LESS IS MORE? RESEARCH JOINT VENTURES AND ENTRY DETERRENCE

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Abstract

This paper analyses the incentives of incumbent firms to form a first-mover RJV when faced with possible entry. If entry is accommodated, firms' relative profits under R&D competition and RJV formation depend on R&D spillovers and firms' R&D efficiency. RJV formation may make entry unprofitable if spillovers are sufficiently low. If entry is deterred, RJV formation may be more profitable. Similarly, whether accommodation or deterrence is more profitable under RJV formation depends on spillovers and the firms' efficiency. How welfare is affected by RJV formation depends on whether output is exported or domestically consumed. There may be a role for active government policy to affect market outcomes.

JEL Classification: D2, L2, L4

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1. Introduction

Innovation has long been recognised as essential in improving or maintaining the competitiveness of not just individual good and service providers, but also individual economies and economic regions. In attempting to implement the Lisbon Strategy and the Europe 2020 Strategy, innovation programmes like the EU Framework Programme for Research and Technological Development (FP7) and EUREKA were developed. A 'block exemption' for Joint Ventures from EU competition law was also introduced. Given the impact of globalisation and recent global economic difficulties, relatively well developed economies have emphasised the importance of their indigenous industries 'moving up the value chain' or entering the 'smart economy' by producing goods and services that require higher skills, greater investment in innovative activities and an increased competence in absorbing technological advances developed elsewhere.

One of the problems of the innovation process is that the knowledge gained may 'leak out' or 'spill over' to an innovator's rivals, who benefit from the innovator's effort without incurring similar costs, thereby reducing the private incentive to undertake R&D, as the benefits of innovation cannot be fully appropriated by the innovator. Other issues are that the outcome of any innovation process may be uncertain, the financial investment required may be relatively large and innovators are duplicating the efforts of their rivals, which is socially wasteful. Public solutions to overcome some of these problems include patents and R&D subsidies. A 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. As well as this, innovators can decide on the level of information sharing within the RJV, so that effective spillover levels are endogenous, and can also co-ordinate their innovation efforts to eliminate any possibility of duplication.

While RJV formation may overcome the inappropriability problem, it may be harmful in other ways. RJV's may be formed by a subset of firms to attain or increase a competitive advantage over non-RJV firms, leading to increased market power of RJV firms in their final market. Another problem is that co-operation at the innovation stage may be extended, implicitly, to the final output market. RJV's may also be used to prevent entry into an industry in order to maintain or increase existing levels of market power that would be reduced in the absence of RJV formation. This may be beneficial in terms of greater consumer welfare if increased innovation reduces marginal production costs and, consequently, final output prices. This, however, may be a short-run effect as, in the longer term, prices may be higher if potential entrants are faced with greater barriers to entry. Consequently, the social desirability of RJV formation depends on the net effect of these competing outcomes.

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, focuses 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* in R&D, by choosing their R&D levels to maximise own profits, or *co-operate* in R&D (form a RJV), by choosing their R&D to maximise the sum of joint profits. [1] In contrast, the firms remain rivals in the output market, in accordance with antitrust regulations.

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 where the final good is consumed. 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. At low spillovers, over-investment in R&D leads to greater output and higher consumer welfare that dominates the higher profits of RJV formation. At relatively high spillovers, RJV formation leads to lower prices and higher profits and, hence, is welfare-enhancing.[4]

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.[5] Despite the taxonomy of R&D organisation, their results are identical to those of D'Aspremont and Jacquemin.

Poyago-Theotoky (1995) looks at where a subset of firms forms a full information-sharing RJV. 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

[1] Earlier related papers include Dasgupta & Stiglitz (1980), Katz (1986) and Spence (1988). Several papers extend the D'Aspremont & Jacquemin framework without fundamentally adding to their analysis. Such papers include 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 ½ 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 level was not identical due to a different demand specification.

[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.

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 author 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 can increase both total industry profits and welfare. A convex R&D cost function implies that for any given level of total R&D investment, asymmetric investment will increase total R&D costs at the pre-output stage, but this will be offset by higher profits at the production stage so that overall profits and, consequently, welfare, will be higher, even in the case where there are no exogenous R&D spillovers.

One issue with the papers referred to above is that they look at where R&D decisions are taken simultaneously. 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 and that there is some degree of uncertainty with regard to either demand or rivals' marginal production costs.

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. Whether this happens will depend on the extent of fixed entry costs. 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 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.

While the existing literature concentrates on the formation of RJV's by all or a subset of existing firms in an industry, 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) which looks at where two incumbent firms undertake R&D to

[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.

gain a competitive advantage over an entrant that cannot undertake R&D. This advantage may ensure that entry is unprofitable. In contrast to the basic model of other papers, and also this paper, 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. Among them, 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. These findings lead them to argue that "…knowledge 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's motivation is that from a theoretical and policy perspective, a RJV where members fully share information between themselves, but not with non-members, may give them a competitive advantage to the extent that entry is prevented, despite it being profitable in the absence of a RJV. This will have the effect of preventing increased competition in the output market, possibly leading to antitrust considerations. While the total profit of the RJV members may increase relative to when they do not form a RJV, any negative impact on consumer surplus may imply that RJV formation at the pre-output stage leads to a decrease in welfare levels. Where this paper differs from those discussed above is that the incumbents can undertake their R&D investment *prior* to that of the entrant. This allows the incumbents to accommodate or deter the entrant through its R&D choice.

The structure of the paper is as follows: Section 2 describes the model while Section 3 looks at the incentives of the firms to undertake R&D investment in a general demand framework. Section 4 analyses the case of linear demand and quadratic R&D costs, while Section 5 simulates the linear demand model by imposing restrictions on the parameters of the model. Section 6 concludes.

2. The Model

This paper is concerned with the incentives of symmetric incumbent firms to form a research joint venture (RJV) when faced with the possible entry of a firm into an homogenous good industry, currently characterised by a Cournot duopoly. All active firms undertake process R&D, which is costly, and face identical convex R&D cost functions. As well as this,

[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.

there are exogenous spillovers of each firm's R&D to its rivals. The benefit of R&D is that it reduces marginal production costs, where the entrant's R&D efficiency can differ from that of the incumbents.[9] The incumbent firms can either compete in R&D by maximising their own profits, or co-operate in R&D by forming a RJV in which they maximise their joint profits and fully share information. In both cases, the incumbent firms compete in R&D with the entrant. In contrast to the innovation stage, all firms compete in the output market, in accordance with antitrust considerations. All production takes place in one economy, while output may be consumed domestically or exported in its entirety to another economy. All firms are assumed to be profit maximisers and have complete information with regard to demand, own and rival marginal production and R&D costs, spillovers, etc.

It is assumed that the incumbents choose their R&D levels *before* the entrant makes its entry decision and so can accommodate or deter entry. In the entry *accommodation* case, the incumbents choose their R&D levels to maximise own or joint profits. The entrant then derives its profit maximising R&D and output levels and enters the industry if it is profitable to do so. [10] If entry is not profitable in this case, it is said to be blockaded. In the *entry deterrence* case, however, the incumbent firms specifically set their R&D levels so that entry is unprofitable and the output market remains a duopoly. Given complete information, all firms determine own and rivals' profit levels before undertaking their own R&D. In all cases, the model is solved by backward induction. As each firm takes into account the effects of their actions in all stages of the game, the resulting equilibria are subgame perfect.

The main question of this paper relates to the *entry accommodation* case: if entry is profitable when the incumbent firms compete in R&D, will the formation of a full information-sharing RJV by the incumbents make entry unprofitable? If so, a RJV prevents greater 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 had been formed, though incumbent profits will be higher if entry is blockaded. Also, will incumbent profits always exceed those of the entrant or will there be a second-mover advantage? Another interesting question is whether entry deterrence leads to greater profit and/or welfare levels than entry accommodation. If welfare increases as a result of RJV formation, then greater industry concentration leads to higher welfare, i.e. less is more.

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[9] 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 traditional businesses of developing computer operating systems and hi-fi equipment, respectively.

[10] If entry does not occur, the output market remains a duopoly similar to that of D'Aspremont & Jacquemin (1988) though incumbent R&D investment may be undertaken on the basis of three firms in the market if this determines the unprofitability of entry. Duopoly R&D levels may make entry profitable, given that the entrant chooses its R&D after the incumbents. Also, producing output may be profitable for the entrant even if it does not undertake R&D, especially if spillovers are relatively high.

Given the assumption of complete information, each game played between the firms consists of three or four stages, depending on the entry decision of the potential entrant. Firstly, the incumbent firms decide to compete in R&D or commit to forming a RJV. In the second stage, the incumbents choose their R&D investment, with each incumbent firm taking the R&D of the other incumbent as given and the R&D reaction function of the entrant into account. Thirdly, if entry is profitable, the entrant chooses its own profit maximising R&D level, while in the fourth stage, all firms simultaneously choose their profit maximising output levels. On the other hand, if entry is not profitable, the incumbents simultaneously choose their profit maximising output levels in the third stage.

The inverse demand function faced by the firms, p(Q), has the following properties

$$p^{/}(Q) = -b \qquad \text{and} \qquad p^{//}(Q)Q/p^{/} \equiv r \tag{1}$$

where b is the slope of the inverse demand function (not necessarily constant) and r is a measure of the concavity of demand and industry output ($Q = q + q^* + q^e$) is the sum of active firms' outputs.[11] Direct R&D costs are $\Gamma(x)$, $\Gamma^*(x^*)$ and $\Gamma^e(x^e)$ for the incumbent and entrant firms, respectively, where x denotes R&D, $\Gamma^{/}(.) > 0$ and $\Gamma^{//}(.) > 0$. For simplicity, it is assumed that entry is costless.[12]

The benefits of R&D occur through the firms' marginal production cost functions that are assumed to be a linear function of own and rival R&D and have the following properties:

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

where θ, θ^* and $\theta^e > 0$ denote the effectiveness of R&D in reducing marginal production costs, and $0 \leq \beta, \beta^*, \beta^e \leq 1$ denote the exogenous spillover parameters, for respective firms. It then follows that $\theta\beta$, for example, is the *effective* spillover that the representative incumbent receives from its rivals.[13] When the incumbent firms form a RJV and fully share information, then $c_{x^*} = -\theta$ and $c^*_x = -\theta^*$.

Given R&D and output levels, the profit of the representative incumbent firm is

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

while the entrant's profit, in the absence of any fixed 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 total industry profits and is

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

[11] To differentiate among firms, the non-representative incumbent is denoted by * and the entrant by e.

[12] The emphasis in this paper is on the effect of RJV formation on entrant profitability, especially if entry is profitable in its absence. To isolate this effect, fixed entry costs are set to zero.

[13] Similarly, $\theta^*\beta^*$ and $\theta^e\beta^e$ are the effective spillovers of the other incumbent and entrant, respectively.

where ω(Q) is a measure of consumer surplus.[14]

Two scenarios are considered in both the entry accommodation and deterrence cases. In the *entry accommodation* case

(i) Game N: All firms *compete* in R&D. The incumbent firms choose their R&D to maximise their *own* profits, taking the rival incumbent's R&D as given and the entrant's R&D reaction function into account. The entrant then chooses its profit maximising R&D, given the incumbents' R&D.

(ii) Game C: The incumbent firms co-operate in R&D by forming a full information-sharing RJV, where each incumbent chooses its R&D to maximise the sum of *joint* profits, taking their RJV partner's R&D as given and the entrant's R&D reaction function into account. As in (i), the incumbents compete in R&D vis-à-vis the entrant and the entrant chooses its R&D to maximise its own profits, taking incumbent R&D as given.

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

In the entry *deterrence* game, the incumbent firms choose their R&D to ensure that entry is unprofitable. The incumbents take the entrant's R&D reaction function into account and, either competitively or co-operatively, choose their R&D to ensure that the entrant optimally chooses not to produce any output and, hence, does not enter the industry.

3. Output Production and R&D Investment incentives

3.1. Output stage

From (1) and (3), profit maximisation for the representative incumbent firm implies

$$\pi_q = p(Q) - c(x, x^*, x^e) - bq = \pi_q(q, q^*, q^e, x, x^*, x^e) = 0 \qquad \textbf{(6)}$$

Totally differentiating (6),

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

Similar conditions exist for the other firms, so that from (2), (6) and (7),

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

[14] If all output is exported, there is no consumer surplus and welfare is defined by total industry profit.

As the firms' outputs are homogenous, the matrix of second derivatives on the left hand side of (8) is negative-definite if demand is not 'too' convex.[15] If entry is unprofitable and the output market remains a duopoly, (8) is reduced to

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

3.2 Profitable Entry: Accommodation & R&D competition

In stage three, the entrant's profit maximising R&D condition, from (4), is

$$\frac{d\pi^e}{dx^e} = \underbrace{\frac{\partial \pi^e}{\partial x^e}}_{direct\,effect} + \underbrace{\frac{\partial \pi^e}{\partial q}\cdot\frac{\partial q}{\partial x^e} + \frac{\partial \pi^e}{\partial q^*}\cdot\frac{\partial q^*}{\partial x^e}}_{strategic\,output\,effects} = 0 \quad \textbf{(10)}$$

where the *direct* effect of R&D is the benefit of reduced variable production costs less the marginal cost of R&D. As the firms remain rivals in the output market, however, the *strategic* output effects of R&D may be non-zero. By strategically investing in R&D, a firm may not be maximising its profits at the R&D stage, but its investment increases output market profit to an extent that overall profit is higher.[16] Given (1), (4) and (6), (10) can be expressed as

$$\frac{d\pi^e}{dx^e} = \pi^e_{x^e} = \left[\theta^e - b\frac{\partial q}{\partial x^e} - b\frac{\partial q^*}{\partial x^e}\right] q^e - \Gamma^{e/}(x^e) = \mu^{eN} q^e - \Gamma^{e/}(x^e) = 0 \quad \textbf{(11)}$$

where μ^{eN} is the entrant's marginal return to R&D per unit of output.[17] Non-strategic R&D investment requires $\mu^{eN} = \theta^e$, so that given the relevant derivatives in (8), the entrant over (under) invests in R&D (see Appendix) if

$$\theta^e > (<) \frac{(\theta\beta + \theta^*\beta^*)(2+\sigma^e r)}{2+(1-\sigma^e)r} \equiv \overline{\theta^e} \quad \textbf{(12)}$$

As the entrant becomes relatively more efficient (θ^e increases and/or θ and θ^* decrease), the greater its incentive to over-invest in R&D to profit-shift from the relatively less efficient

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[15] From (1), (2) and (6), $\pi_{qq} = -b(2+\sigma r)$, $\pi^*_{q^*q^*} = -b(2+\sigma^* r)$ and $\pi^e_{q^eq^e} = -b(2+\sigma^e r)$, which must be negative to satisfy the firms' second-order conditions, where σ, σ^* and σ^e are the market shares of the respective firms. Similarly, $\pi_{qq^*} = \pi_{qq^e} = -b(1+\sigma r)$, $\pi^*_{q^*q} = \pi^*_{q^*q^e} = -b(1+\sigma^* r)$ and $\pi^e_{q^eq} = \pi^e_{q^eq^*} = -b(1+\sigma^e r)$, which are also negative given that outputs are homogenous. For each firm, the effects of own output on own marginal profitability must exceed the cross-effects. This is satisfied if $r > -1/\sigma$, $r > -1/\sigma^*$ and $r > -1/\sigma^e$.

[16] A firm may 'over-invest' in R&D to profit-shift from its rival if R&D is a strategic substitute, or under-invest in R&D to 'free-ride' rival R&D if R&D is a strategic complement. Over-investment in R&D refers to when the firms invest in R&D where the marginal private benefit of R&D is less than the marginal private cost. The reverse occurs when firms under-invest in R&D. A firm's R&D is a strategic substitute (complement) for rival R&D if an increase in a firm's R&D reduces (increases) the marginal profitability of rival R&D.

[17] The entrant's second-order R&D condition requires $\Gamma^{e//}(x^e) - \mu^{eN}\cdot\frac{dq^e(x, x^*, x^e)}{dx^e} - q^e\frac{d\mu^{eN}}{dx^e} > 0$.

incumbents to increase output market profits. Conversely, as the entrant becomes relatively less efficient, it free-rides on the R&D of the incumbent firms by under-investing in R&D. [18]

As the entrant chooses its R&D after incumbents, it is necessary to derive the entrant's R&D reaction function. Expressing (11) as a function of R&D levels and totally differentiating, the slope of the entrant's R&D reaction function can be derived (see Appendix). Unfortunately, given the non-linearity of the demand and R&D cost functions, no simple conclusions can be drawn from such an expression without imposing restrictions on the behavioural functions. This will be attempted in Section 4.

In stage two, each incumbent firm chooses its R&D to maximise its own profits, taking the R&D of the other incumbent firm and the entrant's R&D reaction function into account. The representative incumbent's profit maximising R&D condition is

$$\frac{d\pi}{dx}=\frac{\partial\pi}{\partial x}+\frac{\partial\pi}{\partial q^*}\cdot\frac{\partial q^*}{\partial x}+\frac{\partial\pi}{\partial q^e}\cdot\frac{\partial q^e}{\partial x}+\left[\frac{\partial\pi}{\partial x^e}+\frac{\partial\pi}{\partial q^*}\cdot\frac{\partial q^*}{\partial x^e}+\frac{\partial\pi}{\partial q^e}\cdot\frac{\partial q^e}{\partial x^e}\right]\frac{\partial x^e}{\partial x}=0 \qquad \textbf{(13)}$$

Given (1), (2) and (8), (13) can be re-written as

$$\frac{d\pi}{dx}=\pi_x=\left\{\theta-b\frac{\partial q^*}{\partial x}-b\frac{\partial q^e}{\partial x}+\left(\theta\beta-b\frac{\partial q^*}{\partial x}-b\frac{\partial q^e}{\partial x}\right)\frac{\partial x^e}{\partial x}\right\}q-\Gamma^{/}(x)=\mu^N q-\Gamma^{/}(x)=0 \qquad \textbf{(14)}$$

where μ^N is the incumbent's return to R&D per unit of output and non-strategic R&D investment requires $\mu^N = \theta$.[19] Given ex-post incumbent symmetry which implies that $\theta = \theta^*$ and $\beta = \beta^*$, R&D and output levels are also identical so that $\sigma = \sigma^*$.[20] Applying incumbent symmetry to (8) and the entrant's R&D reaction function, the R&D investment incentives of the incumbents can be determined (see Appendix). Again, however, given the non-linearity of the demand and R&D cost functions, no conclusions can be drawn from such conditions without imposing restrictions on the behavioural functions. This is attempted in Section 4.

3.3 Profitable Entry: Accommodation & RJV formation (R&D co-operation)

When the incumbents form a full information-sharing RJV, $c_{x^*}=-\theta$ and $c^*_x=-\theta^*$ so that the total differentials of the first-order output conditions in (8) are now

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[18] If demand is linear (r = 0), the entrant over (under) invests in R&D if $\theta^e > (<)\theta\beta+\theta^*\beta^*\equiv\bar{\theta}^e$. This is consistent with D'Aspremont and Jacquemin (1988) where all firms are symmetric so that $\beta = \beta^* = \beta^e$ and $\theta = \theta^* = \theta^e = 1$ and the firms over (under) invest in R&D when $\beta <$ (>) ½.

[19] The incumbents' second order condition requires $\Gamma^{//}(x)-\mu^N\cdot\frac{dq\left(x,x^*,x^e(x,x^*)\right)}{dx}-q\frac{d\mu^N}{dx}>0$.

[20] Ex-post symmetry implies that, from (8), $\frac{\partial q}{\partial x^e}=\frac{\partial q^*}{\partial x^e}$, $\frac{\partial q^e}{\partial x}=\frac{\partial q^e}{\partial x^*}$, $\frac{\partial q}{\partial x}=\frac{\partial q^*}{\partial x^*}$ and $\frac{\partial q^*}{\partial x}=\frac{\partial q}{\partial x^*}$. Also, $\pi_{qq}=\pi^*_{q^*q^*}=-b(2+\sigma r)$, $\pi_{qq^*}=\pi_{qq^e}=\pi^*_{q^*q}=\pi^*_{q^*q^*}=-b(1+\sigma r)$ and $\pi^e_{q^eq}=\pi^e_{q^eq^*}=-b(1+\sigma^e r)$.

$$\begin{bmatrix} \pi_{qq} & \pi_{qq^*} & \pi_{qq^e} \\ \pi^*_{q^*q} & \pi^*_{q^*q^*} & \pi^*_{q^*q^e} \\ \pi^e_{q^eq} & \pi^e_{q^eq^*} & \pi^e_{q^eq^e} \end{bmatrix} \begin{bmatrix} dq \\ dq^* \\ dq^e \end{bmatrix} = -\begin{bmatrix} \theta \\ \theta^* \\ \theta^e\beta^e \end{bmatrix} dx - \begin{bmatrix} \theta \\ \theta^* \\ \theta^e\beta^e \end{bmatrix} dx^* - \begin{bmatrix} \theta\beta \\ \theta^*\beta^* \\ \theta^e \end{bmatrix} dx^e \quad \textbf{(15)}$$

If entry is unprofitable for the entrant, the output market equilibrium is represented by

$$\begin{bmatrix} \pi_{qq} & \pi_{qq^*} \\ \pi^*_{q^*q} & \pi^*_{q^*q^*} \end{bmatrix} \begin{bmatrix} dq \\ dq^* \end{bmatrix} = -\begin{bmatrix} \theta \\ \theta^* \end{bmatrix} dx - \begin{bmatrix} \theta \\ \theta^* \end{bmatrix} dx^* \quad \textbf{(16)}$$

As the entrant remains in R&D competition with the incumbents, its R&D investment incentive is unchanged (see (12)).[21] The incumbents choose their R&D to maximise joint profits so that the representative incumbent's profit maximising R&D condition is

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

where the first term on the right hand side of (17) is given by (13). The marginal benefit of R&D is now the *sum* of reductions in RJV members' variable production costs. Ex-post incumbent symmetry implies that θ = θ* and β = β* so that incumbent R&D and output levels are identical (see footnote 21). Given (1) and (2), (17) can be re-written as

$$\frac{d(\pi+\pi^*)}{dx} = 2\left\{ \theta - b\frac{\partial q}{\partial x} - b\frac{\partial q^e}{\partial x} + \left(\theta\beta - b\frac{\partial q}{\partial x^e} - b\frac{\partial q^e}{\partial x^e} \right)\frac{\partial x^e}{\partial x} \right\} q - \Gamma^{/}(x) = \mu^C q - \Gamma^{/}(x) = 0 \quad \textbf{(18)}$$

Non-strategic R&D investment now requires $\mu^C = 2\theta$.[22] Again, an expression of the incumbents' R&D incentives can be derived (see Appendix), but the ability to draw any firm conclusions, given the non-linearity of demand and R&D cost functions, requires imposing particular functional forms on the behavioural functions. This will be attempted in Section 4.

3.4 Entry deterrence

The incumbents now choose their R&D to ensure entry is unprofitable.[23] Taking the other incumbent's R&D as given and the entrant's R&D reaction function into account, their R&D induces the entrant to not produce output so that the industry remains a duopoly.[24] In this case, there is no profit maximising R&D condition for the incumbents.[25]

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[21] The slope of the entrant's R&D reaction function with respect to the representative incumbent's R&D has an identical expression to the competitive R&D case (see Appendix), though the actual value of the slope differs due to the effect of full information sharing within the RJV.

[22] The incumbents' second-order condition R&D requires $\Gamma^{//}(x) - \mu^C \cdot \frac{dq(x,x^*,x^e(x,x^*))}{dx} - q\frac{d\mu^C}{dx} > 0$.

[23] The incumbent firms do not co-ordinate their R&D investment, but each incumbent chooses its entry deterring R&D investment given that the other incumbent will also choose its level.

[24] The incumbents do not choose their R&D to ensure that the entrant does not undertake any R&D, as it may still be profitable to enter the industry if effective spillovers are relatively high.

[25] While the main interest of this chapter is on the formation of a RJV when the incumbents accommodate entry, the entry deterrence case in the absence of fixed costs is included given the move

From the entrant's profit maximising output condition,

$$\frac{d\pi^e}{dq^e} = \pi^e_{q^e} = p - c^e + p^/(Q)q^e = 0 \Rightarrow q^e(x, x^*, x^e(x, x^*)) = -\frac{p(Q) - c^e}{p^/(Q)} \quad \textbf{(19)}$$

As the demand curve has a strictly negative slope, the incumbents deter entry by investing in R&D to ensure that the output price equals the marginal production cost of the entrant.[26] This condition holds for both R&D competition and RJV formation by the incumbents. By doing this, however, the incumbents may have to undertake such a large investment in R&D that the increased R&D expenditure more than offsets any increased profit from remaining a duopoly in the product market. In this case, the incumbent firms will prefer to accommodate entry.

Due to the difficulties associated with using non-linear demand and R&D cost functions, drawing firm conclusions about the firms' behaviour requires imposing certain functional forms on the behavioural functions. The remainder of this paper focuses on the effects of these restrictions.

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 the various models to enable comparison between them. The firms are assumed to face the linear inverse demand function

$$p(q,q^*,q^e) = a - bQ = a - b(q+q^*+q^e) \quad \textbf{(20)}$$

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

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

$$c^e(x,x^*,x^e) = A - \theta^e(\beta^e x + \beta^e x^* + x^e), \quad \textbf{(21)}$$

for the incumbent and entrant firms, respectively. It is assumed that a > A to ensure positive output levels. Finally, the firms' R&D cost functions are

$$\Gamma(x) = \gamma x^2/2, \quad \Gamma^*(x^*) = \gamma x^{*2}/2, \quad \text{and} \quad \Gamma^e(x^e) = \gamma x^{e2}/2 \quad \textbf{(22)}$$

for the respective firms, where $\gamma > 0$ is a measure of common unit R&D costs.[27] Profits and welfare expressions are as in (3), (4) and (5). From (20), consumer surplus is $\omega(Q) = bQ^2/2$.

order of the game. This is only likely to occur when R&D is a strategic substitute and R&D reaction functions are downward-sloping in R&D space. Costless entry implies that the incumbents' 'Stackelberg' R&D choice when accommodating entry will be lower than when deterring entry (see Dixit (1980) or Tirole (1988)). While the deterrence case increases R&D expenditure, this may be offset by higher output market profits so that total deterrence profits are higher. A more thorough analysis of entry deterrence in the presence of fixed costs is beyond the scope of this paper.

[26] In the absence of fixed costs, this is the lowest price that will deter entry. If fixed costs were strictly positive, price would only have to be driven down to average total cost to deter entry.

[27] This differs from Muniagurria and Singh (1997) where unit R&D costs differ because of learning between R&D stages. In this paper, however, the benefits of R&D spillovers accrue through lower

To distinguish between various games, competitive (non co-op) R&D is denoted by N, RJV formation (co-op R&D) by C, entry accommodation by A and deterred entry by D.[28] For example, CD refers to when the incumbent firms form a RJV and deter entry.

4.1 Output stage

When the incumbent firms accommodate entry, then irrespective of whether they compete in R&D or form a RJV, profit maximisation for the representative incumbent, from (3), (20), (21) and (22), implies

$$p - c - bq = 0 \Rightarrow 2bq + bq* + bq^e = a - c \qquad \textbf{(23)}$$

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

$$\begin{bmatrix} q \\ q* \\ q^e \end{bmatrix} = \frac{1}{4b}\begin{bmatrix} a - 3c + c* + c^e \\ a + c - 3c* + c^e \\ a + c + c* - 3c^e \end{bmatrix} \qquad \textbf{(24)}$$

that, given (21), are a linear function of own and rival R&D. If entry is not profitable, duopoly output levels are

$$\begin{bmatrix} q \\ q* \end{bmatrix} = \frac{1}{3b}\begin{bmatrix} a - 2c + c* \\ a + c - 2c* \end{bmatrix} \qquad \textbf{(25)}$$

Given the first-order conditions of all firms, then using (23) in (3), and similarly for the other firms, profit levels in both the entry accommodation and deterrence cases are

$$\begin{bmatrix} \pi \\ \pi * \\ \pi^e \end{bmatrix} = \begin{bmatrix} bq^2 - \frac{\gamma x^2}{2} \\ bq*^2 - \frac{\gamma x*^2}{2} \\ bq^{e2} - \frac{\gamma x^{e2}}{2} \end{bmatrix} \qquad \textbf{(26)}$$

where $\pi^e \leq 0$ implies that entry does not occur. Finally, given (20) and (26), welfare is

$$W = \frac{bQ^2}{2} + bq^2 - \frac{\gamma x^2}{2} + bq*^2 - \frac{\gamma x*^2}{2} + bq^{e2} - \frac{\gamma x^{e2}}{2} \qquad \textbf{(27)}$$

4.2 Profitable Entry: Accommodation & R&D competition (NA)

Using (21) in (24), each firm's output level can be expressed in terms of the R&D levels of all firms so that

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

[28] As entry is costless, entry deterrence is equivalent to preventing activity by a firm that has entered an industry by, for example, receiving an operating licence.

$$\begin{bmatrix} q \\ q^* \\ q^e \end{bmatrix} = \frac{1}{4b}\begin{bmatrix} \alpha + (3\theta - \theta^*\beta^* - \theta^e\beta^e)x + (3\theta\beta - \theta^* - \theta^e\beta^e)x^* + (3\theta\beta - \theta^*\beta^* - \theta^e)x^e \\ \alpha + (3\theta^*\beta^* - \theta - \theta^e\beta^e)x + (3\theta^* - \theta\beta - \theta^e\beta^e)x^* + (3\theta^*\beta^* - \theta\beta - \theta^e)x^e \\ \alpha + (3\theta^e\beta^e - \theta - \theta^*\beta^*)x + (3\theta^e\beta^e - \theta\beta - \theta^*)x^* + (3\theta^e - \theta\beta - \theta^*\beta^*)x^e \end{bmatrix} \quad \mathbf{(28)}$$

where $\alpha = a - A > 0$. The effect of a firm's R&D on output levels depends on both the firms' efficiency in reducing marginal production costs through R&D and effective R&D spillovers.

In stage three, the entrant's profit maximising R&D condition is given by (10). From (20), (21), (22) and (28), this can be reduced to

$$\frac{d\pi^e}{dx^e} = \left[\theta^e - b\left(\frac{3\theta\beta - \theta^*\beta^* - \theta^e}{4b}\right) - b\left(\frac{3\theta^*\beta^* - \theta\beta - \theta^e}{4b}\right)\right]q^e - \gamma x^e = \mu^{eN}q^e - \gamma x^e = 0 \quad \mathbf{(29)}$$

Given (21), non-strategic R&D investment requires $\mu^{eN} = \theta^e$ so the entrant over (under) invests in R&D if $\theta^e > (<) \theta\beta + \theta^*\beta^* = \bar{\theta}^e$.[29] From (29), entrant R&D can be expressed as

$$x^e = \left[\frac{3\theta^e - \theta\beta - \theta^*\beta^*}{2\gamma}\right]q^e \quad \mathbf{(30)}$$

Using the entrant's output from (28) in (30), the entrant's *R&D reaction function* is

$$x^e(x, x^*) = \frac{(3\theta^e - \theta\beta - \theta^*\beta^*)\left\{\alpha + (3\theta^e\beta^e - \theta - \theta^*\beta^*)x + (3\theta^e\beta^e - \theta\beta - \theta^*)x^*\right\}}{8b\gamma - (3\theta^e - \theta\beta - \theta^*\beta^*)^2} \geq 0 \quad \mathbf{(31)}$$

so that the representative incumbent's R&D is a strategic substitute (complement) for that of the entrant if $\left(3\theta^e - \theta\beta - \theta^*\beta^*\right)\left(3\theta^e\beta^e - \theta - \theta^*\beta^*\right) < (>) 0$.[30]

In stage two, the representative incumbent's first order R&D condition is given by (15). Given (20), (21), (22) and (31), (15) can be re-written as

$$\frac{d\pi}{dx} = \left\{ \begin{matrix} \theta - b\left[\dfrac{3\theta^*\beta^* - \theta - \theta^e\beta^e}{4b}\right] - b\left[\dfrac{3\theta^e\beta^e - \theta - \theta^*\beta^*}{4b}\right] \\ + \left[\theta\beta - b\left(\dfrac{3\theta^*\beta^* - \theta\beta - \theta^e}{4b}\right) - b\left(\dfrac{3\theta^e - \theta\beta - \theta^*\beta^*}{4b}\right)\right]\left[\dfrac{(3\theta^e - \theta\beta - \theta^*\beta^*)(3\theta^e\beta^e - \theta - \theta^*\beta^*)}{8b\gamma - (3\theta^e - \theta\beta - \theta^*\beta^*)^2}\right] \end{matrix} \right\} q - \gamma x = \mu^N q - \gamma x = 0$$

(32)

Non-strategic R&D investment requires $\mu^N = \theta$. Ex-post incumbent symmetry implies $\theta = \theta^*$ and $\beta = \beta^*$ so from (32), if $\beta < \frac{\theta - \theta^e\beta^e}{\theta}$, the incumbents over (under) invest in R&D when $b\gamma > (<) \frac{\theta(3\theta^e - 2\theta\beta)\left[\theta^e(1-2\beta) + 2\beta(\theta\beta - \theta^e\beta^e)\right]}{4[\theta(1-\beta) - \theta^e\beta^e]}$.[31] Conversely, if $\beta > \frac{\theta - \theta^e\beta^e}{\theta}$, the incumbents over (under) invest in R&D if $b\gamma < (>) \frac{\theta(3\theta^e - 2\theta\beta)\left[\theta^e(1-2\beta) + 2\beta(\theta\beta - \theta^e\beta^e)\right]}{4[\theta(1-\beta) - \theta^e\beta^e]}$.[32]

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[29] The intuition to this result is given in Section 3.2.

[30] From (29), the entrant's second-order R&D condition for requires $8b\gamma - (3\theta^e - \theta\beta - \theta^*\beta^*)^2 > 0$.

[31] Leahy and Neary (1996) define $\eta = \theta^2 / b\gamma$ as the relative effectiveness of R&D in that R&D is more effective at increasing profits as unit R&D costs (γ) decrease or as the firms become more efficient at reducing marginal production costs through R&D. It would be easy to include such a parameter here if

If firms are symmetric ($\theta^e = \theta$ and $\beta = \beta^e$) and $\beta < ½$, the incumbents over-invest in R&D for all unit R&D costs to profit-shift not only from the entrant, given their first-mover position, but also from each other given their output market rivalry. If $\beta > ½$, however, the incumbents under-invest in R&D as the incentive to free-ride on the R&D of other incumbent dominates any incentive to profit-shift from the entrant.[33] If $\theta^e \neq \theta$, the incumbents' incentives depend on their R&D efficiency, effective R&D spillovers and unit R&D costs.[34]

From (28), (31) and (32), the incumbents' R&D levels can be expressed

$$x = x^* = \left[\frac{\left[\theta(3-\beta) - \theta^e\beta^e\right]\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right] + (2\theta\beta - \theta^e)(3\theta^e - 2\theta\beta)[(3\theta^e\beta^e - \theta(1+\beta)]}{2\gamma\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right]}\right]q \qquad \textbf{(33)}$$

Substituting (30) and (33) into (28), and solving for output levels implies

$$\begin{bmatrix} q^{NA} \\ q^{eNA} \end{bmatrix} = \frac{2\alpha\gamma}{\Delta}\begin{bmatrix} [8b\gamma - (3\theta^e - 2\theta\beta)^2][8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)] \\ 8b\gamma[8b\gamma - (3\theta^e - 2\theta\beta)^2] + 4[2\theta^e\beta^e - \theta(1+\beta)]\left\{[\theta(3-\beta) - \theta^e\beta^e]\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right] + (2\theta\beta - \theta^e)(3\theta^e - 2\theta\beta)[(3\theta^e\beta^e - \theta(1+\beta)]\right\} \end{bmatrix} \qquad \textbf{(34)}$$

where

$$\Delta = [8b\gamma - (3\theta^e - 2\theta\beta)^2]\left\{\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right]\left[8b\gamma - 2[\theta(1+\beta) - \theta^e\beta^e[[\theta(3-\beta) - \theta^e\beta^e]\right] - 4(2\theta\beta - \theta^e\beta^e)(3\theta^e - 2\theta\beta)(2\theta - \theta^e\beta^e)\left[3\theta^e\beta^e - \theta(1+\beta)\right]\right\}$$
$$-2(2\theta\beta - \theta^e)^2(3\theta^e - 2\theta\beta)^2\left[3\theta^e\beta^e - \theta(1+\beta)\right]^2$$

Substituting the relevant output level from (34) into (30) and (33), R&D levels are

$$\begin{bmatrix} x^{NA} \\ x^{eNA} \end{bmatrix} = \frac{\alpha}{\Delta}\begin{bmatrix} [8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)]\left\{\left[\theta(3-\beta) - \theta^e\beta^e\right]\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right] + (2\theta\beta - \theta^e)(3\theta^e - 2\theta\beta)[(3\theta^e\beta^e - \theta(1+\beta)]\right\} \\ (3\theta^e - 2\theta\beta)\left\{\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right]\left[8b\gamma - 4\left[\theta(3-\beta) - \theta^e\beta^e\right][\theta(1+\beta) - \theta^e\beta^e]\right] - 4(2\theta\beta - \theta^e)(3\theta^e - 2\theta\beta)[(3\theta^e\beta^e - \theta(1+\beta)][\theta(1+\beta) - 2\theta^e\beta^e]\right\} \end{bmatrix} \qquad \textbf{(35)}$$

If all firms are symmetric ($\theta^e = \theta$, $\beta = \beta^e$), then $x^{NA}\binom{>}{=}x^{eNA}$ if $\beta\binom{\neq}{=}\frac{1}{2}\,\forall b\gamma$. As the incumbents are Stackelberg R&D leaders, their R&D choice occurs where their highest iso-profit curve is tangential to the entrant's R&D reaction function. When $\beta \neq ½$, the incumbents' R&D are either a strategic substitute (when $\beta < ½$) or strategic complement (when $\beta > ½$) for that of the entrant so that, given the slopes of the R&D reaction functions, the incumbents' R&D exceeds that of the entrant.[35] Conversely, when $\beta = ½$, R&D is neither a strategic substitute

all firms were symmetric. In this paper, 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.

[32] The incumbents' second-order R&D condition requires
$\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right]\left\{8b\gamma - [\theta(3-\beta) - \theta^e\beta^e]\right\} - (2\theta\beta - \theta^e)(3\theta^e - 2\theta\beta)[\theta(3-\beta) - \theta^e\beta^e][3\theta^e\beta^e - \theta(1+\beta)] > 0$

[33] In the symmetric case, the incumbents' second-order R&D condition requires
$\left[8b\gamma - \theta^2(3-2\beta)^2\right]^2 - \theta^4(2\beta-1)^2(3-2\beta)^2 > 0$ so the incumbents under-invest in R&D when $\beta > ½$.

[34] As the incumbents become relatively more efficient (θ and θ^* increase and/or θ^e decreases), the threshold spillover at which the incumbents switch from over-investing to under-investing in R&D is expected to increase as there is a greater incentive to use the first-mover advantage to profit-shift from a relatively more inefficient entrant than to free-ride on the other incumbent.

[35] The incumbents' R&D are strategic substitutes (complements) for the entrant's R&D if $(3\theta^e - 2\theta\beta)[3\theta^e\beta^e - \theta(1+\beta)] < (>) 0$, while, the entrant's R&D is a strategic substitute (complement) for incumbent R&D if $(2\theta\beta - \theta^e)\left\{\left[\theta(3-\beta) - \theta^e\beta^e\right]\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right] + (2\theta\beta - \theta^e)(3\theta^e - 2\theta\beta)\left[3\theta^e\beta^e - \theta(1+\beta)\right]\right\} < (>) 0$. In the symmetric case ($\theta^e = \theta$, $\beta = \beta^e$), if $\beta < ½$, the latter reduces to strategic substitute (complement)

nor strategic complement and all firms choose identical R&D levels. Comparing R&D levels when the incumbents and entrant are asymmetric ($\theta^e \neq \theta$) is difficult due to the number of variables, though it is conceivable that even if the entrant is relatively more efficient ($\theta^e > \theta$), its R&D level will still be less than that of the incumbents, particularly for relatively low spillovers, due to the latter's first-mover advantage.[36]

By substituting (34) and (35) into (26), profit levels are

$$\begin{bmatrix} \pi^{NA} \\ \pi^{eNA} \end{bmatrix} = \frac{\gamma\alpha^2}{2\Delta^2}\left[\frac{\left[8b\gamma - 4(3\theta^e - 2\theta\beta)(\theta^e - \theta\beta)\right]^2\left\{8b\gamma\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right]^2 - \left\{\left[\theta(3-\beta) - \theta^e\beta^e\right]\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right] + (2\theta\beta - \theta^e)(3\theta^e - 2\theta\beta)[3\theta^e\beta^e - \theta(1+\beta)]\right\}^2\right\}}{\left[\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right]\left\{\left[8b\gamma - (3\theta^e - 2\theta\beta)^2\right]\left[8b\gamma - 4[\theta(3-\beta) - \theta^e\beta^e][\theta(1+\beta) - 2\theta^e\beta^e]\right] - 4(2\theta\beta - \theta^e)(3\theta^e - 2\theta\beta)\left[3\theta^e\beta^e - \theta(1+\beta)\right]\left[\theta(1+\beta) - 2\theta^e\beta^e\right]\right\}\right]^2}\right] \qquad \textbf{(36)}$$

Again looking at the symmetric firm case ($\theta^e = \theta$ and $\beta = \beta^e$), it can be shown that

$$\pi^{NA} = \pi^{*NA} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \pi^{eNA} \text{ if } \psi \equiv 64b\gamma\theta^6(2\beta-1)^3(3-2\beta)\left\{16b^2\gamma^2 - \theta^2(3-2\beta)(15-14\beta)b\gamma + 2\theta^4(3-2\beta)(5-2\beta)(1-\beta)^2\right\} \begin{pmatrix} < \\ = \\ > \end{pmatrix} 0 \qquad \textbf{(37)}$$

If $\beta = ½$, profits are identical as R&D is neither a strategic substitute nor strategic complement. Given the second-order conditions, the {.} term in (37) is positive for all spillover parameters. When $\beta < ½$, incumbent profits exceed the entrant's as their higher R&D level and low spillover benefit to the entrant ensure that the incumbents' marginal production costs are lower. When $\beta > ½$, however, the entrant's profit exceeds that of the incumbents, as the entrant benefits to a large degree from the incumbents' R&D without incurring the higher R&D costs. While the entrant's marginal production costs may be higher than the incumbents', this is offset by lower R&D expenditure so that its profits are higher.

When $\theta^e \neq \theta$, the threshold effective spillover at which the second-mover advantage occurs is expected to be negatively related to entrant's relative efficiency. Even if $\theta^e\beta^e > \theta\beta$, however, the first-mover ability may ensure that incumbent profits are higher at relatively low spillover parameter values.

Substituting output levels in (34) and profits in (36) into (27), we can derive the welfare level. Unfortunately, given the relevant expressions, it is difficult to draw any conclusions about this welfare level, even when allowing firms to be symmetric. As the relevant variables are expressed in terms of θ, θ^e, β, β^e and γ, welfare levels can be simulated by imposing particular values on these parameters. This is attempted in the Section 5.

<u>4.3 Profitable entry: Accommodation & RJV formation (CA)</u>

A full information-sharing RJV implies $c_{x*} = -\theta$ and $c*_x = -\theta*$ so that from (21) and (24), output levels can be expressed as

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when $b\gamma > (<) \theta^2(1-\beta)$. Conversely, when $\beta > ½$, entrant R&D is a strategic substitute (complement) when $b\gamma < (>) \theta^2(1-\beta)$. Given the entrant's second-order R&D condition, $b\gamma > \theta^2(1-\beta)$ for all spillovers.

[36] A comparison is made in Section 5 when restrictions are imposed on the parameters of the model.

$$\begin{bmatrix} q \\ q^* \\ q^e \end{bmatrix} = \frac{1}{4b}\begin{bmatrix} \alpha + (3\theta - \theta^* - \theta^e\beta^e)x + (3\theta - \theta^* - \theta^e\beta^e)x^* + (3\theta\beta - \theta^*\beta^* - \theta^e)x^e \\ \alpha + (3\theta^* - \theta - \theta^e\beta^e)x + (3\theta^* - \theta - \theta^e\beta^e)x^* + (3\theta^*\beta^* - \theta\beta - \theta^e)x^e \\ \alpha + (3\theta^e\beta^e - \theta - \theta^*)x + (3\theta^e\beta^e - \theta - \theta^*)x^* + (3\theta^e - \theta\beta - \theta^*\beta^*)x^e \end{bmatrix} \quad \textbf{(38)}$$

The entrant's profit maximising R&D condition and R&D expression are given by (10) and (30), respectively. Substituting the entrant's output level from (38) into (30), the entrant's R&D reaction function is

$$x^e(x, x^*) = \frac{(3\theta^e - \theta\beta - \theta^*\beta^*)[\alpha + (3\theta^e\beta^e - \theta - \theta^*)x + (3\theta^e\beta^e - \theta - \theta^*)x^*]}{8b\gamma - (3\theta^e - \theta\beta - \theta^*\beta^*)^2} \quad \textbf{(39)}$$

so that incumbent R&D is a strategic substitute (complement) for entrant R&D if $(3\theta^e - \theta\beta - \theta^*\beta^*)(3\theta^e\beta^e - \theta - \theta^*) < (>) 0$.[37] If all firms are symmetric ($\theta = \theta^* = \theta^e$ and $\beta = \beta^* = \beta^e$), this reduces to strategic substitutes (complements) when $\beta < (>)\ 2/3$, that contrasts with a threshold spillover of ½ when all firms compete in R&D due to full information-sharing within the RJV giving the RJV firms a competitive advantage over the entrant.[38] As in the competitive R&D case, the entrant over (under) invests in R&D when $\theta^e > (<) \theta\beta + \theta^*\beta^* = \overline{\theta}^e$ as it competes in R&D vis-à-vis the incumbents.[39]

The representative incumbent's profit maximising R&D condition is given by (17).[40] Ex-post incumbent symmetry implies $\theta = \theta^*$ and $\beta = \beta^*$ so that that $q = q^*$. Given this, then from (20), (21), (22), (38) and (39), (17) can be expressed as

$$\frac{d(\pi + \pi^*)}{dx} = 2\left\{\theta - b\left[\frac{2\theta - \theta^e\beta^e}{4b}\right] - b\left[\frac{3\theta^e\beta^e - 2\theta}{4b}\right] - \left[\theta\beta - b\left(\frac{2\theta\beta - \theta^e}{4b}\right) - b\left(\frac{3\theta^e - 2\theta\beta}{4b}\right)\right]\left[\frac{(3\theta^e - 2\theta\beta)(3\theta^e\beta^e - 2\theta)}{8b\gamma - (3\theta^e - 2\theta\beta)^2}\right]\right\}q - \Gamma'(x)$$

$$= \mu^C q - \gamma x = 0 \quad \textbf{(40)}$$

Non-strategic R&D investment requires $\mu^C = 2\theta$, so the incumbents over (under) invest in R&D if $b\gamma < (>) \frac{\theta(3\theta^e - 2\theta\beta)[2\theta^e\beta\beta^e + (\theta^e - 2\theta\beta)]}{4\theta^e\beta^e}$.[41] If $\beta^e = 0$, the incumbents over-invest for all R&D costs to profit-shift from the entrant. If all firms are symmetric ($\theta = \theta^e$ and $\beta = \beta^e$) and $0 < \beta < ½$, the incumbents under-invest in R&D to free-ride on the R&D of the RJV partner, except if $b\gamma < \frac{\theta^2(3 - 2\beta)[2\beta^2 - 2\beta + 1]}{4\beta}$ at which they over-invest in R&D, due to relatively low unit R&D costs, to profit-shift from the entrant. When $\beta \geq ½$, the incumbents always under-invest in R&D. Though incumbent R&D is a strategic substitute for the entrant R&D when $\beta < 2/3$, each incumbent's R&D is a strategic complement for its RJV partner's

[37] The entrant's second-order condition for R&D requires $8b\gamma - (3\theta^e - \theta\beta - \theta^*\beta^*)^2 > 0$.

[38] A similar point was made by Poyago-Theotoky (1995).

[39] The intuition to this result is given in Section 3.2.

[40] The incumbents' second-order condition requires
$[8b\gamma - (3\theta^e - 2\theta\beta)^2][8b\gamma - 2(2\theta - \theta^e\beta^e)^2] - 2(2\theta - \theta^e\beta^e)(2\theta\beta - \theta^e)(3\theta^e - 2\theta\beta)(3\theta^e\beta^e - 2\theta) > 0$

[41] Given incumbent symmetry and full information-sharing within the RJV, $\frac{\partial(\pi + \pi^*)}{\partial x} = \theta + \theta^* = 2\theta$.

R&D for all spillovers.[42] When ½ < β < 2/3, free-riding on RJV partner R&D dominates profit-shifting from the entrant and the incumbents under-invest in R&D.

Substituting the incumbent's output expression in (38) into (40),

$$x = 2\left\{\frac{(2\theta-\theta^e\beta^e)[8b\gamma-(3\theta^e-2\theta\beta)^2]+(2\theta\beta-\theta^e)(3\theta^e-2\theta\beta)(3\theta^e\beta^e-2\theta)}{2\gamma[8b\gamma-(3\theta^e-2\theta\beta)^2]}\right\}q \quad \textbf{(41)}$$

Using (30) and (41) in (38), output levels are

$$\begin{bmatrix} q^{CA}=q^{*CA} \\ q^{eCA} \end{bmatrix} = \frac{2\alpha\gamma}{\Omega}\begin{bmatrix} [8b\gamma-(3\theta^e-2\theta\beta)^2][8b\gamma-4(3\theta^e-2\theta\beta)(\theta^e-\theta\beta)] \\ [8b\gamma-(3\theta^e-2\theta\beta)^2][8b\gamma-16(2\theta-\theta^e\beta^e)(\theta-\theta^e\beta^e)]-16(2\theta\beta-\theta^e)(3\theta^e-2\theta\beta)(3\theta^e\beta^e-2\theta)(\theta-\theta^e\beta^e) \end{bmatrix} \quad \textbf{(42)}$$

where $\Omega = 8b\gamma[8b\gamma-(3\theta^e-2\theta\beta)^2]^2 - 4\left\{(2\theta-\theta^e\beta^e)\left[8b\gamma-(3\theta^e-2\theta\beta)^2\right]+(2\theta\beta-\theta^e)(3\theta^e-2\theta\beta)(3\theta^e\beta^e-2\theta)\right\}^2$.

Using the relevant output levels from (42) in (30) and (41), R&D levels are

$$\begin{bmatrix} x^{CA}=x^{*CA} \\ x^{eCA} \end{bmatrix} = \frac{\alpha}{\Omega}\begin{bmatrix} [8b\gamma-4(3\theta^e-2\theta\beta)(\theta^e-\theta\beta)]\left\{2(2\theta-\theta^e\beta^e)[8b\gamma-(3\theta^e-2\theta\beta)^2]+2(2\theta\beta-\theta^e)(3\theta^e-2\theta\beta)(3\theta^e\beta^e-2\theta)\right\} \\ (3\theta^e-2\theta\beta)\left\{[8b\gamma-(3\theta^e-2\theta\beta)^2][8b\gamma-16(2\theta-\theta^e\beta^e)(\theta-\theta^e\beta^e)]-16(2\theta\beta-\theta^e)(3\theta^e-2\theta\beta)(3\theta^e\beta^e-2\theta)(\theta-\theta^e\beta^e)\right\} \end{bmatrix} \quad \textbf{(43)}$$

If all firms are symmetric ($\theta^e = \theta$ and $\beta = \beta^e$), then

$$x^{CA} = x^{*CA}\begin{pmatrix} > \\ = \\ < \end{pmatrix} x^{eCA} \text{ if } \phi \equiv 8b^2\gamma^2 + \theta^2(3-2\beta)\left(20\beta^2-36\beta+17\right)b\gamma - 4\theta^4(3-2\beta)^2(1-\beta)^2(1+\beta)\begin{pmatrix} > \\ = \\ < \end{pmatrix} 0 \quad \textbf{(44)}$$

that, given the second-order conditions, implies that incumbent R&D will exceeds entrant R&D, though the difference is decreasing in β for any level of unit R&D cost.

By substituting (42) and (43) into (26), the firms' profits are

$$\begin{bmatrix} \pi^{CA}=\pi^{*CA} \\ \pi^{eCA} \end{bmatrix} = \frac{\gamma\alpha^2}{2\Omega^2}\begin{bmatrix} \left[8b\gamma-4(3\theta^e-2\theta\beta)(\theta^e-\theta\beta)\right]^2\left\{8b\gamma\left[8b\gamma-(3\theta^e-2\theta\beta)^2\right]^2-4\left\{(2\theta-\theta^e\beta^e)\left[8b\gamma-(3\theta^e-2\theta\beta)^2\right]+(2\theta\beta-\theta^e)(3\theta^e-2\theta\beta)(3\theta^e\beta^e-2\theta)\right\}^2\right\} \\ \left[8b\gamma-(3\theta^e-2\theta\beta)^2\right]\left\{\left[8b\gamma-(3\theta^e-2\theta\beta)^2\right]\left[8b\gamma-16(2\theta-\theta^e\beta^e)(\theta-\theta^e\beta^e)\right]-16(2\theta\beta-\theta^e)(3\theta^e-2\theta\beta)(3\theta^e\beta^e-2\theta)(\theta-\theta^e\beta^e)\right\}^2 \end{bmatrix} \quad \textbf{(45)}$$

Using (45) and (42), welfare can again be derived in terms of θ, θ^e, β, β^e and γ. Again, it is difficult to draw any conclusions about profit and welfare levels, even if all firms are assumed to be symmetric.[43] To overcome this, certain values must be imposed on these parameters in order to make a comparison between the various games. This is attempted in Section 5.

<u>4.4 Entry deterrence</u>

To deter entry, incumbent R&D levels must induce the entrant to optimally choose not to produce any output.[44] Equilibrium output levels are then given by (25). As the entrant competes in R&D vis-à-vis the incumbents, its profit maximising R&D condition is again given by (10) and its R&D level in terms of output by (30).

[42] By substituting (39) into (38), the representative incumbent's R&D reaction function can be derived to show that each incumbent's R&D is a complement for its RJV partner's R&D for all spillovers.
[43] If $\pi^{eNA} > 0 > \pi^{eCA}$, RJV formation ensures that entry is *blockaded*.
[44] Each incumbent chooses its deterrence R&D level given that the other incumbent is also doing so.

4.4.1 R&D competition

From (28), the incumbents' R&D levels are chosen so that,

$$4bq^e = \alpha + (3\theta^e\beta^e - \theta - \theta^*\beta^*)x + (3\theta^e\beta^e - \theta\beta - \theta^*)x^* + (3\theta^e - \theta\beta - \theta^*\beta^*)x^e(x, x^*) = 0 \qquad \textbf{(46)}$$

Given ex-post incumbent symmetry and using (31) in (46), entry is deterred when the incumbents choose R&D levels

$$x^{ND} = x^{*ND} = \frac{\alpha}{2[\theta(1+\beta) - 3\theta^e\beta^e]} \qquad \textbf{(47)}$$

which are independent of unit R&D costs and only defined if $\theta^e\beta^e < \frac{\theta(1+\beta)}{3}$.[45] Given any effective spillovers, the incumbents undertake a fixed level of R&D to ensure that entry is unprofitable as output levels in (38) are not directly affected by unit R&D costs. Consequently, if the entrant does not produce any output, neither will it undertake any R&D and, given (38), the incumbents' R&D levels will not depend on unit R&D costs. When $\theta^e\beta^e > \frac{\theta(1+\beta)}{3}$, deterrence is not a viable option as incumbent R&D is a strategic complement for entrant R&D. As the entrant becomes relatively more efficient, the lower the effective spillover of the entrant at which deterrence is a viable option as greater amounts of R&D investment must be undertaken to ensure that entry is not profitable. Conversely, the incumbents' R&D is negatively related to their own effective R&D spillovers as their relative information advantage implies that lower R&D is required to deter entry. Substituting (47) into (31) ensures that the entrant optimally chooses a zero R&D level.

Given (47), profit maximising output levels in (25) are

$$q^{ND} = q^{*ND} = \frac{\alpha[\theta(1+\beta) - 2\theta^e\beta^e)]}{2b[\theta(1+\beta) - 3\theta^e\beta^e]} \geq 0, q^{eND} = 0 \qquad \textbf{(48)}$$

that are again independent of unit R&D costs. Substituting the relevant R&D and output levels from (47) and (48), respectively, into (26) implies that profit levels are

$$\pi^{ND} = \pi^{*ND} = \frac{\alpha^2\left\{2[\theta(1+\beta) - 2\theta^e\beta^e]^2 - b\gamma\right\}}{8b[\theta(1+\beta) - 3\theta^e\beta^e]^2}, \pi^{eND} = 0 \qquad \textbf{(49)}$$

where incumbent profits are negatively related to unit R&D costs. Using (48) and (49) in (27), welfare is

$$W^{ND} = \frac{\alpha^2\left\{4[\theta(1+\beta) - 2\theta^e\beta^e]^2 - b\gamma\right\}}{4b[\theta(1+\beta) - 3\theta^e\beta^e]^2}, \pi^e = 0 \qquad \textbf{(50)}$$

which is also negatively related to unit R&D costs.

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[45] This condition reduces to $\beta < ½$ when all firms are symmetric.

4.4.2 RJV formation (R&D co-operation)

From (38), the incumbents' R&D levels are now chosen so that

$$4bq^e = \alpha + (3\theta^e\beta^e - \theta - \theta^*)x + (3\theta^e\beta^e - \theta - \theta^*)x^* + (3\theta^e - \theta\beta - \theta^*\beta^*)x^e(x, x^*) = 0 \qquad \textbf{(51)}$$

Given (39) and ex-post incumbent symmetry, the incumbents choose R&D levels

$$x^{CD} = x^{*CD} = \frac{\alpha}{2(2\theta - 3\theta^e\beta^e)} \qquad \textbf{(52)}$$

that are again independent of the R&D costs and are now only defined when $\beta^e < \frac{2\theta}{3\theta^e}$.[46] As in the competitive R&D case, incumbent R&D is positively related to the entrant's effective spillover. Substituting (52) into (38) again induces the entrant to optimally choose zero R&D.

Given (52), profit maximising output levels in (25) are

$$q^{CD} = q^{*CD} = \frac{\alpha(\theta - \theta^e\beta^e)}{b(2\theta - 3\theta^e\beta^e)} \geq 0, q^e = 0 \qquad \textbf{(53)}$$

which are again independent of unit R&D costs. Given R&D levels and substituting the relevant output level from (53) into (26), profits are

$$\pi^{CD} = \pi^{*CD} = \frac{\alpha^2\left[8(\theta - \theta^e\beta^e)^2 - b\gamma\right]}{8b(2\theta - 3\theta^e\beta^e)^2}, \pi^e = 0 \qquad \textbf{(54)}$$

so that incumbent profits are again negatively related to unit R&D costs. Welfare levels can again be derived by substituting (53) and (54) into (27) so that

$$W^{CD} = \frac{\alpha^2\left[16(\theta - \theta^e\beta^e)^2 - b\gamma\right]}{4b(2\theta - 3\theta^e\beta^e)^2} \qquad \textbf{(55)}$$

4.4.3 R&D competition v RJV formation

Looking first at R&D levels in (47) and (52), it is the case that

$$x^{ND}\begin{pmatrix} > \\ = \end{pmatrix}x^{CD} \text{ if } \beta\begin{pmatrix} < \\ = \end{pmatrix}1 \qquad \textbf{(56)}$$

When all firms compete in R&D, the incumbents do not fully share information, except when exogenous spillovers are complete, and a higher level of R&D is therefore required to deter entry for any spillover. Full information-sharing within the RJV enables deterrence to be a viable option for a greater range of the entrant's effective spillover.

Comparing profit levels in (49) and (54), if $\beta^e < (>) \frac{\theta(3+\beta)}{6\theta^e}$, then

[46] This reduces to β < 2/3 when all firms are symmetric, compared to a threshold spillover of ½ when all firms compete in R&D. Incumbent R&D is now a strategic substitute the entrant R&D when β < 2/3 given full information-sharing within the RJV. This is similar to Poyago-Theotoky's (1995) result.

$$\pi^{CD}\begin{pmatrix} > \\ = \\ < \end{pmatrix}\pi^{ND} \text{ if } b\gamma\left(\begin{pmatrix} > \\ = \\ < \end{pmatrix}\begin{pmatrix} < \\ = \\ < \end{pmatrix}\right)\frac{2\theta^2(1+\beta)(2\theta-\theta^e\beta^e)-8\theta^e\beta^e[\theta(1+\beta)(4\theta-3\theta^e\beta^e)-\theta^e\beta^e(7\theta-6\theta^e\beta^e)]}{\theta(1-\beta)[6\theta^e\beta^e-\theta(3+\beta)]} \quad \textbf{(57)}$$

In the symmetric case ($\theta = \theta^e$ and $\beta = \beta^e$), a comparison can only be made when $\beta < ½$ so that the denominator in (57) is negative.[47] Given this, it can be shown that

$$\pi^{CD}\begin{pmatrix} > \\ = \\ < \end{pmatrix}\pi^{ND} \text{ if } b\gamma\begin{pmatrix} > \\ = \\ < \end{pmatrix}\frac{2\theta^2\beta(1-\beta)(4-7\beta)}{(3-5\beta)} \quad \textbf{(58)}$$

which, given the second-order conditions, imply that entry deterrence is more profitable for the incumbent firms when they form a RJV due to the lower R&D expenditure required to deter entry when RJV members fully share information sharing between themselves. To determine which action is more profitable when $\theta \neq \theta^e$ requires imposing restrictions on the parameters of the model. This is attempted in Section 5.

If the profits from entry deterrence are positive, they must be compared to those from accommodating entry as the higher R&D costs required to deter entry may offset any increased profits from remaining a duopolist in the output market. To determine the incumbents' action requires simulation of the above models. This is attempted in Section 5.

4.5 Blockaded entry

If, given non-negative R&D and output levels by the three firms, entrant profits are non-positive, entry is *blockaded* and the output market remains a duopoly. This, however, does not imply that the incumbents act as if the R&D market is also 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. Given complete information, it may be more profitable for the incumbent firms to invest in R&D on the basis of three firms in the output market, as it is these R&D levels that can blockade entry. If this is the case, the incumbents can choose duopoly output levels in (25) based on these R&D levels, or output levels in (28) with zero entrant R&D, depending on which is more profitable.

On the other hand, it may be more profitable for the incumbents to act as a duopoly in the R&D stage, even if this ensures that entry is profitable and the entrant undertakes R&D, leading to the output expressions in (28) being relevant. If such R&D levels still make entry unprofitable, the incumbents again choose duopoly output levels in (25).

The important question is how this affects welfare, particularly if RJV formation makes entry unprofitable when it was profitable under R&D competition. To enable

[47] R&D levels are only defined for $\beta < ½$ when all firms are symmetric and compete in R&D.

comparison with where only two firms are active at all stages, the main results of the D'Aspremont and Jacquemin paper are presented below.

4.5.1 R&D competition

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

$$\mathrm{x}^{\mathrm{N}} = \mathrm{x}^{*\mathrm{N}} = \frac{2\alpha\theta(2-\beta)}{9\mathrm{b}\gamma - 2\theta^2(2-\beta)(1+\beta)} \qquad \textbf{(59)}$$

while profits are

$$\pi^{\mathrm{N}} = \pi^{*\mathrm{N}} = \frac{\gamma\alpha^2\left[9\mathrm{b}\gamma - 2\theta^2(2-\beta)^2\right]}{\left[9\mathrm{b}\gamma - 2\theta^2(2-\beta)(1+\beta)\right]^2} \qquad \textbf{(60)}$$

and welfare is

$$\mathrm{W}^{\mathrm{N}} = \frac{2\gamma\alpha^2\left[18\mathrm{b}\gamma - 2\theta^2(2-\beta)^2\right]}{\left[9\mathrm{b}\gamma - 2\theta^2(2-\beta)(1+\beta)\right]^2} \qquad \textbf{(61)}$$

4.5.2 RJV formation (R&D co-operation)

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

$$\mathrm{x}^{\mathrm{C}} = \mathrm{x}^{*\mathrm{C}} = \frac{4\alpha\theta}{9\mathrm{b}\gamma - 8\theta^2} \qquad \textbf{(62)}$$

which are independent of exogenous spillovers.[48] Given (62) and unprofitable entry, incumbent profits are

$$\pi^{\mathrm{C}} = \pi^{*\mathrm{C}} = \frac{\gamma\alpha^2}{\left[9\mathrm{b}\gamma - 8\theta^2\right]} \qquad \textbf{(63)}$$

and welfare is

$$\mathrm{W}^{\mathrm{C}} = \frac{2\gamma\alpha^2\left[18\mathrm{b}\gamma - 8\theta^2\right]}{\left[9\mathrm{b}\gamma - 8\theta^2\right]^2} \qquad \textbf{(64)}$$

4.6 Unprofitable incumbents

If profitable entry implies a loss for the incumbents, they may cease to be active in the market. In this case, the entrant will be an output market monopolist where its R&D decision may be based on having one or three active firms, depending on which is most profitable. In the output market, the entrant's marginal production cost function is

[48] The results in (62) – (64) are equivalent to D'Aspremont & Jacquemin when β = 1. Given no entry and full information-sharing, the incumbents do not care about R&D 'leakages' to non-RJV firms.

$c^e = A - \theta^e x^e$, where its R&D is either given by its best response to zero incumbent R&D in (31) or its monopoly R&D level. The entrant may not act as a R&D monopolist as, given this, it may be profitable for the incumbents to produce positive outputs in the final stage. Also, the entrant may, given its R&D choice, choose its output based on three firms being active, with zero incumbent R&D (see (28)), or its monopoly level, depending on the most profitable.[49]

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 level[50] is

$$x^{eM} = \frac{\alpha\theta^e}{2b\gamma - {\theta^e}^2} \qquad \textbf{(65)}$$

that is independent of the spillover parameter. Given (65), if being active is unprofitable for the incumbents, then given (65) and (26a), the entrant's profit is

$$\pi^{eM} = \frac{\gamma\alpha^2}{2\left[2b\gamma - {\theta^e}^2\right]} \qquad \textbf{(66)}$$

leading to welfare level

$$W^{eM} = \frac{\gamma\alpha^2\left[3b\gamma - {\theta^e}^2\right]}{2\left[2b\gamma - {\theta^e}^2\right]^2} \qquad \textbf{(67)}$$

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 (28), with incumbent R&D levels equal to zero and the entrant's R&D given by (65).

5. Results

To facilitate a comparison between the various cases, it is necessary to simulate the models by imposing restrictions on the parameters of the behavioural functions. It is assumed that the exogenous spillover parameter is identical for all firms so that $\beta = \beta^e$. It is also assumed that $\theta^e = \varepsilon\theta$ where $\varepsilon > 0$ denotes the entrant's relative R&D efficiency.[51] Furthermore, α, b and θ are normalised to unity, while β, ε and γ are exogenous variables.[52] In simulating the models, R&D, profit and welfare levels will be analysed for given levels of the entrant's relative efficiency (ε) and unit R&D costs (γ) as the spillover parameter varies between zero and one. To ensure comparison over most spillover levels, this section mostly

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

[50] In what follows, M denotes monopoly level of R&D, profits etc.

[51] This implies that the same proportion of each firm's R&D 'leaks out' to its rivals so that the effective spillover of each firm depends on its efficiency in reducing marginal production costs through R&D.

[52] By normalising b and θ to unity, the relative effectiveness of R&D is equivalent to the inverse of unit R&D costs. Also, $\theta = 1$ implies that the effective spillovers of the incumbent firms are identical to the exogenous spillover parameter β, while the entrant's effective spillover is $\varepsilon\beta$.

looks at symmetric firms ($\varepsilon = 1$) when unit R&D costs (γ) are 3, though cases of relative efficiency can be analysed by looking at situations where ε is 0.5 and 1.5.[53]

5.1 R&D: Entry Accommodation

When all firms are symmetric and compete in R&D, incumbent R&D exceeds that of the entrant for all spillovers, except when $\beta = ½$ where they are identical (see (35)). When the entrant is less efficient than the incumbents ($\varepsilon < 1$), incumbent R&D exceeds entrant R&D for all spillovers. The interesting question is what happens when the entrant is relatively more efficient? In this case, entrant R&D may be less than incumbent R&D when exogenous spillovers are relatively low and high. In the former, the incumbents will tend to over-invest in R&D which may imply higher R&D levels than the entrant. In the latter, the entrant may free-ride on the R&D of the incumbents so that its R&D level may be lower. Once a threshold level of relative efficiency is reached, the entrant's R&D exceeds that of the incumbents for all spillover levels. In Figure 1 where $\varepsilon = 1.5$, this threshold has already been attained.[54] When $\beta = 0.1$, the incumbents do not undertake R&D investment, possibly because producing positive output levels is unprofitable. On the other hand, all firms choose positive R&D levels if $\beta \geq 0.2$ that may reflect greater output market competition.[55]

When the incumbents form a RJV, their R&D exceeds the entrant's for all spillovers when the incumbents are at least as efficient (see (44)). When $\varepsilon = 1.5$ in Figure 2, the entrant's R&D is higher for all relevant spillovers, despite the incumbents' first-mover advantage and full information-sharing.[56] When $0.1 \leq \beta \leq 0.2$, it is more profitable for the incumbents to choose duopoly R&D levels, even if this makes entry profitable. At these effective spillovers, incumbent R&D is constant as they fully share information and R&D levels do not take account of another firm. On the other hand, entrant R&D increases in the spillover as it over-invests in R&D due to its greater efficiency and to overcome the RJV's information-sharing advantage. When $\beta \geq 0.3$, incumbent R&D is negatively related to the spillover level, suggesting that they increasingly free-ride on the relatively high R&D of the more efficient entrant, against whom they compete in R&D, as spillovers increase. Also, entrant R&D begins to decrease due to the increasing spillover gain to the incumbents.

5.2 R&D: Entry deterrence

[53] Varying unit R&D cost levels does not affect the general results as R&D, profit and welfare levels tend to decrease as unit R&D costs increase. When $\gamma = 3$, the functions are generally well-behaved.
[54] In Figure 1, there is no Nash equilibrium outcome at $\beta = 0$.
[55] This will become clearer when looking at profit levels. Also, it would be possible to determine the spillover at which the incumbents' R&D functions become positive by using a finer grid in Figure 1.
[56] When $\beta = 0$, one of the second-order conditions is not satisfied.

When the incumbents deter entry, R&D levels are higher under R&D competition, except when the exogenous spillover parameter is complete (see (56)).

5.3 R&D: Accommodation v deterrence

In Figure 3 where $\varepsilon = 1$, when $\beta < 0.5$, R&D is usually highest when all firms compete in R&D and the incumbents deter entry, as the lack of endogenous information sharing between incumbents implies that higher R&D is required to deter entry.[57] The exception is when $\beta = 0.1$ where R&D is highest when the incumbent firms form a RJV and accommodate entry, suggesting that entry is blockaded. It also suggests that deterring entry will be more profitable due to lower R&D costs. At this spillover, unit R&D costs are sufficiently low that the incumbents will over-invest in R&D to shift profits from the entrant given their first-mover and information advantages. Interestingly, when $\beta = 0$, incumbent R&D levels when forming a RJV and accommodating are much lower, possibly because it is most profitable for the incumbents to act as duopolists at this spillover level.

When $0.5 \leq \beta < 0.667$, R&D is highest when the incumbents form a RJV and deter entry, while if $\beta \geq 0.667$, R&D is only undertaken when the incumbents accommodate entry and is highest when they form a RJV.[58] By forming a RJV and fully sharing information, incumbent R&D is increased relative to the competitive R&D case for all spillovers when accommodating entry.

As the entrant becomes relatively more efficient, the R&D required to deter entry increases for any spillover for both the competitive R&D and RJV cases, while R&D in the accommodation cases should decrease. On the other hand, if the entrant is less efficient, it is likely that when the firms form a RJV, R&D in the accommodation case exceeds that of the deterrence case for a greater range of spillovers.

5.4 Profits: Entry accommodation

Looking first at the case of R&D competition, we know that when $\varepsilon = 1$, incumbent profits are higher when $\beta < ½$, while the entrant makes greater profits when $\beta > ½$. Extending this to the non-symmetric case in Figure 4, entrant profits are higher for all spillovers when $\varepsilon = 1.5$. Even though the incumbents choose their R&D before the entrant, the entrant's greater R&D level (see Figure 1) and its greater R&D efficiency enable it to earn higher profits.

[57] See page 12 for a description of the legend in Figure 3.
[58] In Figure 3, R&D levels in the deterrence cases approach infinity as spillovers approach the level at which R&D levels are not defined.

Interestingly, the entrant is an output market monopolist when $\beta = 0.1$ as the incumbents will make a loss when accommodating entry. This is consistent with no incumbent R&D at this spillover (see Figure 1). For the entrant, however, it is most profitable to choose its R&D based on its best response to no incumbent R&D when three firms are active, rather than act as an R&D monopolist. This higher R&D, combined with low spillovers, makes the incumbents unprofitable in the output market. When choosing output, it is more profitable for the entrant, given its R&D level, to choose its output based on three active firms. When $\beta \geq 0.2$, it is profitable for the incumbents to produce positive output levels and their profits increase in the spillover as they free-ride on the relatively high R&D of the entrant.[59, 60]

When the incumbent firms form a RJV, then in Figure 2.5 where $\varepsilon = 1$, entrant profits are higher when $\beta > 0.85$ (approx). This contrasts with a threshold spillover of ½ in the competitive R&D case due to full information-sharing within the RJV. An interesting outcome is that when $\beta = 0$, the incumbents are more profitable when they act as duopolists at the R&D stage. This leads to much lower R&D levels (see Figure 3), which are offset by higher marginal production costs that reduce output market profits, though the former effect dominates so that total profit is higher. In this case, entry is profitable as the relatively low R&D of the incumbents means that the entrant has less 'catching up' to do in terms of reducing marginal production costs.

When $0.1 \leq \beta \leq 0.2$, the incumbents are output market duopolists, though it is more profitable for the incumbents to choose their R&D and, given this, their output, on the basis of three active firms. The incumbents' information advantage and their relatively high R&D investment (see Figure 3) implies that the R&D expenditure required by the entrant to be competitive will be greater than their net revenue in the output market so that entry is blockaded, *even in the absence of fixed costs*.[61, 62]

As entry becomes profitable, incumbent profits are decreasing in the spillover as their information advantage decreases. On the other hand, the entrant's profits are increasing in the spillover as it free-rides on the relatively high R&D of the incumbents.

<u>5.5 Profits: Entry deterrence</u>

[59] Again, there is some threshold spillover at which it becomes profitable for the incumbents to produce positive output levels. This is consistent with the R&D functions in Figure 2.1.

[60] Given the results above, it is reasonable to suggest that that a threshold level of ε, less than unity, exists, below which the entrant will not make greater profits for any spillover. Conversely, when $1 < \varepsilon < 1.5$, there is some threshold level above which the entrant makes greater profits for all spillovers.

[61] This relates to discussion about R&D in Figure 3 where, when the incumbents formed a RJV, R&D in the accommodation case exceeded that of the deterrence case.

[62] When $\varepsilon < 1$, it is likely that entry will be unprofitable for greater spillover ranges and that the incumbents' profits will exceed those of the entrant for all spillover levels. Conversely, when $\varepsilon > 1$, it is less likely that entry will be blockaded and more likely that the entrant's profits will exceed those of the incumbents for greater spillover ranges.

When $\varepsilon = 1$, entry deterrence is more profitable under RJV formation than R&D competition due to the lower R&D costs required to deter entry (see (58)). Intuitively, the same result holds for $\varepsilon > 1$. On the other hand, when $\varepsilon = 0.5$, Figure 6 shows that the more profitable action depends on spillovers and unit R&D costs. As spillovers increase, the threshold level of unit R&D costs at which RJV formation is more profitable is increasing. When spillovers are complete, R&D levels are identical in both cases, so profits are also identical, irrespective of the entrant's relative efficiency.

When spillovers are relatively high and unit R&D costs relatively low, R&D competition is more profitable than RJV formation. While R&D expenditure is greater under R&D competition (see (56)), the benefits of higher R&D investment, in the form of lower marginal production costs, are large enough to imply higher profits. Once unit R&D costs exceed a particular threshold, however, the benefit of lower marginal production costs is not sufficient to offset the higher R&D expenditure required to deter entry and, consequently, RJV formation is more profitable. As spillovers decrease, the lower R&D expenditure required to deter entry when forming a RJV begins to dominate at lower unit R&D costs given the increasing information advantage of the incumbents.

5.6 Accommodate or deter?

In Figure 7, where $\varepsilon = 0.5$, forming a RJV and accommodating entry is the most profitable action for all spillovers. When $\beta \leq 0.3$, entry is blockaded due to the incumbents' first-mover advantage and full information-sharing, though the incumbents' most profitable R&D and, given this, output choice is based on three active firms. When deterring entry, the relative inefficiency of the entrant ensures that a relatively large R&D investment by the incumbents is not required, and such R&D levels are below those of accommodation. Consequently, the relatively high R&D investment of the accommodation case, though more expensive, reduces marginal production costs to such a degree that increased output market profits dominate the higher R&D costs.

As entry becomes profitable in the accommodation case ($\beta \geq 0.4$), incumbent profits remain higher when they form a RJV. Though R&D levels decrease in the spillover in the accommodation case and increase when deterring, the increased R&D cost required to deter entry is sufficiently high to offset any output market benefit from being a duopolist. Similarly, incumbent profits when accommodating entry are always higher under RJV formation given the effect of joint profit maximisation and full information-sharing, though the benefits of these are decreasing in the spillover. It is also worth noting that, for the incumbents, deterring and competing in R&D is never profitable given the R&D expenditure required.

In Figure 8, where ε = 1, entry deterrence when forming a RJV is the most profitable action for relatively low spillover levels ($\beta \leq 0.2$). As the entrant is now as efficient as the incumbents, an increased level of R&D expenditure is required to deter entry, though this will reduce marginal production costs. When $\beta = 0$, and the incumbents form a RJV and accommodate entry, they choose relatively low duopoly R&D levels (see Figure 3), even though this induces entry. Increased output market competition then reduces profits below deterrence levels. When $0.1 \leq \beta \leq 0.2$ and the incumbents accommodate entry, they choose R&D levels based on three firms so that entry is blockaded. In this case, R&D expenditure when forming a RJV is higher than that required to deter entry (see Figure 3), but is not sufficiently offset by output market profits so deterrence is more profitable. As spillovers increase further, deterrence requires such increased R&D expenditure that the benefit of remaining duopolists in the output market is not sufficient to make deterrence a more profitable strategy than accommodation. Again, in the accommodation cases, RJV formation is always more profitable than R&D competition, the difference again decreasing in the spillover. Also, deterrence and R&D competition is never profitable for the incumbents given the R&D expenditure required. [63]

As the entrant becomes more efficient (Figure 9 where ε = 1.5), RJV formation and entry deterrence is again most profitable when $\beta \leq 0.2$, though deterrence is now profitable for a lower spillover range due to the entrant's increased efficiency. When $\beta = 0.1$, activity is not profitable for the incumbents when accommodating entry under R&D competition. When $\beta \geq 0.22$ (approx), accommodating entry and forming a RJV is again most profitable for the incumbents given full information-sharing and higher R&D costs if deterring entry.

5.7 Welfare – output exported

When all output is exported, there are no consumer welfare considerations and welfare is simply measured by total industry profit. When ε = 0.5, incumbent profits are highest when accommodating entry and forming a RJV (see Figure 7). In Figure 10, when $\beta \leq 0.3$, entry is blockaded when entry is accommodated so that the output market is a duopoly in both the accommodation and deterrence cases. Given this, welfare is highest under RJV formation and entry accommodation. Similarly, when $\beta \geq 0.4$, the increased incumbent profit

[63] If entry costs are positive, entry deterrence may be profitable for the incumbents over greater spillover ranges, while entry may be blockaded for higher spillover levels.

when forming a RJV more than offsets, when required, the lower profit of the entrant so that total industry profits are higher under RJV formation.

When the entrant is as efficient as the incumbents (Figure 11), welfare is highest under RJV formation and entry deterrence when $\beta \leq 0.2$. When $\beta = 0$, greater output market competition, due to incumbents choosing duopoly R&D levels that makes entry profitable, leads to lower total industry profit. On the other hand, when $0.1 \leq \beta \leq 0.2$, entry is blockaded under accommodation so the output market is a duopoly, but as incumbent profits are higher under deterrence (see Figure 8), so too is welfare. For other spillover levels, RJV formation and accommodation leads to highest total industry profits as, relative to R&D competition, incumbent profit, when needed, more than offsets the lower profit of the entrant.

When $\varepsilon = 1.5$, a number of interesting issues emerge (see Figure 12). When $\beta = 0.1$, welfare is highest when the incumbents form a RJV and deter entry.[64] This strategy is also most profitable for the incumbents (see Figure 9). Under R&D competition, the entrant is a monopolist. Despite this, lower R&D expenditure and full information-sharing within a RJV when deterring entry ensures that total industry profit and, consequently, welfare is highest.

When $0.2 \leq \beta \leq 0.3$, entry accommodation and R&D competition is welfare dominant. In this case, deterrence is less profitable due to the higher R&D expenditure required. Also, while the incumbents are better off by forming a RJV, entrant profits are higher under R&D competition to the extent that total industry profits are highest in this case. Unfortunately, from a welfare perspective, the incumbents will form a RJV and either accommodate or deter (see Figure 9), neither of which induces the highest welfare level. This can justify a role for government to discourage RJV formation. For the remaining spillover levels ($\beta \geq 0.4$), welfare is highest when the incumbents form a RJV and accommodate entry, as lower R&D expenditure offsets lower operating profit due to greater market competition. Such an outcome coincides with the interests of the incumbents (see Figure 9).

Given this, we can conclude that when all output is exported, the strategy that leads to the highest profit for the incumbents is quite often that which leads to highest welfare. If the entrant is more efficient, however, it may be the case that, for a range of relatively low spillover levels, the incumbents' most profitable strategy is not welfare dominant, possibly justifying some form of government intervention.

5.8 Welfare – output consumed domestically.

[64] Comparing deterrence and accommodation is not possible when $\beta = 0$, as there is no equilibrium in the R&D competition case, while at least one stability condition is not satisfied under RJV formation.

If output is consumed domestically, consumer welfare will affect overall welfare levels. RJV formation that prevents entry may imply lower output and higher prices relative to where entry is not prevented that, in turn, may reduce consumer welfare to an extent that welfare is lower. In the entry accommodation case when all firms compete in R&D, over-investment in R&D may increase welfare above that of when the incumbents form a RJV.

Looking firstly at where $\varepsilon = 0.5$ in Figure 13, when $\beta \leq 0.3$, welfare is highest when the incumbents form a RJV and accommodate entry. In this case, entry is blockaded at these spillovers and the relatively high R&D serves to reduce marginal production costs and output prices. In the deterrence case, the R&D required to deter entry is relatively low given the inefficiency of the entrant so that consumer benefits from R&D are also relatively low. A combination of higher total industry profits (see Figure 10) and greater consumer surplus means that welfare is higher under RJV formation and accommodation. As what is privately efficient (see Figure 7) is also welfare dominant, there is no role for government.

On the other hand, when $\beta \geq 0.4$, welfare is highest when the incumbents form a RJV and deter entry. As spillovers increase, the R&D expenditure required to deter entry is also increasing, though these R&D costs will be relatively low given the entrant's relative inefficiency. The welfare cost of deterring entry in terms of lower total industry profits (see Figure 10) will be offset by the benefit of lower marginal production costs that reduces prices. Given this, we can state that RJV formation that seeks to deter greater output market competition is welfare enhancing, i.e. *less is more*. Despite this, the incumbents will not choose the welfare dominant strategy as they will form a RJV and accommodate entry as profit is higher (see Figure 7). Again, there may be a role for government intervention in, for example, subsidising R&D expenditure when incumbent firms are faced with potential entry.

Looking at Figure 14 where $\varepsilon = 1$, RJV formation always leads to the highest welfare level, though whether accommodation or deterrence is welfare dominant will depend on the spillover level. When $\beta = 0$, deterrence dominates. At this spillover, the incumbents, when accommodating entry, choose relatively low duopoly R&D levels that induce entry. In contrast, deterrence R&D levels are higher (see Figure 3) which may lead to lower marginal production costs and prices. Also, less output market competition leads to higher industry profits (see Figure 11). The higher profits dominate any possible gain to consumer welfare from having three active firms. Also, deterrence is most profitable for the incumbents so there is no conflict between private and social incentives.

When $0.1 \leq \beta \leq 0.2$, RJV formation and accommodation is welfare dominant. At these spillovers, entry is blockaded (see Figure 5) as the incumbents choose relatively high R&D levels (see Figure 3) based on three active firms in the market. These R&D levels, and associated costs, exceed those of RJV formation and deterrence, while the benefits in terms of consumer welfare are also higher even though the output market remains a duopoly in both cases. The higher consumer surplus of accommodation dominates the greater industry profit of deterrence (see Figure 11) to the extent that welfare is higher under accommodation. Unfortunately, at these spillovers, RJV formation and entry deterrence is what is most profitable for the incumbents (see Figure 8). In this case, a stringent competition policy that seeks to prevent abuse of a dominant position may be justified.

As spillovers increase still further to $0.3 \leq \beta \leq 0.5$, deterrence dominates accommodation under RJV formation, as the consumer benefits of the relatively high R&D required to deter entry (see Figure 3) offset the lower total industry profit so that welfare is higher. In contrast to lower spillover levels, it is now RJV formation and entry accommodation that is most profitable for the incumbent firms (see Figure 8) so that government policy may again seek to subsidise R&D investment that prevents greater output market competition, or introduces a more stringent licensing system for new firms.

When $\beta > 0.5$, deterring entry is no longer welfare enhancing as the R&D costs required become so prohibitively large that any consumer benefits are more than offset by lower profits and welfare decreases. Given this, welfare is highest when the incumbents form a RJV and accommodate entry. At these spillover levels, private and social incentives are again aligned (see Figure 8).

As the entrant becomes still more efficient ($\varepsilon = 1.5$ in Figure 15), RJV formation and deterrence leads to the highest welfare when spillovers are relatively low ($\beta \leq 0.3$), with RJV formation and accommodation dominating for all other spillovers. In the former, the R&D costs required to deter the entry of the more efficient entrant are increased but the benefit of this is lower marginal production costs and prices that increase consumer surplus. At certain spillover levels ($0.2 \leq \beta \leq 0.3$), this effect can dominate the larger total industry profit of the R&D competition case (see Figure 12). With the exception of when $\beta = 0.3$, private and social incentives are again aligned as what is most profitable for the incumbents is also welfare dominant (see Figure 9).

6. Summary and Conclusions

This paper is concerned with the incentives of symmetric incumbent firms to form a RJV when faced with potential, costless, entry into an homogenous good industry, currently characterised by a Cournot duopoly. The incumbent firms can either compete in R&D or form a RJV, but always compete in R&D vis-à-vis the entrant. The benefit of being first-movers in R&D is that the incumbent firms, when choosing their R&D, can either accommodate or deter entry into the industry. Irrespective of whether entry occurs or not, all active firms in the output market simultaneously choose non-cooperative output levels.

The most interesting questions of this paper are as follows: Firstly, if entry is profitable when the incumbent firms compete in R&D, will the formation of a RJV by the incumbents, in which they fully share information, make entry unprofitable and prevent greater output market competition? Secondly, will the incumbents always make greater profits than the entrant or are there circumstances in which the entrant profits are higher? Also, will the incumbents accommodate or deter the entrant? Finally, will the most profitable action of the incumbents also be that which leads to the highest level of welfare?

If all firms compete in R&D and the incumbents accommodate entry, incumbent profits are at least as high when they are at least as efficient as the entrant. On the other hand, the entrant can make greater profits for all spillovers when it is more efficient. If the incumbents form a RJV, however, then for relatively high spillovers, the entrant may make greater profits, even when all firms are symmetric. The threshold spillover at which the entrant is more profitable is decreasing in the entrant's relative efficiency level.

If the incumbent firms deter entry when the entrant is relatively inefficient, the threshold unit R&D cost at which RJV formation becomes more profitable than R&D competition is increasing in the spillover. As the entrant becomes more efficient, however, RJV formation tends to dominate R&D competition for all unit R&D costs and spillovers.

Given the absence of any fixed entry costs, if the incumbents form a RJV, entry accommodation is more profitable than deterrence for all spillover levels if the entrant is sufficiently inefficient relative to the incumbents. As the entrant becomes more efficient, deterrence may be more profitable for relatively low spillover levels. A more interesting result is that RJV formation when accommodating may make entry unprofitable, even if all firms are symmetric, especially when exogenous spillovers are sufficiently low.

Welfare levels will depend crucially on whether all output is exported or domestically consumed. If exported in its entirety, then if the incumbents are at least as efficient as the entrant, the action that leads to the highest welfare level will also be that which leads to highest incumbent profits. On the other hand, if the entrant is more efficient, what may be most profitable for the incumbents may not lead to the highest welfare level, thereby justifying a role for government to increase welfare. If output is consumed domestically, however, a conflict between what is most profitable and what leads to the highest welfare is more likely, particularly for relatively high spillovers levels when the entrant is less efficient than the incumbents, and for some relatively low spillover levels when the entrant is more efficient. Consequently, there may be a role for government policy to affect market outcomes.

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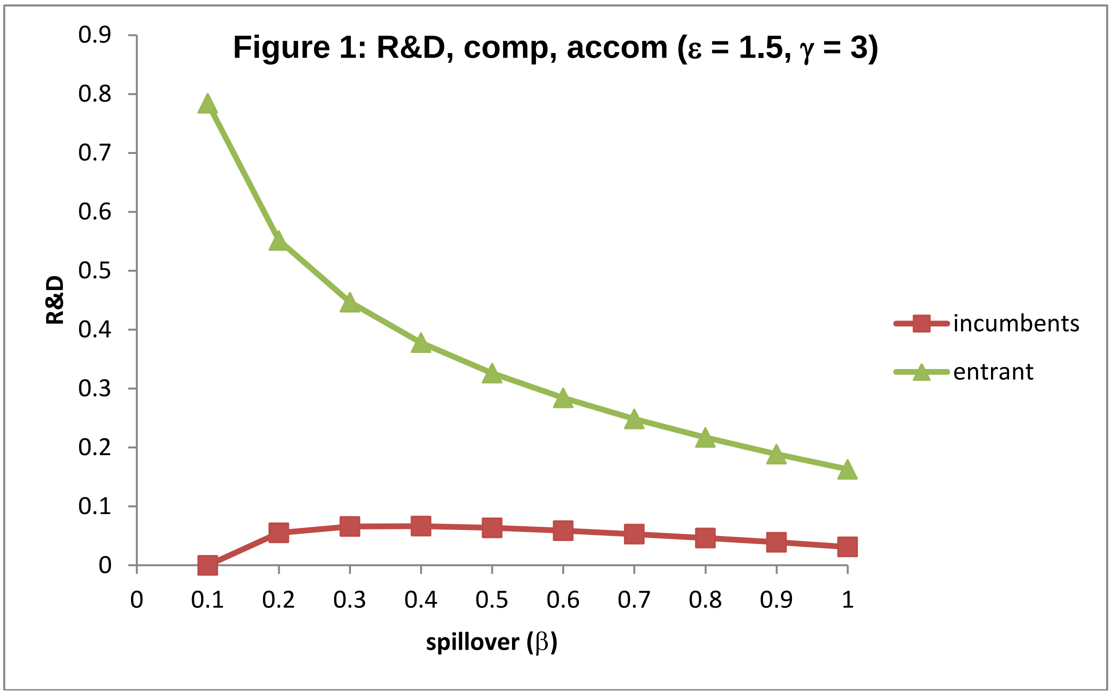
Figure 1: R&D, comp, accom (ε = 1.5, γ = 3)
R&D
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
spillover (β)
incumbents
entrant

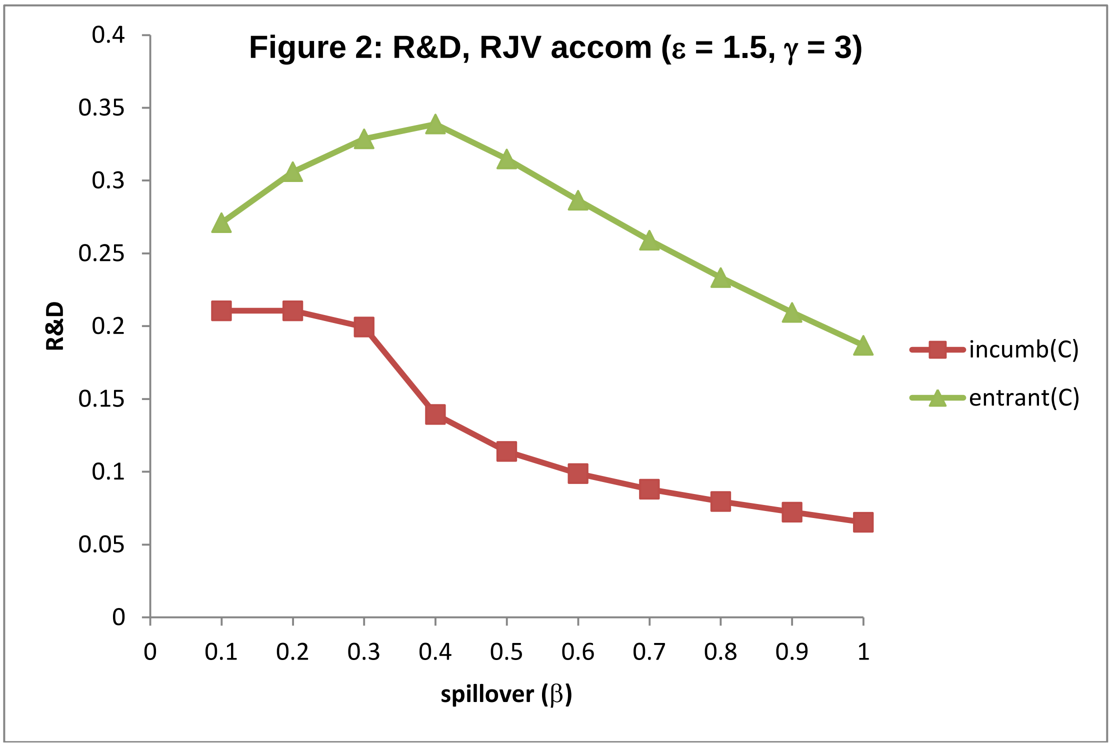
Figure 2: R&D, RJV accom (ε = 1.5, γ = 3)
R&D
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
spillover (β)
incumb(C)
entrant(C)

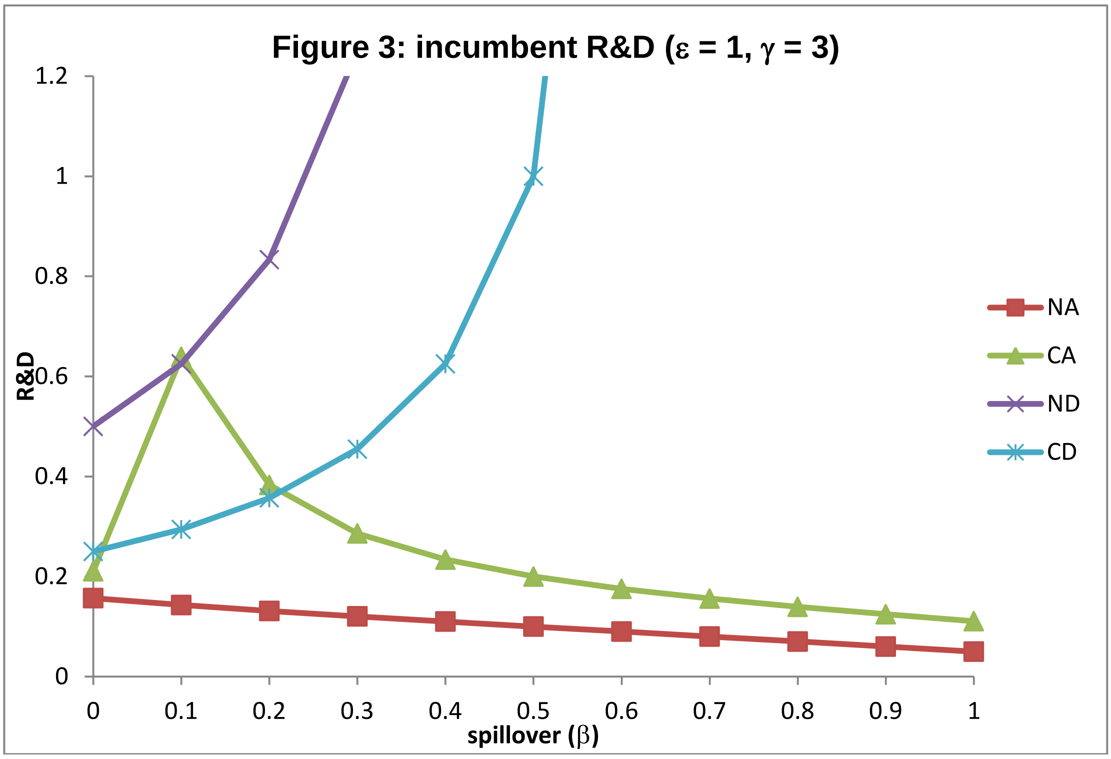

Figure 3: incumbent R&D (ε = 1, γ = 3)
R&D
spillover (β)
NA
CA
ND
CD

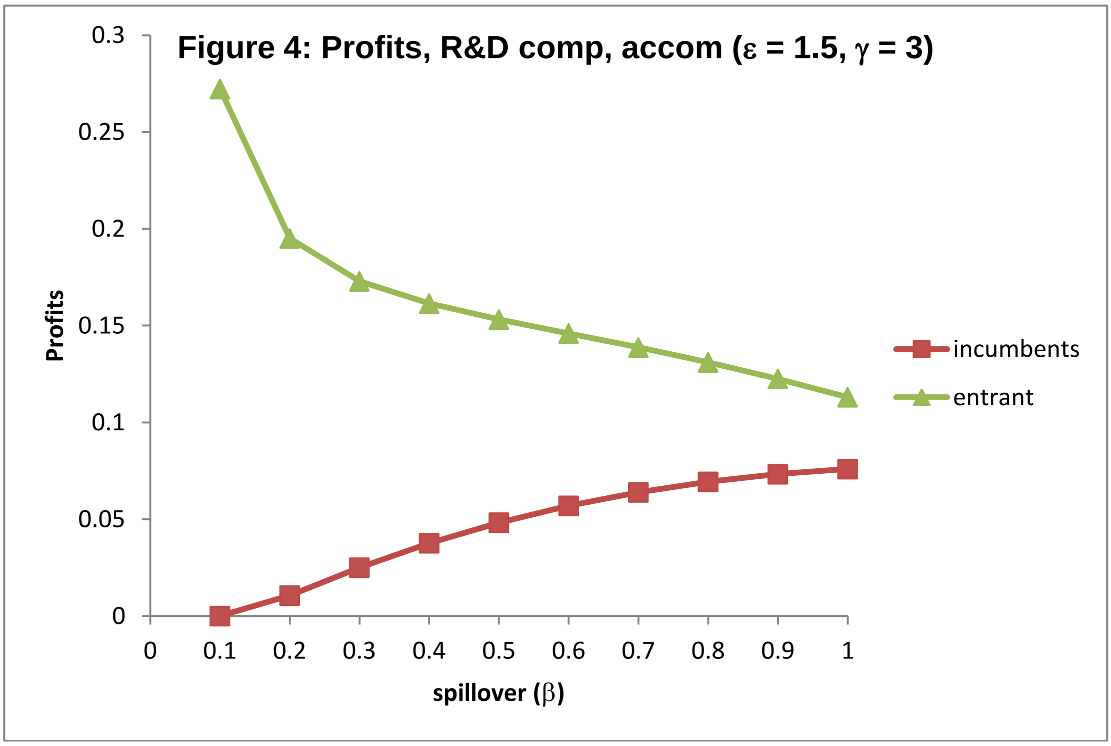

Figure 4: Profits, R&D comp, accom (ε = 1.5, γ = 3)
Profits
spillover (β)
incumbents
entrant

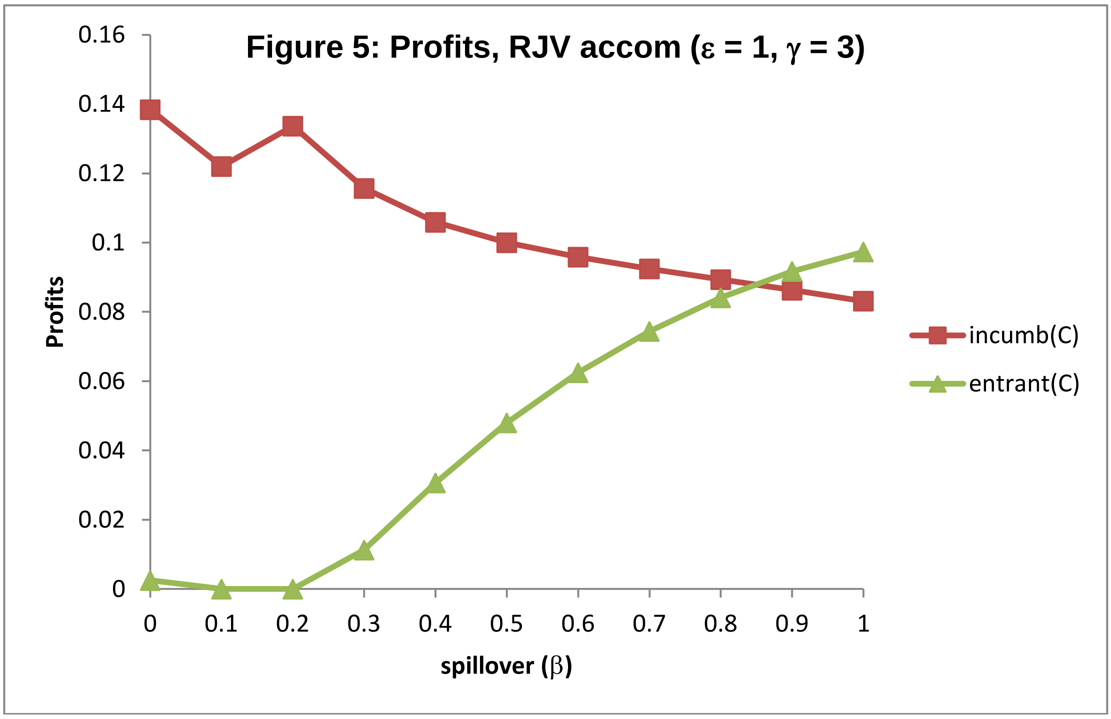
Figure 5: Profits, RJV accom (ε = 1, γ = 3)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Profits
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
spillover (β)
incumb(C)
entrant(C)

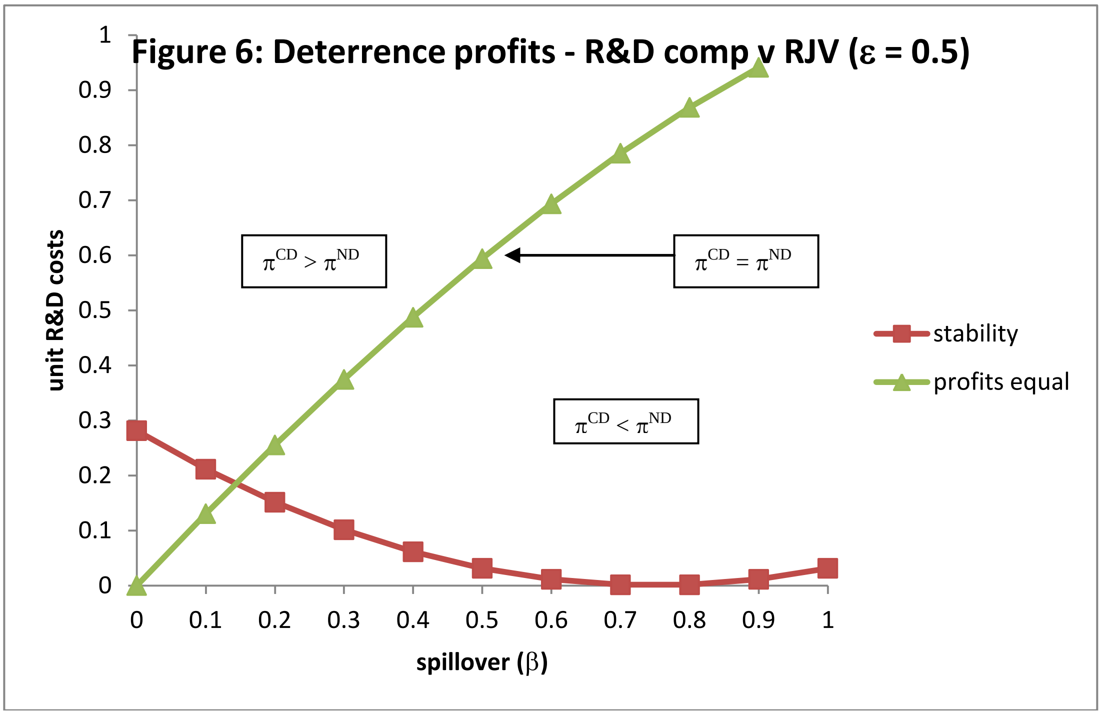
Figure 6: Deterrence profits - R&D comp v RJV (ε = 0.5)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
unit R&D costs
$\pi^{CD} > \pi^{ND}$
$\pi^{CD} = \pi^{ND}$
$\pi^{CD} < \pi^{ND}$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
spillover (β)
stability
profits equal

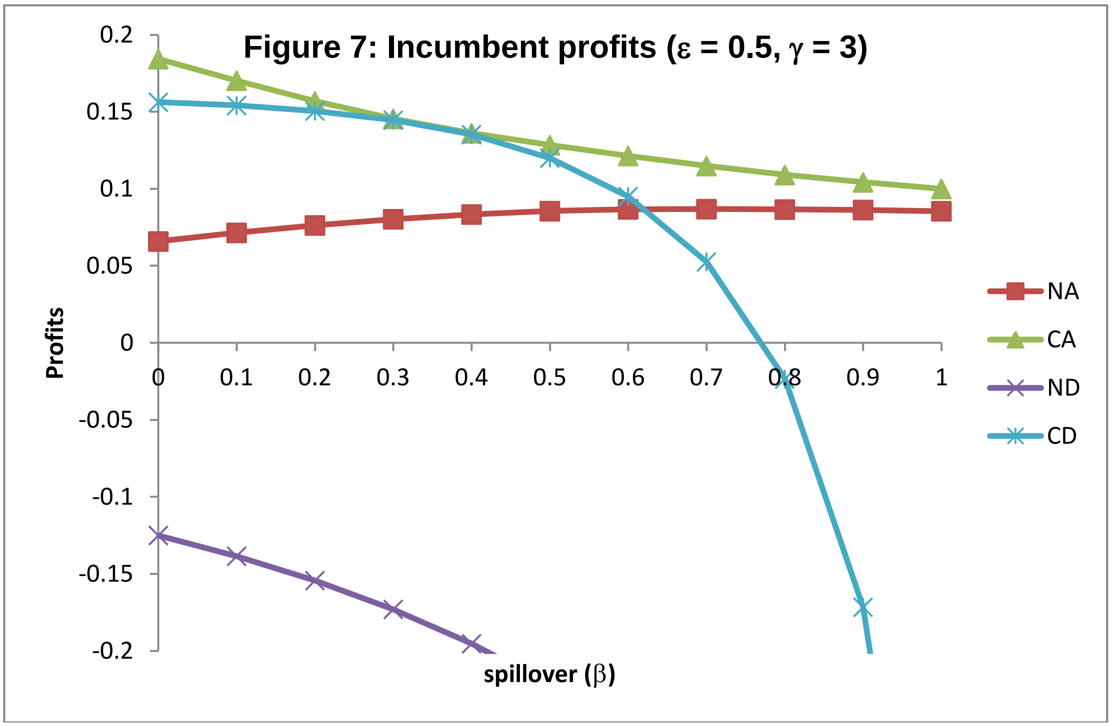
Figure 7: Incumbent profits (ε = 0.5, γ = 3)
Profits
spillover (β)
NA
CA
ND
CD
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

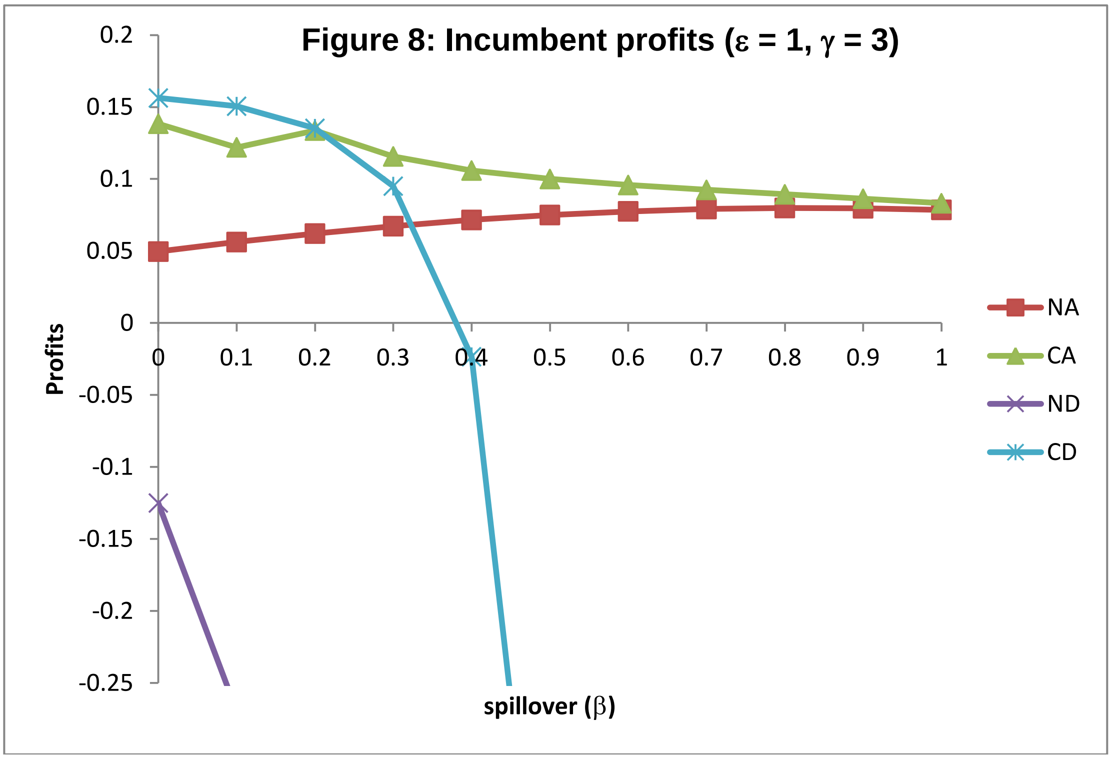
Figure 8: Incumbent profits (ε = 1, γ = 3)
Profits
spillover (β)
NA
CA
ND
CD
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

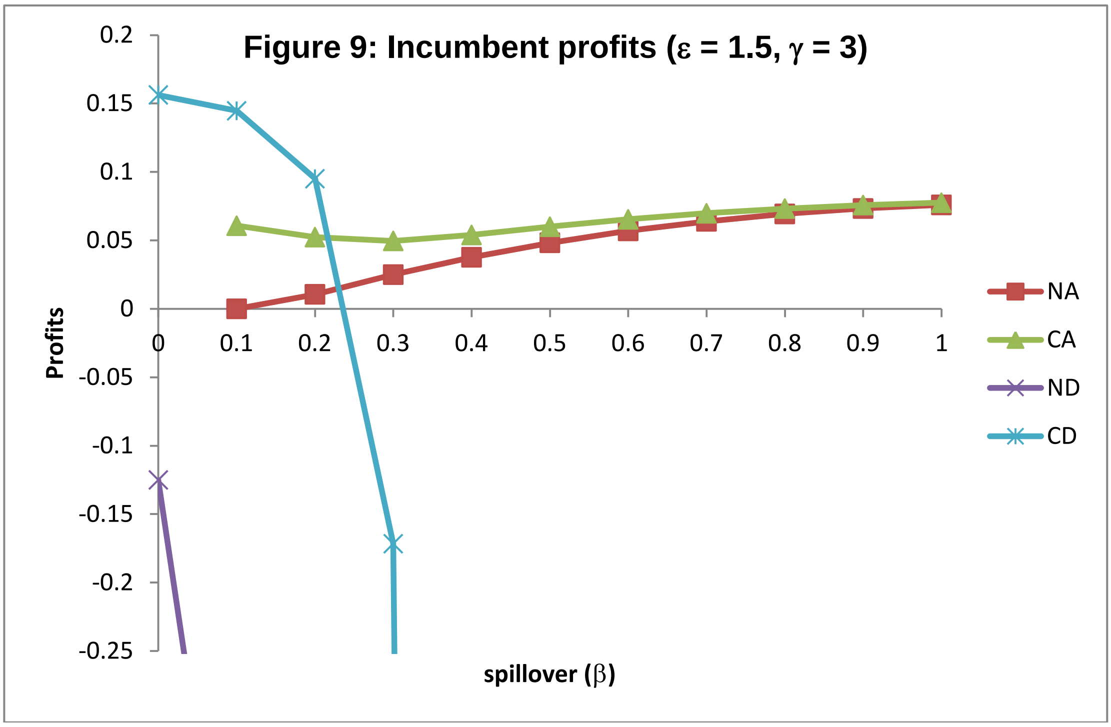
Figure 9: Incumbent profits (ε = 1.5, γ = 3)
Profits
spillover (β)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
NA
CA
ND
CD

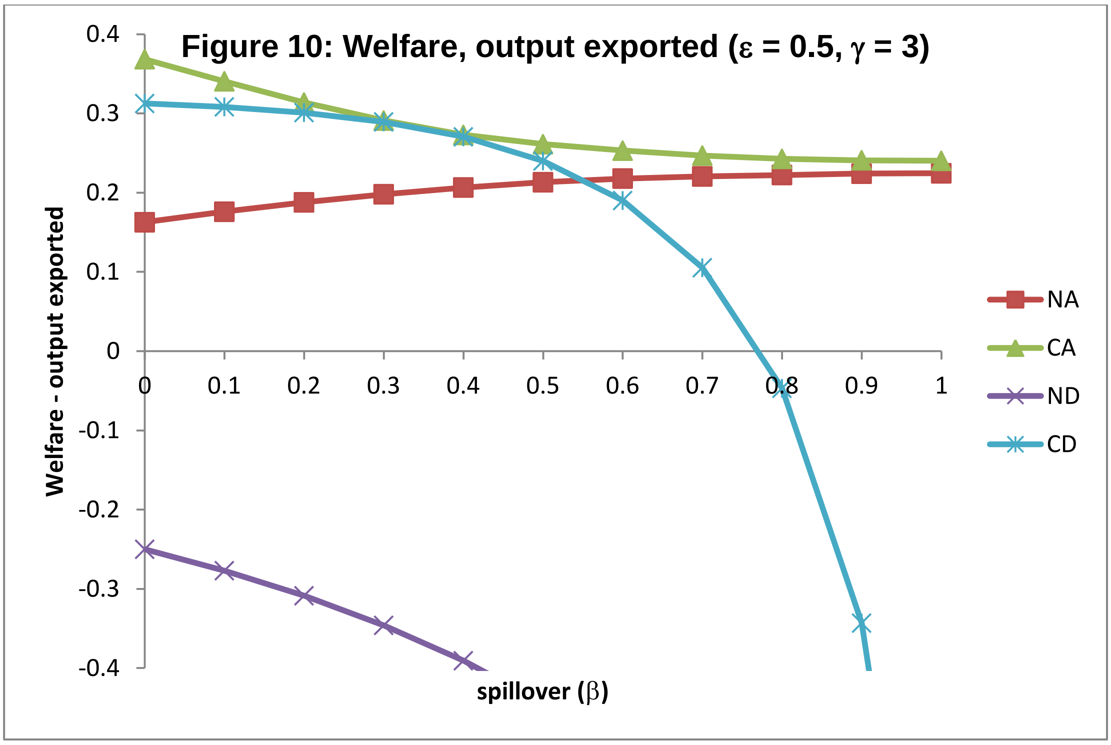
Figure 10: Welfare, output exported (ε = 0.5, γ = 3)
Welfare - output exported
spillover (β)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
NA
CA
ND
CD

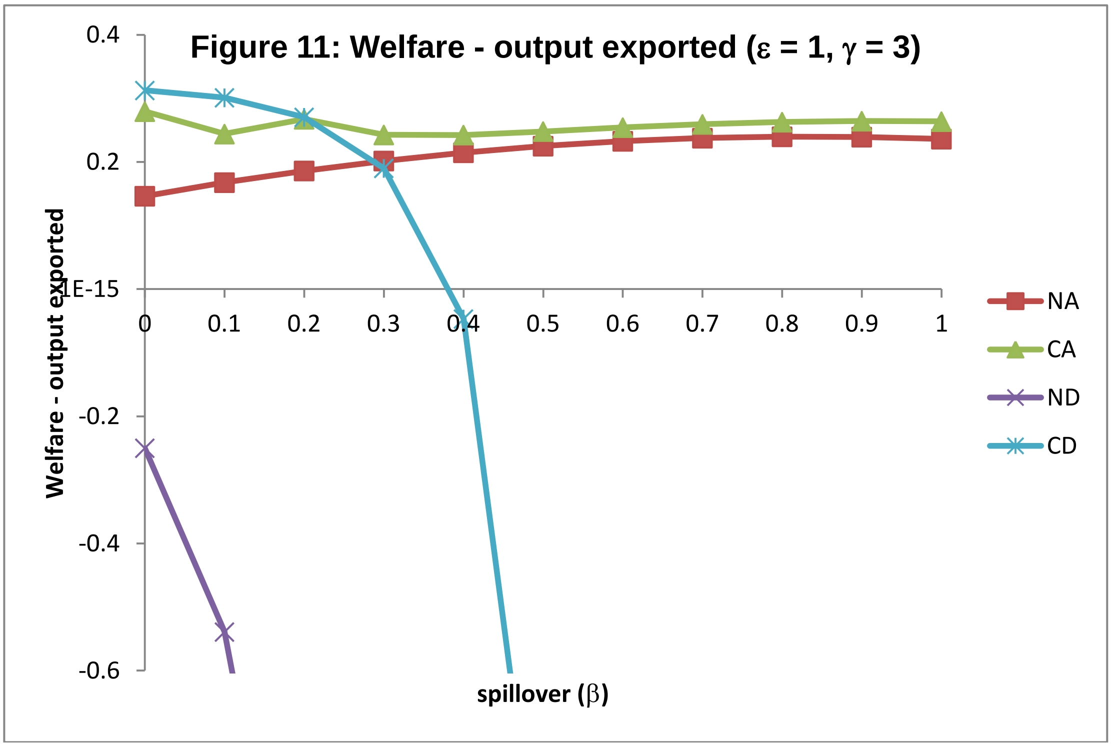
Figure 11: Welfare - output exported (ε = 1, γ = 3)
0.4
0.2
1E-15
-0.2
-0.4
-0.6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Welfare - output exported
spillover (β)
NA
CA
ND
CD

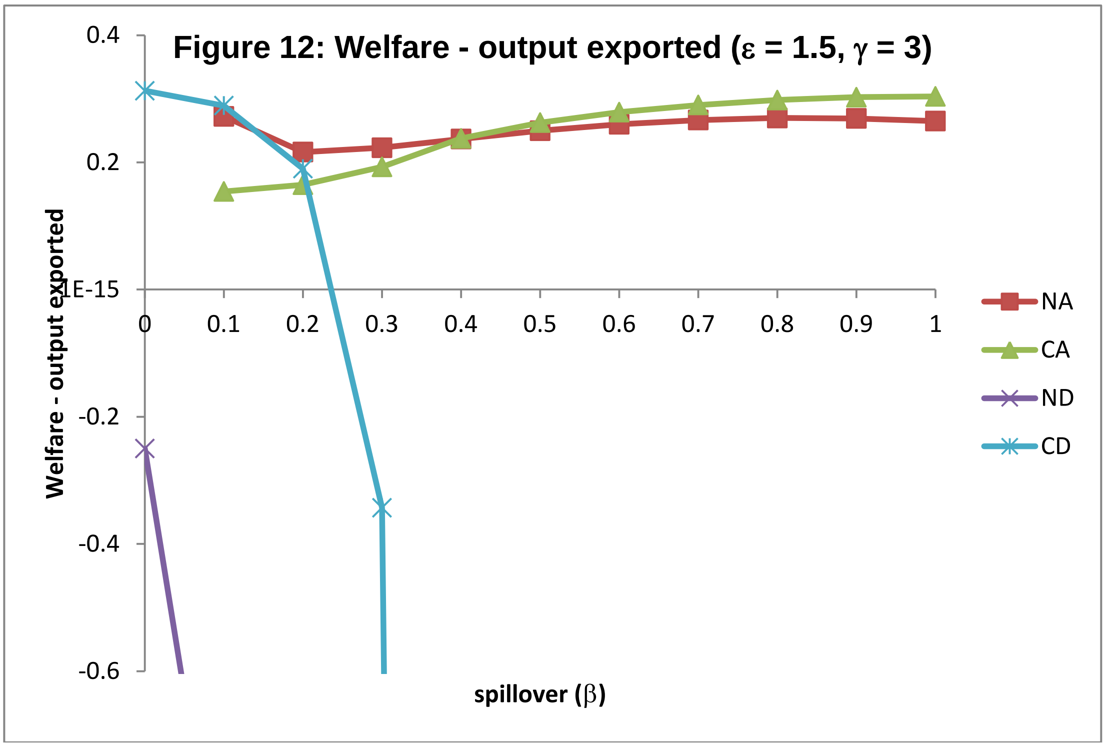
Figure 12: Welfare - output exported (ε = 1.5, γ = 3)
0.4
0.2
1E-15
-0.2
-0.4
-0.6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Welfare - output exported
spillover (β)
NA
CA
ND
CD

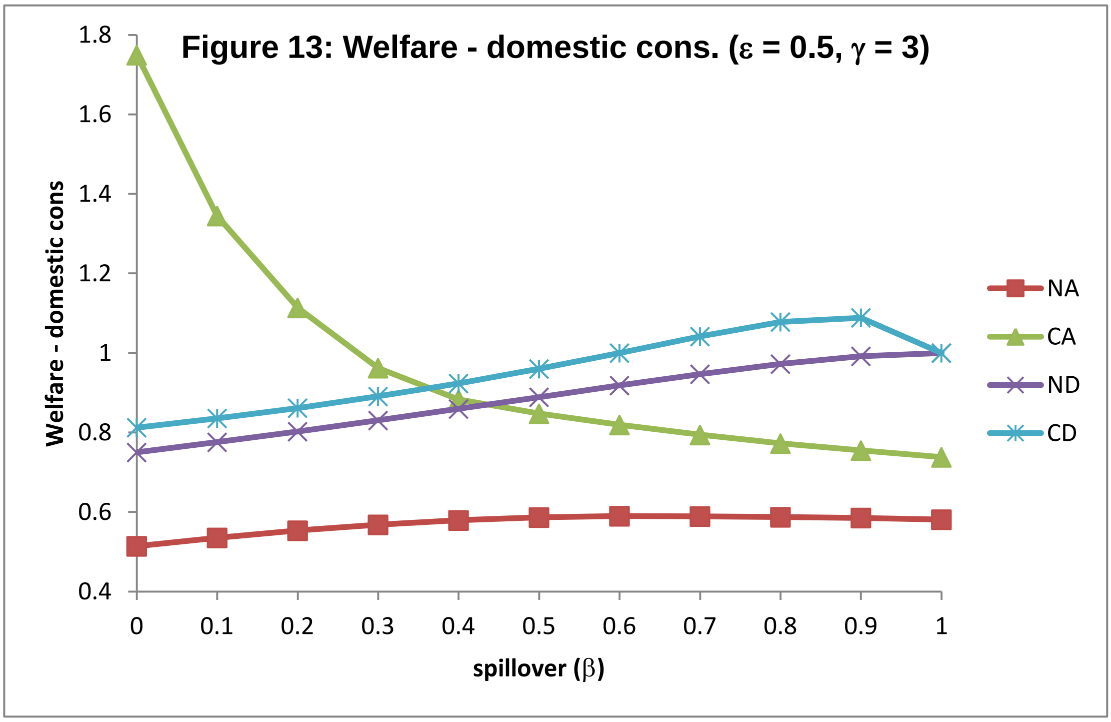
Figure 13: Welfare - domestic cons. (ε = 0.5, γ = 3)
Welfare - domestic cons
spillover (β)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
NA
CA
ND
CD

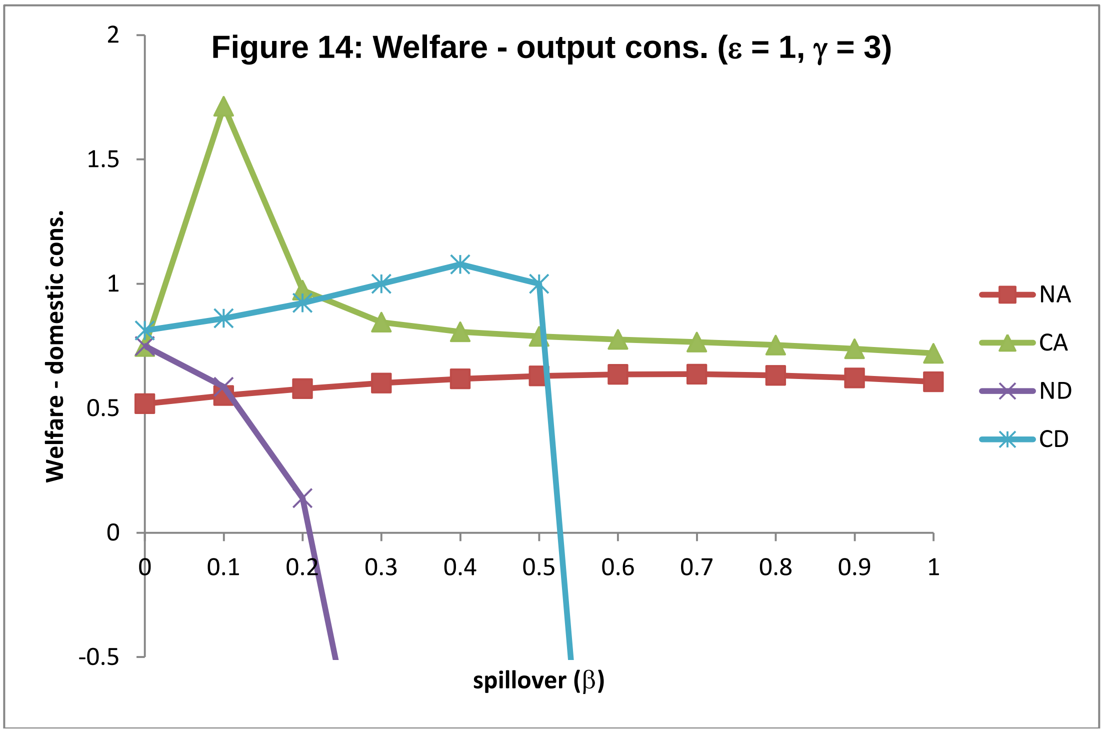
Figure 14: Welfare - output cons. (ε = 1, γ = 3)
Welfare - domestic cons.
spillover (β)
2
1.5
1
0.5
0
-0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
NA
CA
ND
CD

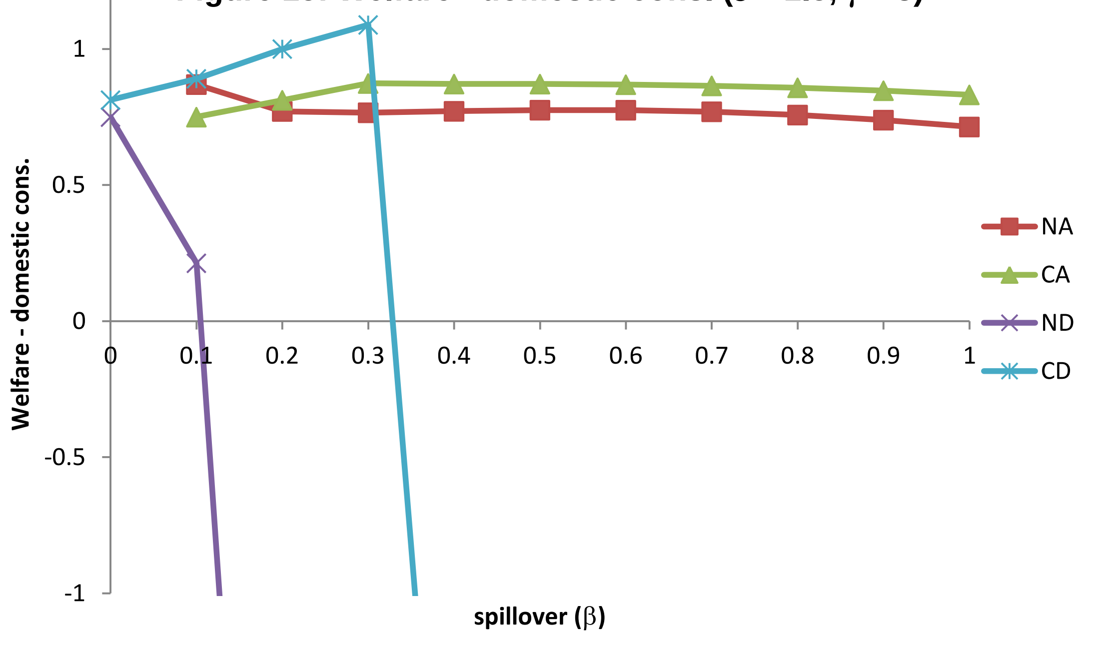

Figure 15: Welfare - domestic cons. (ε = 1.5, γ = 3)

APPENDIX

Profitable entry: Accommodation & R&D competition

Given the relevant derivatives in (8), and as the determinant of the matrix of second derivatives in (8) is negative, then from (11), the entrant over (under) invests in R&D if

$$\frac{\theta\beta\left[\frac{\pi^*_{q^*q}-\pi^*_{q^*q^*}}{\pi_{qq}}\right]+\theta^*\beta^*\left[\frac{\pi_{qq^*}}{\pi_{qq}}-1\right]+\theta^e\left[\psi\left(\frac{\pi^*_{q^*q^*}-\pi^*_{q^*q}}{\pi_{qq}}\right)+\psi^*\left(1-\frac{\pi_{qq^*}}{\pi_{qq}}\right)\right]}{\Delta}<(>)0 \qquad \textbf{(A2.1)}$$

In (A2.1), $\phi=\frac{\pi^e_{q^eq}}{\pi_{qq}}=\frac{\pi^e_{q^eq^*}}{\pi_{qq}}, \psi=\frac{\pi_{qq^e}}{\pi^e_{q^eq^e}}, \psi^*=\frac{\pi^*_{q^*q^e}}{\pi^e_{q^eq^e}}$ and $\Delta=\frac{|D|}{\pi_{qq}\pi^e_{q^eq^e}}$, where $|D|<0$ is the determinant of the matrix of second derivatives in (8).[65] As Δ < 0, this can be reduced to the condition of over (under) investment in R&D if

$$\theta\beta\left[\frac{\pi^*_{q^*q}-\pi^*_{q^*q^*}}{\pi_{qq}}\right]+\theta^*\beta^*\left[\frac{\pi_{qq^*}}{\pi_{qq}}-1\right]>(<)\theta^e\left[\psi\left(\frac{\pi^*_{q^*q}-\pi^*_{q^*q^*}}{\pi_{qq}}\right)+\psi^*\left(\frac{\pi_{qq^*}}{\pi_{qq}}-1\right)\right] \qquad \textbf{(A2.2)}$$

If demand is linear (r = 0), so that $\psi=\psi^*=\frac{1}{2}$ and the entrant over (under) invests in R&D when $\theta^e>(<)\theta\beta+\theta^*\beta^*\equiv\bar{\theta}^e$.[66]

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[65] ϕ is the relative effect of representative incumbent output on entrant and own marginal profitability. ψ and ψ* denote the relative effects of entrant output on incumbent and own marginal profitability.

As the entrant chooses its R&D investment given the R&D of the incumbents, it is necessary to derive the entrant's R&D reaction function as the incumbent firms will take this into account when undertaking their own R&D. Re-writing (11) as

$$\pi^e_{x^e}(x,x^*,x^e) = \left\{\theta^e - b\left(q(x,x^*,x^e), q^*(x,x^*,x^e), q^e(x,x^*,x^e)\right)\left[\frac{\partial q(x,x^*,x^e)}{\partial x^e} + \frac{\partial q^*(x,x^*,x^e)}{\partial x^e}\right]\right\} q^e(x,x^*,x^e) - \Gamma^{e\prime}(x^e) = 0 \quad \textbf{(A2.3)}$$

and totally differentiating (A2.3), the slope of the entrant's R&D reaction function with respect to the R&D of the representative incumbent is

$$\frac{dx^e}{dx} = \frac{\left[\theta^e + \left[-b + p''(Q)q^e\left[\frac{\partial q}{\partial x^e} + \frac{\partial q^*}{\partial x^e}\right]\right]\frac{\partial q^e}{\partial x} + q^e\left[-b\left[\frac{\partial^2 q}{\partial x^e \partial x} + \frac{\partial^2 q^*}{\partial x^e \partial x}\right] + p''(Q)\left[\frac{\partial q}{\partial x} + \frac{\partial q^*}{\partial x}\right]\left[\frac{\partial q}{\partial x^e} + \frac{\partial q^*}{\partial x^e}\right]\right]\right]}{\Gamma^{e\prime\prime}(x^e) - \left[\theta^e + \left[-b + p''(Q)q^e\left[\frac{\partial q}{\partial x^e} + \frac{\partial q^*}{\partial x^e}\right]\right]\frac{\partial q^e}{\partial x^e} - q^e\left[-b\left[\frac{\partial^2 q}{\partial x^{e2}} + \frac{\partial^2 q^*}{\partial x^{e2}}\right] + p''(Q)\left[\frac{\partial q}{\partial x^e} + \frac{\partial q^*}{\partial x^e}\right]^2\right]\right]} \quad \textbf{(A2.4)}$$

where the denominator in (A2.4) is positive to satisfy the entrant's second-order condition. Whether the incumbents' R&D is a strategic substitute or strategic complement for the entrant's R&D will depend on whether the numerator in (A2.4) is negative or positive.

Applying incumbent symmetry to (8) and (14), the incumbent firms over (under) invest in R&D if

$$b\Gamma^{e\prime\prime}(x^e) < (>) \frac{\left\{\begin{array}{l}\left[2\left[-b + p''(Q)q^e\right]\frac{\partial q}{\partial x^e} + \theta^e\right]\left[\left(\theta\beta - b\frac{\partial q}{\partial x^e}\right)\frac{\partial q^e}{\partial x} + b\frac{\partial q}{\partial x}\frac{\partial q^e}{\partial x^e}\right] \\ + q^e\left\{\begin{array}{l}-b\left[2b\left(\frac{\partial q}{\partial x} + \frac{\partial q^e}{\partial x}\right)\frac{\partial^2 q}{\partial x^{e2}} + \left(\theta\beta - b\left(\frac{\partial q}{\partial x^e} + \frac{\partial q^e}{\partial x^e}\right)\right)\left(2\frac{\partial^2 q}{\partial x^e \partial x}\right)\right] \\ 2p''(Q)\frac{\partial q}{\partial x^e}\left[\left[\theta\beta - b\left(\frac{\partial q}{\partial x^e} + \frac{\partial q^e}{\partial x^e}\right)\right]\frac{\partial q}{\partial x} + \left[\theta\beta - b\left(\frac{\partial q^e}{\partial x^e} - \frac{\partial q}{\partial x^e}\right)\right]\frac{\partial q}{\partial x} + 2b\frac{\partial q^e}{\partial x}\frac{\partial q}{\partial x^e}\right]\end{array}\right\}\end{array}\right\}}{\left[\frac{\partial q}{\partial x} + \frac{\partial q^e}{\partial x}\right]} \quad \textbf{(A2.5)}$$

Profitable entry: Accommodation & RJV formation

Given the relevant derivatives in (15), the representative incumbent over (under) invests in R&D if

$$b\Gamma^{e\prime\prime}(x^e)\begin{pmatrix}<\\>\end{pmatrix} \frac{\left\{\begin{array}{l}\left[\theta^e + 2\left[p'(Q) + p''(Q)q^e\right]\frac{\partial q}{\partial x^e}\right]\left[\left(\beta - b\frac{\partial q}{\partial x^e}\right)\frac{\partial q^e}{\partial x} + b\frac{\partial q}{\partial x}\frac{\partial q^e}{\partial x^e}\right] \\ + 2q^e\left\{\begin{array}{l}p'(Q)\left[b\left(\frac{\partial q}{\partial x} + \frac{\partial q^e}{\partial x}\right)\frac{\partial^2 q}{\partial x^{e2}} + \left(\beta - b\left(\frac{\partial q}{\partial x^e} + \frac{\partial q^e}{\partial x^e}\right)\right)\frac{\partial^2 q}{\partial x^e \partial x}\right] \\ 2p''(Q)\frac{\partial q}{\partial x^e}\left[\left(\beta - b\frac{\partial q^e}{\partial x^e}\right)\frac{\partial q}{\partial x} + b\frac{\partial q^e}{\partial x}\frac{\partial q}{\partial x^e}\right]\end{array}\right\}\end{array}\right\}}{\left[\frac{\partial q}{\partial x} + \frac{\partial q^e}{\partial x}\right]} \quad \textbf{(A2.6)}$$

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[66] This is consistent with D'Aspremont and Jacquemin (1988) where all firms are symmetric so that $\beta = \beta^* = \beta^e$ and $\theta = \theta^* = \theta^e = 1$ and the firms over (under) invest in R&D when $\beta < (>) ½$.