β and γ are exogenous parameters.⁴³ Given this, it is possible to compare R&D, profit and welfare levels for all cases. To ensure comparison for an extensive range of spillover levels, all cases will be compared at a unit R&D cost of 3.⁴⁴ This section mostly considers the case of symmetric firms ($\varepsilon = 1$), though relative efficiency values that may be considered are $\varepsilon = 0.5$ and $\varepsilon = 1.5$.

In Figure 1, where $\varepsilon = 1$, the highest R&D at every spillover occurs when the incumbent firms form a RJV. Full information-sharing gives a greater incentive to undertake R&D, though this incentive is decreasing in the spillover due to the increasing benefit to the entrant. Despite all firms being symmetric, however, when $\beta \leq 0.1$, RJV formation implies that the entrant will choose not to undertake any R&D, possibly because entry is blockaded.⁴⁵ Even if entry is blockaded at these spillovers, the incumbents' R&D is decreasing in the spillover as it is more profitable for the incumbents to choose their R&D levels based on three firms being active in the industry rather than act as a duopoly.⁴⁶ When the entrant begins to invest in R&D, its R&D is initially increasing in the spillover as it attempts to overcome its information disadvantage in order to profit-shift from the incumbent firms, for whom its R&D is a strategic substitute. For relatively high spillovers, however, the entrant's R&D is decreasing in the spillover as it free-rides on the R&D of the incumbents. In the competitive R&D case, R&D levels are identical for all firms as determined in (32).

We also know from (32) that when the firms compete in R&D, the relatively more efficient firm(s) will undertake greater R&D investment. When the incumbents form a RJV, the threshold spillover at which the entrant begins to undertake R&D will be increasing in the relative inefficiency of the entrant (ε falls). The interesting question is what happens as the entrant becomes more efficient. Looking at Figure 2 where $\varepsilon = 1.5$, the outcome is quite different. When all firms compete in R&D, not only is the entrant's R&D higher but the incumbents will now choose not to undertake any R&D investment when $\beta \leq 0.1$ due to the entrant's efficiency advantage. Despite this, the entrant's most profitable action is to act as

⁴² In effect, for any level of R&D undertaken by a firm, a proportion β 'leaks out' to rival firms.

⁴³ As b and θ are normalised to unity, the relative effectiveness of R&D is equivalent to the inverse of unit R&D costs (γ).

⁴⁴ Looking at other values of admissible unit R&D costs does not have a major impact on the analysis.

⁴⁵ It will be possible to determine whether entry is blockaded or not when looking at profits.

⁴⁶ A standard assumption in output-setting games is that total industry profit prior to entry exceeds post-entry profit. If not, then one of the incumbent firms could split its operation into two and make greater profits. In this game, however, when R&D investment has a direct effect on output levels and where R&D spillovers are present, the relatively high R&D of the incumbents when R&D is chosen on the basis of three active firms gives them a competitive advantage over the entrant that makes entry unprofitable. Duopoly R&D levels, which are lower, would make entry more profitable and increase output market competition, thereby reducing the total profit of the incumbents.

though three firms are active, which explains why its R&D is decreasing in the spillover. When the incumbents invest in R&D, their R&D initially increases in the spillover, as they seek to shift profits from the relatively efficient entrant, but then decreases in the spillover at relatively high spillover levels, as the entrant's R&D becomes a strategic complement.

When the incumbents form a RJV, the entrant's relative efficiency is large enough to ensure that its R&D level is higher than that of the incumbents for all relevant spillovers.⁴⁷ Despite forming a RJV, the incumbents not only free-ride on each other but also have an incentive to free-ride on the relatively more efficient entrant. As the entrant becomes still more efficient, zero R&D investment is optimal for the incumbents over a greater range of relatively low spillovers when firms compete in R&D. RJV formation may also imply that there will be no incentive to undertake R&D if exogenous spillovers are relatively high, as the incumbents will just free-ride on the relatively large R&D investment of the entrant without incurring the associated R&D costs.

In Figure 3, where again $\varepsilon = 1$, profits are identical, and positive, for all spillovers when the firms compete in R&D. The interesting question, and the main one that this paper seeks to answer, is how the formation of a RJV will affect the profitability of entry. For low spillovers ($\beta \leq 0.1$), entry is not profitable for the entrant when the incumbents form a RJV so that RJV formation blockades entry, *even in the absence of fixed entry costs*. Consequently, the entrant will not undertake any R&D investment (see Figure 1). If fixed entry costs were positive, the threshold spillover at which entry becomes profitable would increase.⁴⁸

When entry is unprofitable due to RJV formation, it is in the incumbents' interest to choose R&D on the basis that entry is profitable rather than as a duopoly. Once entry becomes profitable, the incumbents' profits are decreasing in the spillover as the incentive to undertake R&D is decreasing as the spillover gain of the rival increases and all firms have a greater incentive to free-ride on each other's R&D. We know from (40) that when $\beta = 1$, the entrant's profits will exceed those of the incumbents. In Figure 3, this outcome also occurs if $\beta > 0.85$ (approx) as the entrant benefits from the incumbents' relatively large R&D (see Figure 1.1) without incurring equivalent R&D costs.

Another interesting finding is that when $\beta < 0.75$ (approx), the entrant's own profits are higher when competing in R&D, as there is no information-sharing between the incumbents, while for $\beta > 0.75$, its profits are higher when the incumbents form a RJV, given the spillover benefit of the incumbents' relatively high R&D and lower R&D costs.

⁴⁷ The R&D functions of the RJV case are not well-behaved when $\beta \leq 0.1$ and so are omitted from the analysis. Consequently, profit and welfare levels at these spillovers are excluded in future comparisons.

⁴⁸ It is also possible that, if such fixed costs are large enough, entry will also be unprofitable, particularly for low spillover levels, when the firms compete in R&D.

When the entrant is less efficient than the incumbents ($\varepsilon < 1$), RJV formation ensures that entry is unprofitable over a greater range of spillovers, even if entry is costless. Also, there is some $\varepsilon < 1$ at which incumbent profits are greater than the entrant's for all spillovers.

The interesting question is what happens as the entrant becomes relatively more efficient ($\varepsilon > 1$). In Figure 4, where $\varepsilon = 1.5$, profitable entry when the firms compete in R&D makes remaining in the industry unprofitable for the incumbents when $\beta \leq 0.1$ so that the entrant is an output market monopolist.⁴⁹ Consequently, the incumbents will not undertake any R&D at these spillovers (see Figure 2). As the market becomes profitable for the incumbents, the entrant's profits will, as expected, be lower and decreasing in the spillover.

RJV formation, on the other hand, gives some interesting results. For all relevant spillovers (see footnote 47), the entrant's profit exceeds those of the incumbents, in contrast to the symmetric case, where entrant profits were only greater for relatively high spillovers. Despite this, if fixed costs were positive, the entrant's total profits may not only imply that its profits are lower than those of the incumbents, but that RJV formation may again make entry unprofitable and the industry will remain a duopoly. In comparison to the symmetric case, the entrant's profits in the case of RJV formation now exceed its profits under R&D competition at a lower spillover level ($\beta = 0.58$ approx) due to its greater efficiency. In each case, it is in the interests of the incumbents to form a RJV as profits are higher.

When all output is exported, welfare is simply the sum of total industry profits. Looking first at the case of symmetric firms in Figure 5, we see that for all spillovers, welfare is highest when the incumbent firms form a RJV as, compared to the competitive case, the higher profits of the incumbents offset, when required, the lower profits of the entrant. Given this, any R&D policy of the domestic government should encourage RJV formation. For relatively high spillovers ($\beta \geq 0.75$ approx.), both the entrant and incumbents make greater profits than in the competitive R&D case (see Figure 3). The interesting outcome is that welfare is highest when $\beta = 0$ as entry is blockaded (see Figure 3). As welfare is the sum of total industry profits, and such profits are highest when there are only two firms in the industry, blockaded entry thus gives the highest welfare level. As entry becomes profitable, greater output market rivalry will initially reduce total industry profits so that welfare is reduced. Consequently, the greater the barriers to entry into this market, the less likely that entry will be profitable and the higher will be welfare. From a policy perspective, therefore, the more that any particular industry in an economy depends on exports for its viability, the more stringent should a regulatory authority's licensing system be.⁵⁰ When $\beta \geq 0.3$, welfare in

⁴⁹ It is more profitable for the entrant to choose its output based on three active firms rather than as a monopolist given its R&D choice. This is similar to the point made in footnote 46.

⁵⁰ Of course, such a conclusion is only relevant if, as is assumed in the demand function, the consuming economy is unable to substitute for the good being produced by the incumbents.

the case of RJV formation is increasing as, from Figure 3, the entrant's variable profits are increasing at a greater rate than those of the incumbents are falling, given that its spillover disadvantage is decreasing and the incumbents fully share information within the RJV.

As the entrant becomes more efficient in Figure 6, where $\varepsilon = 1.5$, when $\beta \leq 0.3$, welfare is highest when all firms compete in R&D, with RJV formation leading to greater welfare for all other spillovers. For relatively low spillovers, R&D competition leads to either zero or very low profits for the incumbents (see Figure 4). Given the entrant's relative efficiency advantage, RJV formation will imply that the output market is relatively competitive so that total industry profits are lower. As spillovers increase, the entrant becomes better off when the incumbents form a RJV (see Figure 4) and this, combined with the fact that the incumbents will always prefer RJV formation, will increase total profits to an extent that welfare is highest when the incumbents form a RJV. Consequently, from a policy perspective, a government will only prefer to sanction RJV formation in this case when spillovers are sufficiently high.

If the producing economy also fully consumes the firms' output, welfare will now be affected by the level of consumer surplus. Again beginning with the symmetric case, in Figure 7, welfare is highest for all spillovers when the incumbent firms form a RJV. Despite the market remaining a duopoly when $\beta \leq 0.1$ (see Figure 3), the relatively high profits of the incumbents, given that they fully share information between them in a RJV, ensure that higher total industry profits (see Figure 5) will offset lower consumer surplus so that overall welfare is higher than when all firms compete in R&D. For all other spillovers, the higher total R&D of the firms when the incumbents form a RJV will imply that output is higher, and prices lower, thereby increasing consumer surplus. As well as that, total industry profits are higher (see Figure 5) so that overall welfare is also higher when the incumbents form a RJV.

As the entrant becomes more efficient, Figure 8 shows that when $\varepsilon = 1.5$, welfare is again highest for all relevant spillovers when the incumbents form a RJV. As the entrant continues to become more efficient, however, we would expect to see R&D competition become unprofitable for the incumbents over a greater range of relatively low spillovers so that the monopoly profits of the entrant may imply that welfare in the competitive R&D case comes to dominate that of the RJV case.

Consequently, from a policy perspective, it could be argued that as long as the entrant is not too efficient, RJV formation will increase welfare for all spillovers. On the other hand, if the entrant is much more efficient than the incumbents, RJV formation may actually be welfare reducing at relatively low spillovers.

6. Summary and Conclusions

This paper examines a one-shot game where two symmetric incumbent firms are faced with the possible, costless, entry of a firm into an homogenous good industry that is currently a Cournot duopoly. The incumbent firms are assumed to be symmetric, while the entrant may differ from the incumbents through the efficiency of R&D in reducing marginal production costs. Irrespective of the number of firms in the industry, all firms simultaneously choose their R&D and output levels, while firms always remain rivals at the output stage. All production takes place in one economy, while output may be consumed domestically or exported in its entirety to another economy.

The decision facing the incumbents is whether to remain competitive at the R&D stage or to form a RJV and fully share information. The interesting question is: if entry is profitable when all firms compete in R&D, will the formation of a RJV by the incumbents make entry unprofitable and prevent greater competition in the output market?

This paper has found that even if the entrant is as efficient as the incumbents and there are no fixed entry costs, RJV formation can make entry unprofitable for low exogenous spillover levels. The higher are fixed costs, the more likely that entry will be blockaded even if the entrant is relatively efficient. The effect of RJV formation may be to increase welfare relative to the competitive R&D case, even though there is less competition in the output market. The latter may be offset by lower output prices generated by higher R&D levels. On the other hand, if the entrant is relatively efficient, R&D competition may imply that remaining in the market is not viable for the incumbents and the entrant is a monopolist. Despite this, however, the incumbents will always prefer to form a RJV.

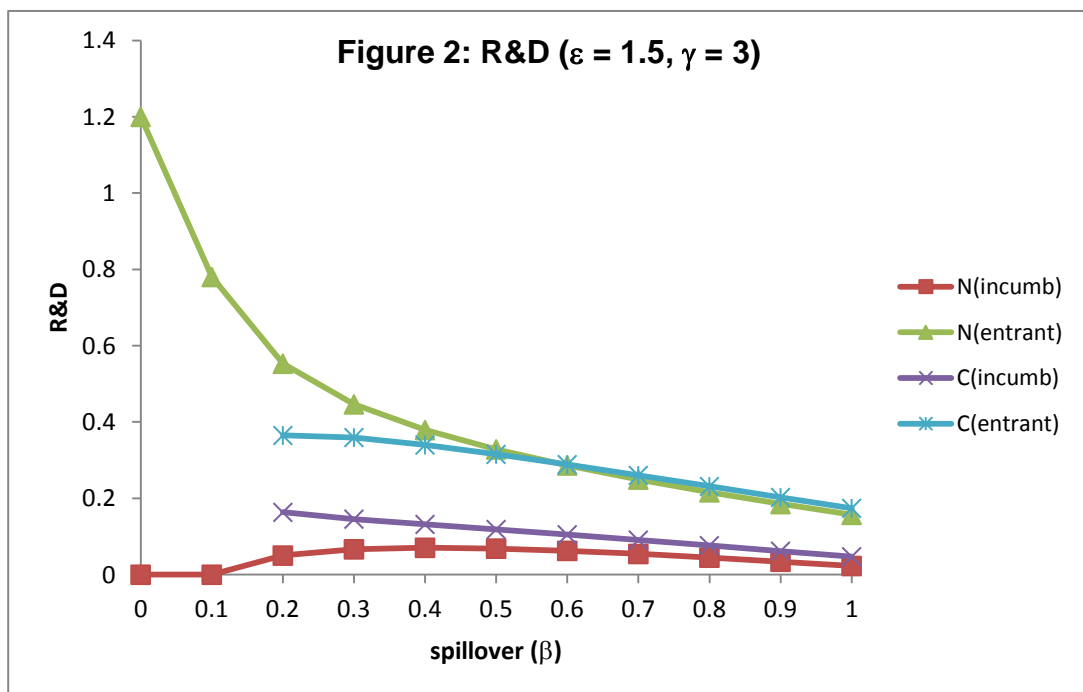
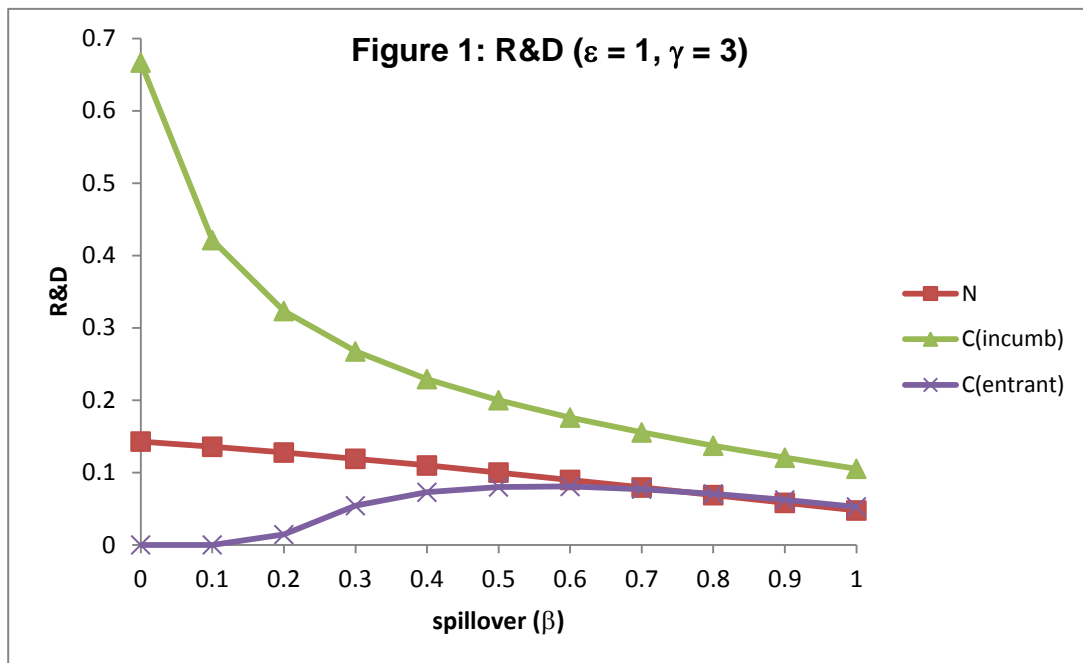
The welfare level of the producing economy will depend on whether output is exported in its entirety or consumed domestically. If exported, and if the entrant is not too efficient, welfare tends to be highest when the incumbents form a RJV and entry is blockaded. If, however, the entrant is efficient enough and spillovers are low, welfare will highest be when the firms compete in R&D as the entrant will be an output market monopolist. If output is consumed domestically, welfare will again tend to be higher when the incumbent firms form a RJV, though R&D competition may be welfare-dominant if spillovers are low and the entrant is sufficiently more efficient than the incumbents.

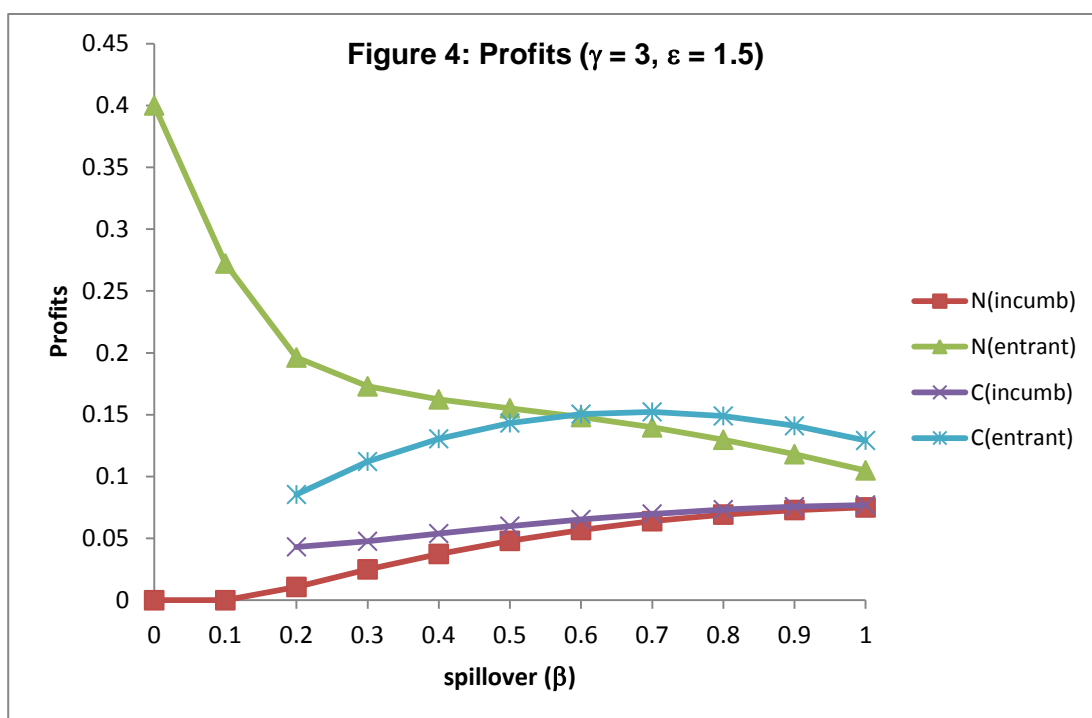
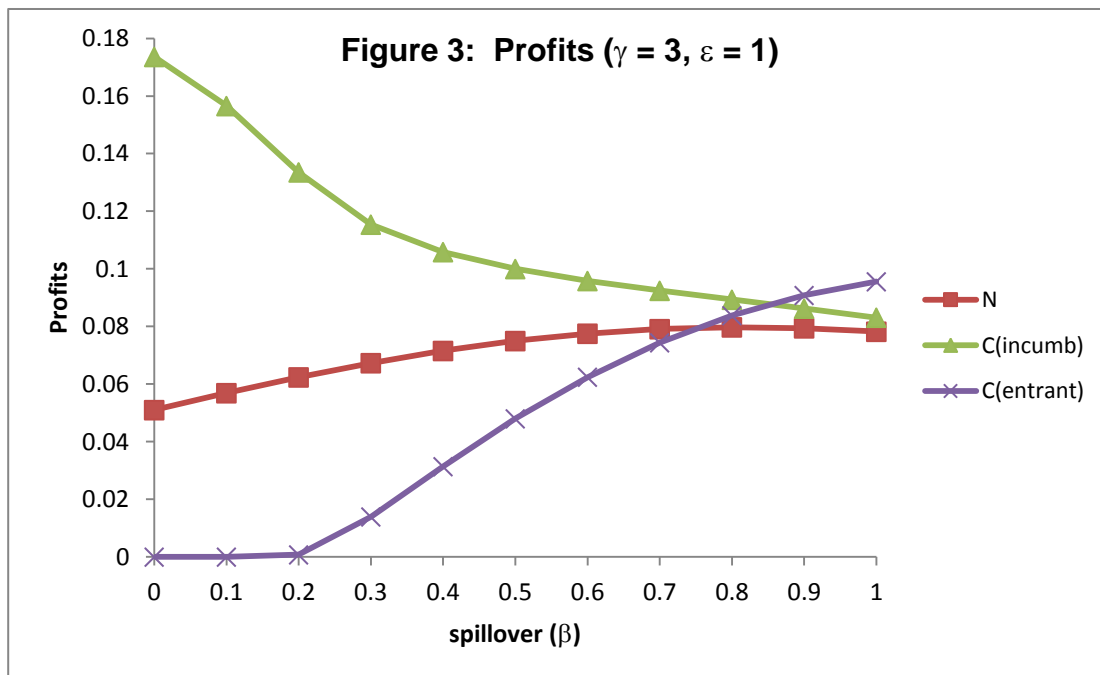
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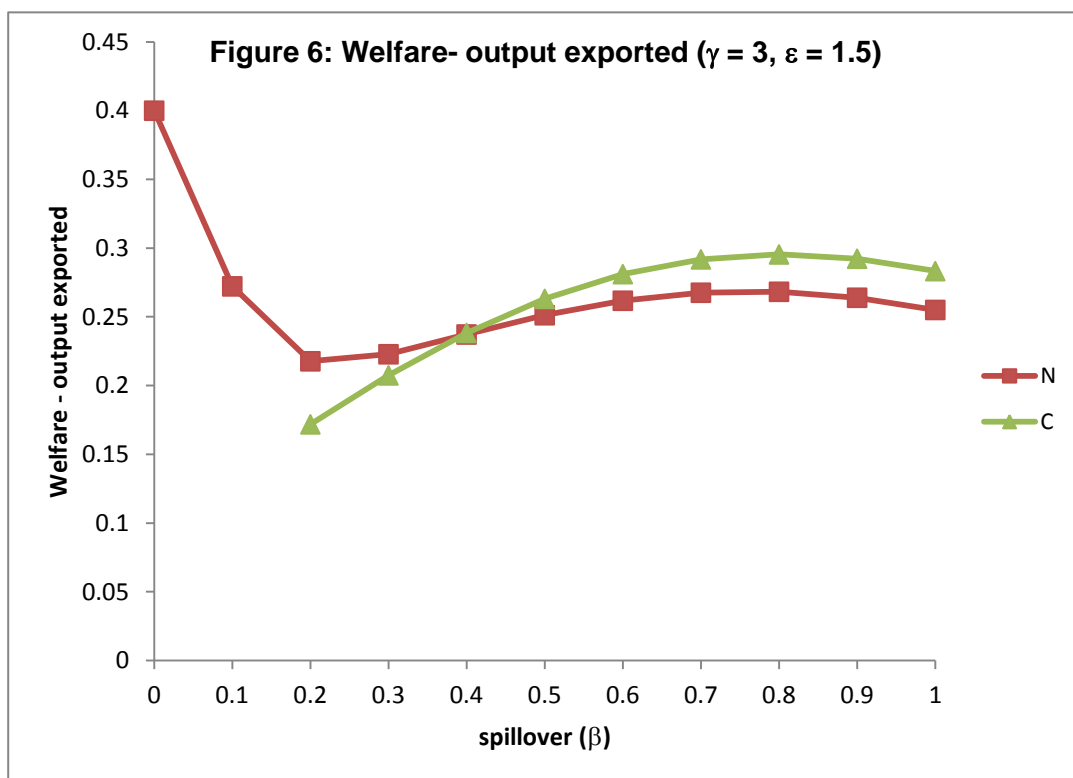
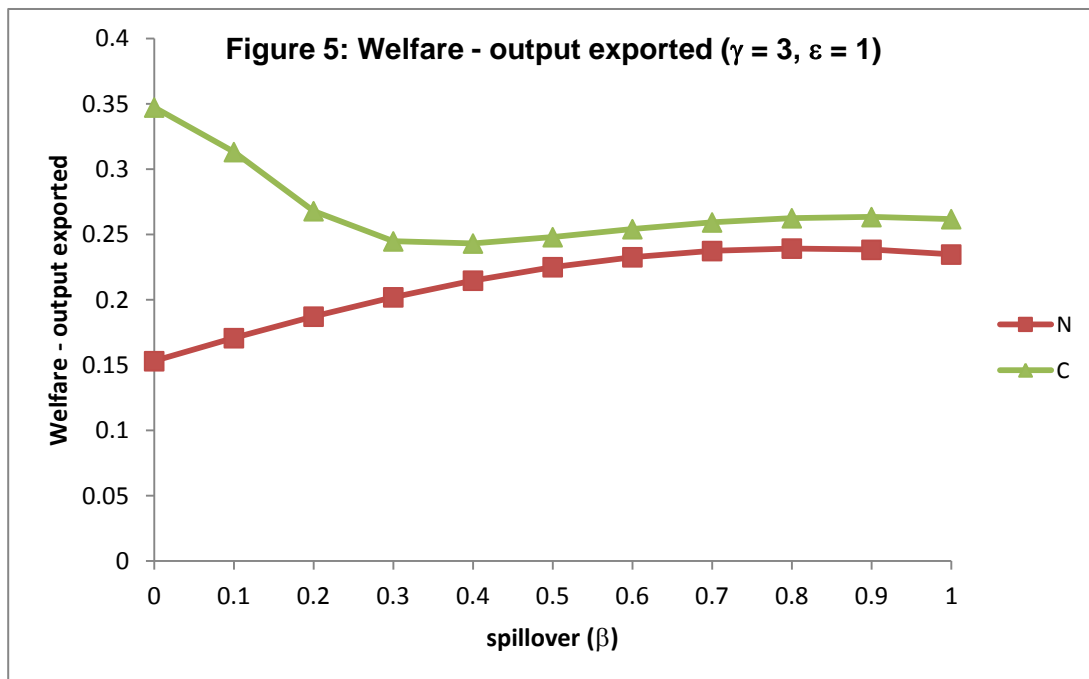
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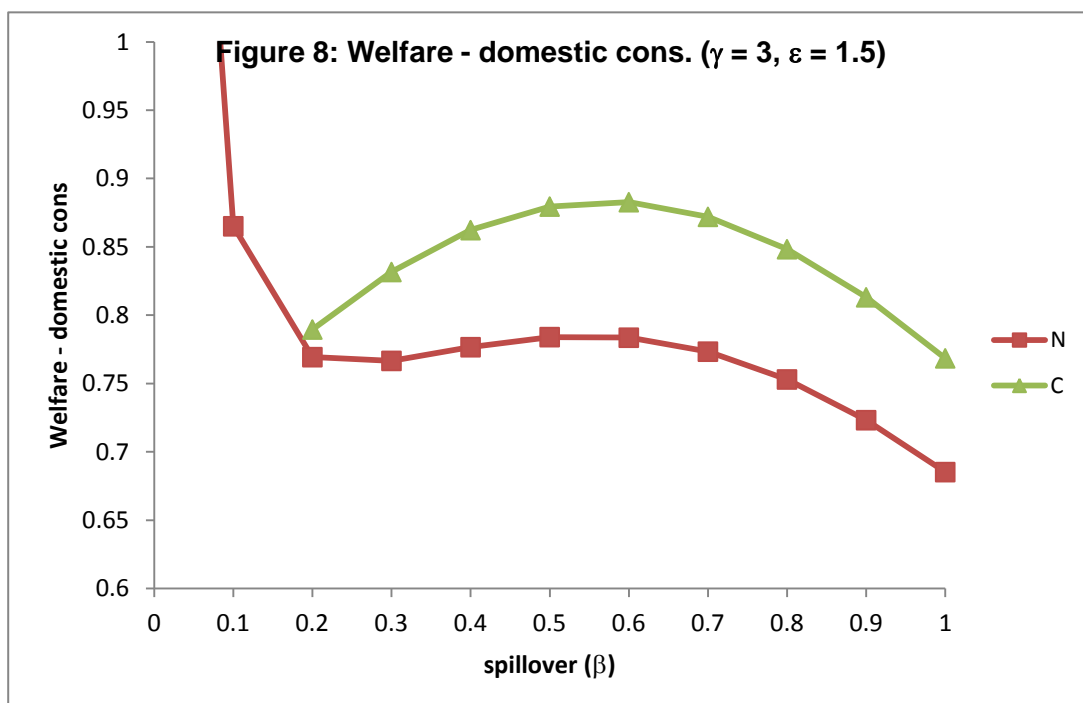
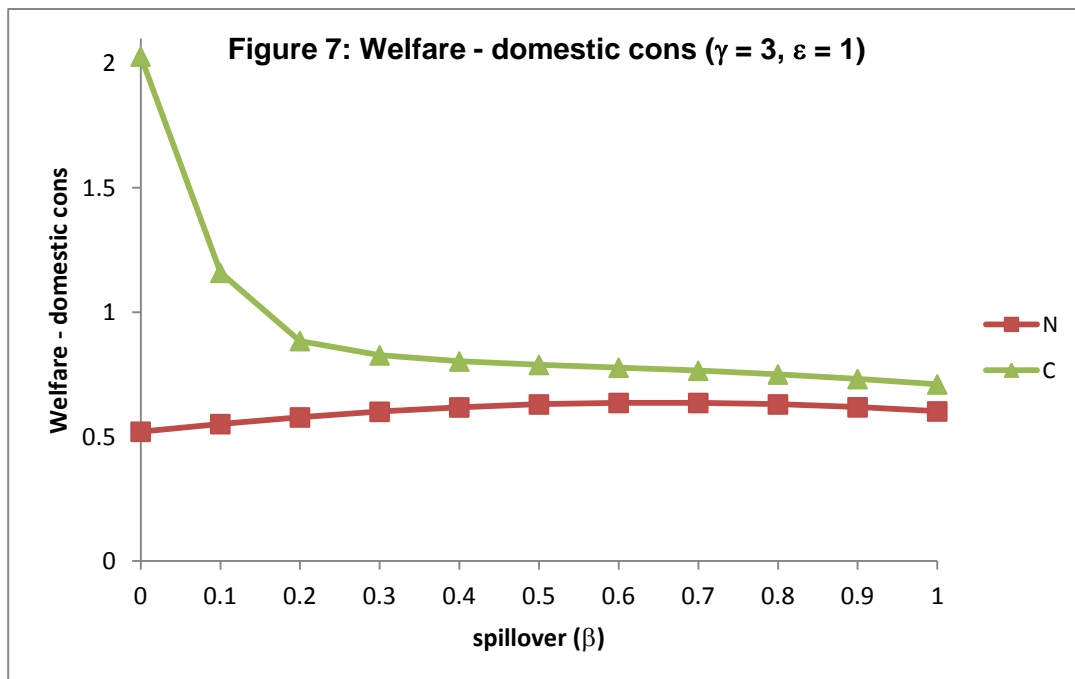
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APPENDIX

Profitable entry: R&D competition

From (12) and the relevant partial derivatives in (8), the incumbents will over (under) invest in R&D if

$$\frac{\theta \left(\frac{\pi_{qq^e}}{\pi_{qq}} + \phi \frac{\pi_{qq}}{\pi_{q^e q^e}} - 2\phi\psi \right) + \theta\beta \left(\frac{\pi_{q^e q^e}^e}{\pi_{q^e q^e}^e} - 1 \right) + \theta^e \beta^e \left(\psi - \frac{\pi_{qq}}{\pi_{q^e q^e}^e} \right)}{\Delta} < (>) 0 \quad (\text{A1.1})$$

where $\phi = \pi_{q^e q^e}^e / \pi_{qq} > 0$, $\psi = \pi_{qq} / \pi_{q^e q^e}^e > 0$ and $\Delta = \frac{|D|}{\pi_{qq} \pi_{q^e q^e}^e} < 0$, where $|D| < 0$ is the

determinant of the matrix of second derivatives on the left hand side of (8).⁵¹ As $\Delta < 0$ and

$\frac{\pi_{q^e q^e}^e}{\pi_{q^e q^e}^e} - 1 < 0$, the expression in (A.1) can be reduced to the condition that the incumbents will

over (under) invest in R&D if

$$\beta < (>) \frac{\theta \left(2\phi\psi - \frac{\pi_{qq^e}}{\pi_{qq}} - \phi \frac{\pi_{qq}}{\pi_{q^e q^e}^e} \right) - \theta^e \beta^e \left(\psi - \frac{\pi_{qq}}{\pi_{q^e q^e}^e} \right)}{\theta \left(\frac{\pi_{q^e q^e}^e}{\pi_{q^e q^e}^e} - 1 \right)} \equiv \bar{\beta}(\beta^e) \quad (\text{A1.2})$$

Given the expressions for own and cross-marginal profit effects (see footnotes 19 and 22), the expression in (A1.2) can be reduced to (13).

From (8) and (15), the entrant will over (under) invest in R&D if

$$\frac{(\theta\beta + \theta^* \beta^* - 2\psi\theta^e) \left[\frac{\pi_{qq^e}}{\pi_{qq}} - 1 \right]}{\Delta} < (>) 0 \quad (\text{A1.3})$$

Given $\Delta < 0$ and $\frac{\pi_{qq^e}}{\pi_{qq}} - 1 < 0$, the entrant will over (under) invest in R&D if

$$\beta < (>) \frac{\psi\theta^e}{\theta} \equiv \tilde{\beta} \quad (\text{A1.4})$$

that, given $\psi = \frac{\pi_{qq^e}}{\pi_{qq}}$ can be reduced to the condition in (16).

⁵¹ ϕ denotes the relative effect of incumbent output on the marginal profitability of entrant and incumbent output. On the other hand, ψ is the relative effect of entrant output on the marginal profitability of incumbent and entrant output.

If all firms are symmetric, ($\theta^e = \theta$ and $\beta = \beta^e$), then R&D and output levels, and hence market shares, are identical for each firm in a Cournot-Nash equilibrium so that $\sigma = \sigma^* = \sigma^e = 1/3$.⁵² Given the own and cross marginal profit effects, (8) can be expressed as

$$\begin{bmatrix} dq \\ dq^* \\ dq^e \end{bmatrix} = \frac{\theta}{3b(4+r)} \begin{bmatrix} 9+2r & -(3+r) & -(3+r) \\ -(3+r) & 9+2r & -(3+r) \\ -(3+r) & -(3+r) & 9+2r \end{bmatrix} \begin{bmatrix} 1 \\ \beta \\ \beta \end{bmatrix} dx + \begin{bmatrix} \beta \\ 1 \\ \beta \end{bmatrix} dx^* + \begin{bmatrix} \beta \\ \beta \\ 1 \end{bmatrix} dx^e \quad (\text{A1.5})$$

From (A1.5), (12) can be re-written as

$$\frac{d\pi}{dx} = \theta \left[\frac{6(3-2\beta) + r(5-2\beta)}{3(4+r)} \right] q - \Gamma'(x) = \mu^N q - \Gamma'(x) = 0 \quad (\text{A1.6})$$

R&D efficiency requires that $\mu^N = \theta$ so that firms will over (under) invest in R&D if

$$\beta < (>) \frac{r+3}{r+6} > 0 \quad (\text{A1.7})$$

In the linear demand case ($r = 0$), the firms will over (under) invest in R&D if $\beta < (>) 1/2$, which is consistent with the symmetric duopoly model of D'Aspremont and Jacquemin.⁵³

Profitable entry: RJV formation

Given (8) and (19), the incumbents will over (under) invest in R&D if

$$\frac{\theta \left[\frac{\pi_{qq^e}}{\pi_{qq}} - 1 + 2\phi \left(\frac{\pi_{qq} - \psi}{\pi_{q^e q^e}^e} \right) \right] + \theta^e \beta^e \left(\psi - \frac{\pi_{qq}}{\pi_{q^e q^e}^e} \right)}{\Delta} < (>) 0 \quad (\text{A1.8})$$

As $\Delta < 0$, this reduces to the condition of incumbent over (under) investment in R&D if

$$\beta^e < (>) \frac{\theta \left[\frac{\pi_{qq^e}}{\pi_{qq}} - 1 + 2\phi \left(\frac{\pi_{qq} - \psi}{\pi_{q^e q^e}^e} \right) \right]}{\theta^e \left[\frac{\pi_{qq}}{\pi_{q^e q^e}^e} - \psi \right]} \equiv \hat{\beta} \quad (\text{A1.9})$$

that, given the relevant second derivatives (see footnotes 19 and 22) can be simplified to the condition in (20).

⁵² Symmetry implies that own marginal profit effects are $\pi_{qq} = \pi_{q^* q^*}^* = \pi_{q^e q^e}^e = -b(2 + r/3) < 0$, while cross-effects are $\pi_{qq^*} = \pi_{q^* q}^* = \pi_{q^* q^e}^* = \pi_{q^e q}^e = \pi_{q^e q^*}^e = \pi_{q^e q^e}^e = -b(1 + r/3) < 0$.

⁵³ As we assume that $r > -1/\sigma$ to satisfy the second-order conditions, then given $\sigma = 1/3$, it must be the case that $r > -3$.