Integrating Competition Policy and Innovation Policy: The Case of R&D Cooperation. *

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Abstract

This paper considers the integration of competition policy and innovation policy in the context of R&D cooperation. An explicit comparison of the welfare losses under ex-ante and ex-post R&D cooperation reveals differing incentives to undertake R&D in both regimes. The strength of these incentives is related to the degree of product market competition. We show that there is a clear relationship between the degree of competition in the product market and the level of welfare losses under ex-ante (e.g. an RJV) and ex-post (e.g. licensing) R&D cooperation. We derive implications for the design of competition law.

JEL Classification: L13, L49, O31 .

Key Words: Competition Policy, Innovation Policy, R&D Cooperation, Licensing, Research Joint Venture, Oligopolistic R&D.

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1 Introduction

This paper is about the effect of competition law on firms' R&D incentives, in particular the effect of the regulations on sharing of technical innovations. We propose that these regulations could be improved to further strengthen firms' R&D incentives. Our proposal is based on the distinction between *ex-ante* R&D cooperation where firms choose to cooperate on an R&D project before they invest in it and *ex-post* R&D cooperation where cooperation arises after the innovation is made. R&D incentives under ex-ante and ex-post R&D cooperation differ. Currently this distinction is not recognised in competition law which can have undesired effects. In this paper we investigate how this problem could be resolved in order to provide stronger R&D incentives to firms.

Competition law is not usually seen as an instrument which can enhance R&D incentives. Indeed Encaoua and Hollander (2002), who survey the nexus of competition law and R&D policy, note that competition law and intellectual property laws, which seek to strengthen R&D incentives, quite frequently conflict. Competition law is characterised by a strong bias in favour of static efficiency in product markets while strong R&D incentives are usually associated with some element of static inefficiency in product markets[1]. This tradeoff between static and dynamic efficiency is also present in the regulation of R&D cooperation. Competition authorities in Europe and the United States currently tolerate R&D cooperation within specific limits in order to enhance R&D incentives[2]. While there are distinct regulations for ex-ante and ex-post R&D cooperation in both jurisdictions these do not recognise the economic differences in the R&D incentives between ex-ante and ex-post R&D cooperation.

This raises the question whether these regulations will have the desired effect. To study this question we compare R&D incentives under ex-ante and ex-post R&D cooperation in a model of competing oligopolists. In this model the strength of firms' innovation incentives is related to the degree of product market competition and to differences in technological opportunities across product markets. We use the model to derive measures of welfare losses that can be related to the strength of firms' R&D incentives. As is well known both ex-ante and ex-post R&D cooperation generally lead to welfare losses[3]. We compare these welfare losses and derive a rule that allows us to predict when ex-ante R&D cooperation is likely to give rise to smaller welfare losses than ex-post R&D cooperation. Our main conclusion states that ex-ante agreements should be favoured over ex-post agreements when product market competition is weak and technological opportunity is high.

While our general conclusions apply to the regulation of R&D cooperation anywhere, they are particularly pertinent to the form of regulation adopted in Europe. In the United States the National Cooperative Research Act lowers the costs of being found in breach of competition

[1] The argument over whether society should prefer static or dynamic efficiency goes back to Schumpeter (1942).

[2] In the United States ex-ante R&D cooperation was legalised by the National Cooperative Research Act (NCRA) of 1984. The reach of this act has since been extended in the NCRPA of 1993. For a review of R&D agreements this act gave rise to refer to Majewski and Williamson (2004). Ex-post R&D cooperation was regulated on the basis of the "Nine No-No's" set out by the Department of Justice in 1970. These have been superseded by the 1995 *Antitrust Guidelines for Licensing Intellectual Property*. For a review of these regulations refer to Gilbert and Shapiro (1997). European legislation exempting ex-ante R&D agreements from scrutiny by the European Commission was first passed in regulation 418/85 in 1985. Ex-post R&D agreements were first regulated in 1962 in the *Notice on Patent Licensing Restrictions*. Current European regulations are noted below.

[3] Arrow (1962) demonstrated that firms tend to underinvest in R&D because they do not take account of the social welfare gains due their innovations. The literature on patent races (Loury (1979), Reinganum (1989)) demonstrates that firms may overinvest in R&D when racing for the same innovation.

law if firms register an agreement to cooperate on R&D ex-ante. In contrast the European Commission has adopted a system of block exemptions from the prohibitions of competition law[4]. These block exemptions impose limits on firms that wish to license technologies ex-post[5] and on firms that seek to collaborate on future R&D [6]. The block exemptions apply as long as certain market share thresholds are not overstepped. We argue below that these thresholds may be set in part to provide R&D incentives.

At present the block exemptions apply to competing firms with a joint market share of under 25% for ex-ante R&D agreements and 20% for ex-post licensing. Where ex-ante agreements fall under the merger guidelines a joint market share under 25% also suggests that the "merger" is unlikely to be challenged. These differences in the market share thresholds suggest that the Commission has a slight preference for ex-ante agreements[7]. Our results imply that such a preference is warranted only where product market competition is weak and technological opportunity is high.

Currently firms in Europe must determine of themselves whether they fall under a block exemption[8]. Where this is not the case they may be prosecuted in a national court for failure to comply with Article 81. This system has been in place since Regulation 1/2003 came into force in May 2004. Clearly the uncertainty surrounding the legality of an R&D agreement close to the threshold of a block exemption will impose significant legal costs on companies. Where the thresholds are differentiated they can be interpreted as an instrument which steers firms in the direction of adopting a particular form of R&D agreement. This instrument has not been investigated in the economic literature to date.

The previous literature on R&D cooperation has not identified the precise nature of the link between the relative size of welfare losses under ex-post and ex-ante cooperation and the degrees of product market competition and technological opportunity. Shapiro (1985) and Scotchmer (2005) survey ex-ante and ex-post R&D cooperation. The economics literature has generally focused either on ex-ante (d'Aspremont and Jacquemin (1988), Kamien et al. (1992), Leahy and Neary (1997)) or on ex-post R&D cooperation (Gallini and Winter (1985), Green and Scotchmer (1995)). Both strands of this literature discuss the possibility of collusion arising from R&D cooperation and investigate efficiencies that R&D cooperation may create. Our paper extends this literature by evaluating ex-ante and ex-post cooperation as alternatives from the perspective of a competition authority. We do not consider the issue of collusion as this is equally possible under ex-ante and ex-post R&D cooperation.

The main theoretical contribution of the paper lies in its connection of dynamic R&D incentives and the static notions of competitiveness in product markets. Earlier work by Boone

[4] Article 81 of the Treaty of the European Communities prohibits agreements between firms that distort competition.

[5] The most recent European rules regarding licensing ex-post are contained in Regulation 772/04 adopted by the Commission in April 2004. For a review of this regulation refer to Korah (2004).

[6] The most recent European rules regarding ex-ante R&D cooperation are contained in the *Guidelines on Horizontal Cooperation Agreements*(Regulation 2659/2000) adopted by the Commission in 2000. Ex-ante agreements may also fall under the merger regulations (Regulation 139/2004) if they are considered to be *full-function joint ventures*. For a review of these Guidelines refer to Motta (2004) or any legal commentary on competition law such as Korah (2004) or Whish (2001).

[7] Korah (2004) (ch. 12) notes that the Commission has been more lenient towards full-function joint ventures than other ex-ante R&D agreements. She argues that this is due to the assumption that stronger integration of parties gives rise to greater efficiency gains. She also suggests that this bias in the rules was exploited by companies seeking exemptions for their cooperative ventures.

[8] Until May 2004 it was possible for companies to notify the Commission of an R&D cooperation agreement when in doubt about its legality. The Commission was then required to rule on the admissibility of the R&D cooperation agreement.

(2000, 2001) explores the connection between the degree of product market competition and innovation incentives in models of R&D competition. He does not consider the possibility of R&D cooperation. He shows that increases in product market competition will not always increase innovation incentives. We draw on his work in choosing the dimensions of product market competition which we investigate below. As we focus on R&D cooperation our paper is complementary to his work.

This paper builds on the unpublished work of Katsoulacos and Ulph (1999). They undertake a welfare analysis of Cournot duopolists who cooperate on R&D. Their work is extended by allowing for competitors of the cooperating firms in the product market and by exploring both Cournot and Bertrand competition. These extensions allow us to investigate the effects of variation in the intensity of product market competition on the size of welfare losses under ex-ante and ex-post R&D cooperation. We find that allowing for additional competitors in our model alters our findings substantially relative to a model of a duopoly of R&D competitors[9].

The structure of this paper is as follows: in the next section we introduce the model. Section 3 contains two central analytical results . In section 4 we analyse how variation in product market competition affects the second of these results. The following section provides an illustration of the analytical predictions of the model using simulation. Section 6 provides a conclusion.

2 The model

Consider an oligopolistic market in which firms may compete in prices or quantities. Prior to competing in the product market two *research active* firms engage in R&D in order to lower marginal costs and raise profits. Their R&D success is uncertain. The research active firms may contract to share R&D results either ex-ante or ex-post. Ex-ante contracts are modelled as RJVs, which means that the research active firms jointly maximise profits at the R&D stage. R&D investments are duplicative and therefore an ex-ante contract between the research active firms may contain a provision to centralise R&D in a common research facility.

Due to the uncertainty of the R&D process the research active firms face a trade-off. If both were to innovate centralisation would lead to cost savings. However the uncertainty of R&D may make it advantageous to undertake two simultaneous attempts at innovation. The choice between centralised and decentralised R&D will depend on the degree of technological opportunity. We model the inverse of technological opportunity as decreasing returns to scale in R&D which we denote as β.

The paper focuses on R&D cooperation between two firms who compete in the product market with m non-research active firms. We include further product market competitors in the model as we find their presence to have important effects for our results.[10].

The model is based on the linear demand specification:

$$p = a - q_i - s \sum_{\substack{j=1 \\ j \neq i}}^{m+2} q_j \qquad -1 \leq s \leq 1 \tag{1}$$

[9]Our paper departs from an implicit convention in the literature on R&D cooperation by not considering a duopoly. This complicates the derivation of our results. We believe this approach has its merits as the results that arise under duopoly in our model are not robust to the introduction of further product market competitors.

[10]Allowing for R&D investment by these firms would not alter the results derived below but would complicate the model.

Here s denotes the degree of substitution between firms' outputs and the parameter a is a general measure of market size. p represents price and q output. We rely on this specification to derive some of our results. Other results do not depend on it and will be more general. Where this is the case it is indicated.

The research active firms are assumed to have constant marginal costs $\bar{c}$ at the outset and their costs remain at this level should they fail to innovate. A firm that does innovate successfully lowers its marginal cost to $\underline{c}$. The non-research active firms have costs $\tilde{c}$[11]. We define the size of the inventive step which firms undertake as $g \equiv \frac{\bar{c}-\underline{c}}{a-\bar{c}}$.

The innovation process is modelled as a three stage game. At the first two stages only the research active firms take decisions. At the third stage all firms choose output or price.

Stage 1 Both research active firms choose a probability ρ of innovating, thereby incurring a cost $\gamma(\rho)$. This represents their investment to reduce marginal costs of production by g. Their objective functions at the first stage are:

$$\max_{\rho} \Pi_A(\rho, g) - 2\gamma(\rho, \beta) \qquad \text{Ex-ante R\&D cooperation} \tag{2}$$

$$\max_{\rho} \Pi_P(\rho, g) - \gamma(\rho, \beta) \qquad \text{Ex-post R\&D cooperation} \tag{3}$$

The expected revenue Π is a function of the probability of innovation, as well as the size of the innovation g and exogenous parameters specific to the product market model. Variables pertaining to the firms cooperating ex-post are denoted by P and to firms cooperating ex-ante by A.

Once the firms have determined the probabilities of innovation ρ_A, ρ_P the uncertainty about who has innovated is resolved.

Stage 2 The identity of the innovating firms is common knowledge at this stage. When only one of the two research active firms innovates, there is scope for information sharing. In this case the firms jointly choose whether or not to transfer the innovation to the firm that has failed to innovate.

Within the RJV the transfer is modelled as direct sharing of the innovation. In the non-cooperative equilibrium the innovating firm will license the innovation to their competitor for a license fee F.

Stage 3 Firms compete in the product market. Both Bertrand and Cournot competition with differentiated products are considered.

This game is solved by backwards induction. Before we go on to derive the solution of the game we describe the R&D cost function in more detail. The R&D cost function is defined to capture the following assumptions about the R&D process:

(i) research active firms always find it optimal to do some R&D,

(ii) the costs of R&D are strictly increasing in the probability of successful innovation,

(iii) no firm can ever innovate with certainty,

(iv) firms in different industries face differing degrees of decreasing returns to scale in R&D.

[11] Below we always restrict $\tilde{c}$ such that all firms are making positive profits post innovation.

These assumptions are captured through the following conditions on the R&D cost function ($\gamma(\rho, \beta)$):

(I) $\gamma(0, \beta) = \frac{\partial \gamma(0,\beta)}{\partial \rho} = 0; \quad \frac{\partial^2 \gamma(0,\beta)}{\partial^2 \rho} > 0$

(II) $\forall \rho, \quad 0 < \rho < 1 \;\; \gamma(\rho, \beta) > 0, \quad \frac{\partial \gamma(\rho,\beta)}{\partial \rho} > 0, \quad \frac{\partial^2 \gamma(\rho,\beta)}{\partial^2 \rho} > 0$

(III) $\lim_{\rho \to 1} \gamma(\rho, \beta) \to C > 0, \lim_{\rho \to 1} \frac{\partial \gamma(\rho,\beta)}{\partial \rho} \to \infty$

Note that henceforth the probability of innovation when operating a single research facility will be denoted as $\boldsymbol{\varrho}$ and the probability of innovation per research facility when operating two facilities will be $\boldsymbol{\rho}$'s. We also define the overall probability of innovation when two research facilities are operated as:

$$\tilde{\varrho} \equiv 1 - (1 - \rho)^2$$

Conditions $I - III$ do not determine all the relevant properties of the R&D cost function. They imply nothing about the relative costs of operating one or two labs at any given overall probability of innovation $\tilde{\boldsymbol{\varrho}}$.

While it is easy to show that with constant returns to scale in R&D the firms in an RJV can lower their costs of R&D by centralising their research in one facility[12] this is not clear with decreasing returns to scale in R&D. Functions for which firms will switch back and forth between centralising and decentralising R&D activities exist[13] but this paper focuses on a class of functions for which the firms may switch at most once. This setup provides a reasonable degree of generality while remaining tractable. The resulting analysis subsumes cases in which the number of research facilities does not change.

It will always be that case that $2\gamma(1) > \gamma(1)$, i.e. for very high probabilities of innovation it will always be less costly to operate a single laboratory. We assume that the R&D cost functions cross only once:

(IV) $\exists \rho_X, \varrho_X \in]0, 1[$ s.t. $2\gamma(\rho_X) = \gamma(\varrho_X)$ and $2\frac{\partial \gamma(\rho_X,\beta)}{\partial \rho_X} > \frac{\partial \gamma(\varrho_X,\beta)}{\partial \varrho_X}$.

3 Solution of the model

In this section the game set out previously is solved. The aim is to derive results about the size and direction of the welfare losses associated with ex-ante and ex-post R&D competition.

The analysis of the product market competition stage of the model is brief as the results are well known. We go on to show when firms will share an innovation with their rival. Finally we compare the welfare losses that arise under ex-ante R&D cooperation with those that arise under ex-post R&D cooperation.

3.1 Stage 3: Solutions of the linear conjectural variations model

At the third stage of the game the outcome of the innovation process and the information sharing decision is known to all firms. In order to capture both the Bertrand and the Cournot model

[12]The probability of innovating with one lab, will always be greater than the probability of innovating with two labs, each of which is half has likely to innovate as a single lab: $\tilde{\varrho} > \left(\frac{\tilde{\varrho}}{2}\right)^2 + 2\left(1 - \frac{\tilde{\varrho}}{2}\right)\frac{\tilde{\varrho}}{2} = \tilde{\varrho} - \frac{\tilde{\varrho}^2}{4}$ where $\tilde{\varrho} > 0$

[13]Notably functions which include a fixed cost for the operation of each laboratory.

of product market competition we adopt a conjectural variations representation of product market competition and restrict firms' conjectures to capture Cournot and Bertrand competition.

Here we present the expressions for outputs and profits of the firms in the following cases: both firms innovate, only one firm innovates and shares the innovation with its rival, only one firm innovates and the innovation is not shared and neither firm innovates. The derivation of these expressions is set out in appendix A.1. The following indeces are employed throughout the paper: variables referring to cases in which: -both firms innovate are indexed as $_{11}$; - a firm is sole innovator is indexed as $_{10}$; -a firm is alone in not innovating as $_{01}$; -neither firm innovates as $_{00}$.

Both firms innovate or information sharing occurs

$$q_{11} = \left(\frac{A}{d}\right)\left[1 + g\left(1 + m\theta\right) - m\theta z\right], \qquad \pi_{11} = \nu q_{11}^2$$
$$\tilde{q}_{11} = \left(\frac{A}{d}\right)\left[1 + z\left(1 + 2\theta\right) - 2g\theta\right], \qquad \tilde{\pi}_{11} = \nu \tilde{q}_{11}^2$$

No information sharing due to failure to innovate

$$q_{00} = \left(\frac{A}{d}\right)\left[1 - z\theta m\right], \qquad \pi_{00} = \nu q_{00}^2$$
$$\tilde{q}_{00} = \left(\frac{A}{d}\right)\left[1 + z\left(1 + 2\theta\right)\right], \qquad \tilde{\pi}_{00} = \nu \tilde{q}_{00}^2$$

No information sharing after innovation

$$q_{01} = \left(\frac{A}{d}\right)\left[1 - \theta g - m\theta z\right], \qquad \pi_{01} = \nu q_{01}^2$$
$$q_{10} = \left(\frac{A}{d}\right)\left[1 + g\left(1 + \theta m\right) + g\theta - m\theta z\right], \qquad \pi_{10} = \nu q_{10}^2$$
$$\tilde{q}_{01} = \left(\frac{A}{d}\right)\left[1 + z\left[1 + 2\theta\right] - \theta g\right], \qquad \tilde{\pi}_{01} = \nu \tilde{q}_{01}^2$$

3.2 Stage 2: The decision to share an innovation

Sharing of the innovation becomes an issue, whenever just one of the research active firms fails to innovate. In this case the firms must determine whether and how much information to exchange.

The joint profits of the research active firms are convex in costs and therefore there can be no interior solution for the level of information sharing; the two firms will either share information fully or not at all. This reasoning applies both in the non-cooperative equilibrium and to an RJV. The license fee payed in the non-cooperative equilibrium does not alter joint profits of the research active firms, but affects only the distribution of profits between the two firms.

The following result can be derived on the basis of the product market model analysed in the previous section:

Result 1
The incentive to share an innovation with a competing research active firm increases with the number of outside competitors.

The intuition for this result is that the research active firms will always be able to increase their market share at the expense of outside competitors by fully sharing information. Stealing business from outside firms in this manner becomes increasingly profitable as the number of outside competitors rises. Simultaneously the effect on the market price which is exerted by cost asymmetries between the research active firms dwindles as the number of competitors rises. This reduces the benefits to the research active firms from manipulating the market price through the asymmetric adoption of an innovation by their members.

Previously Katsoulacos and Ulph (1998) showed that duopolistic firms have an incentive not to share an innovation with one another in order to maintain higher prices in the product market. They argued that ex-ante cooperation on R&D in an RJV might therefore have anti-competitive effects. Our analysis below demonstrates that this finding is rather special. In the context of the linear demand function we introduced above it holds for duopolies and in rare cases triopolies.

We show in appendix A.2 that the difference in joint profits when both firms employ an innovation and when one does not can be reduced to the following expression:

$$\Sigma_{11} - \Sigma_{10} = \underbrace{\frac{\bar{c} - \underline{c}}{a - \bar{c}}}_{g} - \frac{2\,(1 + m\theta)}{2\theta^2 + (1 + m\theta)\,(\theta\,[2 - m\,(1 - 2\mu)] - 1)} \tag{4}$$

where $\theta \equiv \frac{s}{2 - s(1+\delta)}$ and $\mu \equiv \frac{\bar{c} - \tilde{c}}{\bar{c} - \underline{c}} = \frac{z}{g}$

As Katsoulacos and Ulph (1999) show in a Cournot duopoly with homogeneous products the two research active firms will share an innovation as long as it is not too great: $g < \frac{2}{3}$. It is not hard to see that under Bertrand competition as products become increasingly homogeneous ($\theta \to \infty$) the threshold beyond which firms no longer share innovations drops to zero. These results show that duopolist may jointly benefit from cost asymmetries if these are sufficiently large. Katsoulacos and Ulph (1998) point out that duopolists reduce competition and damage consumers by not sharing an innovation in this way. Of course such a course of action implies that there is a side payment from the firm adopting an innovation to the non-adopting firm.

When the research active firms compete with additional firms in the product market the gains to stealing business from these additional firms outweigh any gains from not sharing an innovation. We show in the appendix that the threshold beyond which the research active firms choose not to share the innovation is usually so high, that the firm which does not employ the innovation, would exit the market. Comparing the zero profit condition for the firm which does not employ the innovation with the inequality above we find that the research active firms will share an innovation whenever:

$$m > \sqrt{2} - \frac{1}{\theta} \tag{5}$$

This inequality shows that often just one outside competitor is sufficient to make the sharing of an innovation profitable. Whenever there are at least two such firms sharing of the innovation becomes a certainty.

In the remainder of this paper we restrict ourselves to the analysis of those cases in which the firms cooperating ex-ante will share the innovation.

3.3 Stage 1: The investment decision

This section focuses on the comparison of welfare losses that arise under ex-ante and ex-post R&D cooperation. In this section the main result of the paper is presented and then proved. The results we derive here do not depend on the specific model of product market competition we have derived above.

We begin by setting out the main result of the paper. To prove it we develop our model and derive an intermediate result regarding the kind of welfare losses that arise when firms chose to centralise R&D. We then go on to prove our main result regarding the relative size of welfare losses under ex-ante and ex-post R&D cooperation.

It can be shown that:

Result 2

Welfare losses under ex-ante R&D cooperation are likely to be lower than under ex-post R&D cooperation when:

- *decreasing returns to scale in R&D are lower,*
- *the ratio of the increase in the social surplus to the increase in joint profits of the research active firms which is due to an innovation is smaller.*

This surplus-profits-differences ratio *is defined as:*

$$\alpha \equiv \frac{S_{11} - S_{00}}{\Sigma_{11} - \Sigma_{00}} \quad \text{where } 1 \leq \alpha < \infty \tag{6}$$

The interpretation of the surplus-profits-differences ratio in terms of variables that are widely related to the degree of product market competition in the literature, is the subject of the following section.

As we allow that an ex-ante agreement between the research active firms encompasses the closure of a research facility three possibilities arise logically: (a) it is privately and socially optimal to decentralise R&D ,(b) it is privately and socially optimal to centralise R&D and (c) the socially- and privately optimal organisation of R&D diverge.

Before we are able to prove the result outlined above we describe how the size of the innovation under consideration determines which of these possibilities applies. We describe the social welfare function that applies to this game and its comparative statics with respect to the size of the innovation (g) and the degree of decreasing returns to scale in R&D (β). We also consider whether firms in an ex-ante R&D agreement will centralise their R&D too early or too late w.r.t. the social optimum.

The social welfare function

In the presence of decreasing returns to scale in R&D the research active firms will centralise their R&D only if these are sufficiently weak. We define two functions w_1, w_2 which express the welfare levels attained through the operation of one or two research facilities, respectively:

$$w_1 = S_{11} \cdot \varrho + S_{00} \cdot [1 - \varrho] - \gamma(\varrho, \beta) \tag{7}$$

$$\begin{aligned} w_2 &= S_{11} \cdot \left[1 - (1-\rho)^2\right] + S_{00} \cdot [1-\rho]^2 - 2\gamma(\rho, \beta) \\ &= S_{11} \cdot \tilde{\varrho} + S_{00} \cdot [1 - \tilde{\varrho}] - \Gamma(\tilde{\varrho}, \beta) \end{aligned} \tag{8}$$

where $\Gamma(\tilde{\varrho}, \beta) \equiv 2\gamma\left(1 - \sqrt{1 - \tilde{\varrho}}, \beta\right)$. The social welfare function is the outer envelope of these two functions:

$$W = \max[w_1(\varrho), w_2(\tilde{\varrho})]$$

Based on this definition we can demonstrate the following result:

Result 3

Social welfare is more likely to maximised under centralised R&D if:
(a) the innovation which firms are seeking is large, (b) the degree of decreasing returns to scale in R&D is low.

Comparative statics w.r.t. the size of the innovation Ceteris paribus, a larger innovation will increase S_{11} relative to S_{00} and lead to a higher probability of innovation. This can be demonstrated using the first order conditions for w_1 and w_2. The maxima of the functions w_1 and w_2 can be found where the following first order conditions hold:

$$S_{11} - S_{00} = \gamma'(\varrho_{SP}, \beta) \quad \text{for } w_1 \qquad \text{and} \qquad S_{11} - S_{00} = \Gamma'(\tilde{\varrho}_{SP}, \beta) \quad \text{for } w_2 \tag{9}$$

The marginal benefit derived from an innovation rises where the innovation is larger and therefore the level of equilibrium R&D investment rises and so does the equilibrium probability of innovation. Furthermore as the innovation increases, the social return of centralised R&D, the maximum value of w_1, increases relative to the social return of decentralised R&D, the maximum value of w_2.

To see this consider the probability ϱ_x where w_1 and w_2 intersect. By assumption (IV) $\Gamma'(\tilde{\varrho_X}, \beta) > \gamma'(\varrho_X, \beta)$. If $S_{11} - S_{00} = \gamma'(\varrho_X, \beta)$ then w_1 attains it's maximum at the point of intersection of the two welfare functions. By assumption (IV) and the first order conditions set out above w_2 is decreasing at this point. This implies that $\max w_2 > \max w_1$. If the size of the innovation increases further, such that $S_{11} - S_{00} = \Gamma'(\tilde{\varrho_X}, \beta)$ then w_2 attains it's maximum at the point of intersection and w_1 will be increasing at this point by the same reasoning used above. This shows that as the size of the innovation increases it becomes more likely that $\max w_1 > \max w_2$. Then it is also more likely that social welfare is maximised by the centralisation of R&D.

Comparative statics w.r.t. the degree of decreasing returns to scale in R&D Assume that a higher degree of decreasing returns to scale means higher R&D costs everywhere along the R&D cost function:

$$\frac{\partial \gamma}{\partial \beta} > 0$$

Then a higher degree of decreasing returns to scale raises the marginal cost of undertaking R&D and lowers the equilibrium R&D investment and the equilibrium probability of innovation in the social optimum. This implies that, ceteris paribus, the social planner may now prefer to operate two research facilities if they were initially operating one.

The private decision to centralise R&D The preceding analysis of the social welfare function shows that as the size of innovations increases, the industry moves from states in which it is socially optimal to operate two research facilities to states in which it is socially optimal to operate only one. It remains to investigate whether firms party to an ex-ante R&D agreement will centralise more readily than the social planner or not.

Consider the objective function of firms cooperating ex-ante under centralised and decentralised R&D:

$$\begin{aligned} &\max_{\rho_A} \ \Pi_A(\rho, g, \alpha) - 2\gamma(\rho, \beta) \\ \Leftrightarrow &\begin{cases} \max\limits_{\rho_A} \Sigma_{11}\left(1 - (1-\rho_R)^2\right) - \Sigma_{00}\left(1-\rho_R\right)^2 - 2\gamma(\rho_R, \beta) & \text{Decentralised R\&D} \\ \max\limits_{\varrho_A} \Sigma_{11} \cdot \varrho_R + \Sigma_{00} \cdot (1 - \varrho_R) - \gamma(\varrho_R, \beta) & \text{Centralised R\&D} \end{cases} \end{aligned} \tag{10}$$

The first order conditions which determine the privately optimal R&D investments of the firms in an ex-ante R&D agreement show that the private marginal benefit from R&D investment is always below the social marginal benefit which we derived previously:

$$\begin{aligned} [1-\rho_A]\left(\Sigma_{11}-\Sigma_{00}\right) &= \gamma'(\rho_R,\beta) && \text{Decentralised R\&D} \\ \Sigma_{11}-\Sigma_{00} &= \Gamma'(\tilde{\varrho}_R,\beta) && \text{Centralised R\&D} \end{aligned} \tag{11}$$

First of all we find that firms in ex-ante R&D agreements will always *underinvest* in R&D relative to the social optimum[14]. It follows from the underinvestment result that firms in an ex-ante R&D agreement will not centralise R&D for a range of innovations for which this would be socially optimal. They will only choose to centralise their R&D when their private marginal benefit from R&D is as great as the social return to R&D at which the social planner prefers to centralise R&D. This implies that we must consider the following three cases in order when proving result 2:

1. it is socially and privately optimal to decentralise R&D,
2. it is socially optimal but not privately optimal to centralise R&D,
3. it is socially and privately optimal to centralise R&D in one research facility.

We consider each case in turn.

Decentralised R&D

Here we analyse the range of parameters for which it is neither socially nor privately optimal to centralise R&D. Then the welfare function W is just w_2. We showed above that the firms in an RJV will always underinvest relative to the social optimum. This gives rise to a welfare loss which we define as:

$$l_A = \frac{W_{SP}-W_A}{W_{SP}} = \frac{L_A}{W_{SP}} \tag{12}$$

where W_{SP} is the welfare level, which would be attained if the firms invested at the socially optimal level and W_A is the welfare level which they achieve by maximising profits:

$$W_{SP} \equiv S_{11} - (1-\varrho_{SP})\left[S_{11}-S_{00}\right] - \Gamma(\varrho_{SP},\beta) \tag{13}$$

$$W_A \equiv S_{11} - (1-\varrho_A)\left[S_{11}-S_{00}\right] - \Gamma(\varrho_A,\beta) \tag{14}$$

The diagram below illustrates the welfare loss l_A associated with the probability interval $[\varrho_A, \bar{\varrho}_A]$. This diagram also illustrates that the probability of innovation in the non-cooperative equilibrium must lie within the range $[\varrho_A, \bar{\varrho}_A]$ if the welfare loss in the non-cooperative equilibrium is to be smaller than that in the cooperative equilibrium.

We are now in a position to consider the equilibrium R&D investment of firms in a non-cooperative equilibrium. Their objective function is:

$$\max_{\rho_P} \; \Pi_P(\rho_P, g, \alpha) - \gamma(\rho,\beta) \tag{15}$$

$$\Leftrightarrow \max_{\rho_P} \left[\rho_P\rho\pi_{11} + (1-\rho_P)\,\rho\,(\pi_{11}-F) + \rho_P\,(1-\rho)\,(\pi_{11}+F) + (1-\rho_P)\,(1-\rho)\,\pi_{00} - \gamma(\rho_P,\beta)\right]$$

Notice that the objective function for the non-cooperative firms includes the payment of a license fee $\boldsymbol{F}$ in the case in which only one firm innovates. This fee is payed by the non-innovating firm (i.e. that indexed $_{01}$). The fact that it is payed follows from result 1. The size of the license fee will depend on the relative bargaining power of the two firms.

[14]This is the result is analogous to the underinvestment result derived by Arrow (1962)

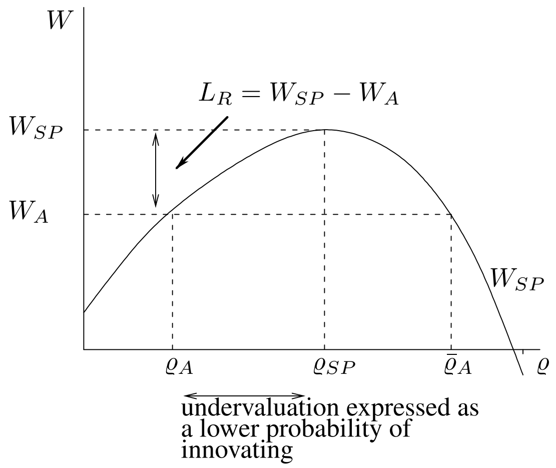

Figure 1: **The welfare function under decentralised R&D**

The first order condition characterising optimal R&D investment (ϱ_P) by the firms cooperating on R&D ex-post is:

$$F\sqrt{1-\varrho_P}\left(1-\sqrt{1-\varrho_P}\right)+(\pi_{11}-\pi_{00})+F=\Gamma'(\varrho_P,\beta)\ . \tag{16}$$

Define the welfare loss arising in this equilibrium as:

$$l_P=\frac{W_{SP}-W_N}{W_{SP}}=\frac{L_N}{W_{SP}}\quad \text{where } W_P\equiv S_{11}-(1-\varrho_P)\left[S_{11}-S_{00}\right]-\Gamma(\varrho_P,\beta) \tag{17}$$

To understand how the welfare losses that arise in this ex-post cooperation equilibrium relate to those that arise in the case of ex-ante R&D cooperation we compare the firms' R&D incentives in both equilibria. These are set out in Table 1 below.

Following Beath et al. (1989) we distinguish between the *profit incentive* and the *competitive threat*. The former captures the incentive of a firm to invest in R&D if its rivals undertake no R&D investment, whereas the latter captures its incentive to invest if the rivals are almost certain to innovate. The competitive threat captures the threat of the disadvantage for a firm if a rival firm should innovate while it fails. This incentive can only arise in models that allow for uncertainty in R&D.

Comparing Innovation Incentives		
	The Profit Incentives	The Competitive Threats
Social Optimum	$S_{10}-S_{00}$	0
RJV	$\Sigma_{11}-\Sigma_{00}$	0
Non-Cooperative Firms	$\pi_{11}-\pi_{00}+F=$ $\frac{1}{2}(\Sigma_{11}-\Sigma_{00})+F$	F

Table 1

The table shows that in the cooperative equilibrium the profit incentive is below that of the social planner. Here underinvestment arises because firms fail to take account of the social surplus created by their innovations. We refer to this as the *undervaluation effect*. The competitive threat is nil under ex-ante R&D cooperation and in the social optimum because the expected return from innovation is the same regardless of whether one or both firms innovate.

In case of ex-post R&D cooperation the table shows that the profit incentive may be greater or smaller than that under ex-ante R&D cooperation. It would be greater if the innovating firm were able to extract the entire return to receiving a license, $\pi_{11} - \pi_{01}$ from the non-innovating firm as a license payment. More interestingly firms cooperating ex-ante face a positive competitive threat. Consequently firms cooperating ex-post may invest in R&D to a much greater extent than firms cooperating ex-ante. Their investment may even be excessive from a social point of view. This result is reminiscent of the patent race literature and arises for the same reasons: the presence of a competitive threat.

Notice that the degree of underinvestment by firms cooperating ex-ante is determined solely by the surplus-profits-differences ratio (α). An increase in this ratio would increase the size of the interval $[\underline{\varrho}_A, \bar{\varrho}_A]$ (Compare figure 1). The larger this interval the more likely it is that the welfare losses under ex-ante R&D cooperation is greater than that under ex-post R&D cooperation.

If the license fee that may be payed by a firm under ex-post R&D cooperation is a function of the profits which an innovation conveys then the license fee will be decreasing in the surplus-profits-differences ratio. The competitive threat which may give rise to overinvestment in the case of ex-post R&D cooperation will decline at the same time as the interval $[\underline{\varrho}_A, \bar{\varrho}_A]$ becomes larger. In the case of decentralised R&D, the firms cooperating ex-ante will be more likely to produce smaller welfare losses than firms cooperating ex-post, the lower is the surplus-profits-differences ratio.

Socially Suboptimal Decentralised R&D

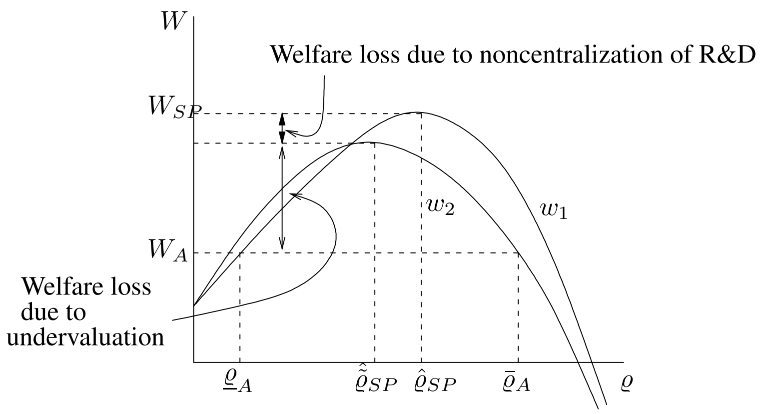

Figure 2: **The welfare function when the RJV does not centralise R&D but this is socially efficient.**

In this case it is socially but not privately optimal to centralise R&D. This implies that the maximum value of w_1 is greater than the maximum value of w_2. Here the maximum welfare level which could be privately achieved through either an ex-ante or an ex-post R&D agreement would be the maximum of the welfare function w_2. The difference between the social welfare levels attainable in the optimum and in the case in which R&D remains decentralised is derived below:

$$\max w_1 = \hat{W}_{SP} \equiv S_{11} - (1 - \hat{\varrho}_{SP})\,[S_{11} - S_{00}] - \gamma(\hat{\varrho}_{SP}, \beta) \tag{18}$$

$$\max w_2 = W_{SP} = S_{11} - (1 - \varrho_{SP})\,[S_{11} - S_{00}] - \Gamma(\varrho_{SP}, \beta) \qquad \text{compare (13)}$$

Then the difference of these is l_{nc} :

$$l_{nc} \equiv \frac{\hat{W}_{SP} - W_{SP}}{\hat{W}_{SP}} \tag{19}$$

Call this welfare loss l_{nc} for the loss arising from **n**ot **c**entralising R&D. Define $\hat{\tilde{\varrho}}$ as that probability at which w_2 is maximised. The question whether firms over- or underinvest can then be restated with respect to this probability $\hat{\tilde{\varrho}}$. The diagram above clarifies that the analysis of the previous section can be reapplied here. The only difference being that the welfare losses of the RJV and the non-cooperative firms which we derived there are augmented by l_{nc}.

Figure 2 demonstrates that the conclusions of the previous section also apply when the RJV fails to close a research facility although this would be socially optimal.

Centralised R&D

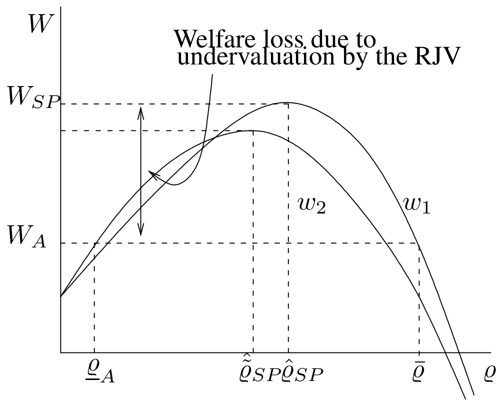

Figure 3: **The welfare function when the RJV centralises R&D and this is socially efficient**

In this case both the firms and the social planner optimally centralise R&D in a single research facility. The welfare level attainable in the social optimum is defined as it was in the previous case in equation (18). The welfare level attainable by firms cooperating ex-ante is defined in equation (17). The firms' objective function that applies here was introduced in equation (10) above. Maximising this we obtain the probability of innovation for firms cooperating ex-ante under centralised R&D:

$$\Sigma_{11} - \Sigma_{00} = \gamma'(\varrho^c_A, \beta) \tag{20}$$

Define the welfare level and the welfare loss which the firms cooperating ex-ante attain by centralising R&D as follows:

$$W^c_R \equiv S_{11} - (1 - \varrho^c_A)\,[S_{11} - S_{00}] - \gamma(\varrho^c_A, \beta) \qquad l^c_A = \frac{\hat{W}_{SP} - W^c_A}{\hat{W}_{SP}} \tag{21}$$

Firms cooperating ex-post are unable to centralise R&D. This implies that the welfare loss l_P is always augmented by the welfare loss l_{nc} which arises because of this failure to centralise R&D.

In contrast the firms cooperating ex-ante now operate the correct number of research facilities and the welfare loss associated with firms cooperating ex-post only arises from undervaluation. The diagram above illustrates this case.

We have now demonstrated that Result 2 holds independently of the precise organisation of R&D. In the following section we turn to the interpretation of this result.

4 Competition and the surplus-profits ratio

We showed above that welfare losses under ex-ante R&D cooperation are more likely to be smaller than under ex-post R&D cooperation the lower is the surplus-profits-differences ratio. In this section the relationship between the ratio and measures of competition in the product market is established. We show that the following results hold given a linear demand function and product market competition between $m + 2$ oligopolists:

Result 4
Ceteris paribus, the surplus-profits-differences ratio is smaller:

- *under Cournot competition than under Bertrand competition if* $m > 1$ [15],
- *the more inefficient are the outside competitors of the* research active *firms,*
- *when innovations undertaken by the* research active *firms are larger.*

This result provides comparative statics results on the surplus-profits-differences ratio. It demonstrates that lower product market competition leads to a smaller surplus-profits-differences ratio on the basis of three different measures of the degree of ex-post competition in the product market. This is a purely technical result which is significant only in light of the theory we have developed above.

There we demonstrated that the ratio of differences in social surplus and profits which characterises a specific R&D project can be used to determine the likelihood that social welfare will be greater under ex-ante R&D cooperation than under ex-post R&D cooperation. In particular we argued that welfare losses due to ex-ante cooperation would be more likely to be smaller than those under ex-post cooperation if this ratio were smaller.

Combining the two results we find that the likelihood that ex-ante R&D cooperation is preferable to ex-post R&D cooperation rises the smaller the surplus-profits-differences ratio. This is the case wherever product market competition is weaker.

In our view this finding suggests that competition policy rules should discriminate against ex-ante R&D cooperation when product market competition is strong and in favour of ex-ante R&D cooperation when it is weak. This would raise R&D incentives relative to the current situation in which the rules governing R&D competition to not discriminate between ex-ante and ex-post R&D agreements. We discuss this argument at length in the conclusion. Here we turn to the derivation of the last result.

[15] In cases in which there is only one further outside competitor $m = 1$ who is more efficient ex-ante than the research active firms it may be that the surplus profits ratio under Bertrand competition is smaller than under Cournot competition.

The precise implications of each part of this result will be discussed after each proof. The surplus-profits-differences ratio may be re-expressed as a convex combination of two other ratios. We show this in appendix A.3. We demonstrate there that this is true for the model of linear demand introduced previously.

$$\begin{aligned}
\alpha \equiv \frac{\triangle S}{\triangle \Sigma} &= 1 + \frac{\triangle CS}{\triangle \Sigma} && \text{where } 1 \leq \alpha < \infty \\
&= 1 + \left[1 + \frac{\triangle \tilde{\Sigma}}{\triangle \Sigma}\right] \frac{(1-s)}{2\nu} + \frac{\triangle (Q^2)}{\triangle (q^2)} \frac{s}{4\nu} && \nu \equiv (1 - s\delta). \qquad (22)
\end{aligned}$$

The expression shows that the surplus-profits-differences ratio is a convex combination of two other ratios: the ratio of the change in others' profits $(\triangle \tilde{\Sigma})$ to the change in profits of the RJV and that of the change in total output to the change in output of the RJV. The larger the share of the contracting firms' profits out of those of their competitors and the larger their output relative to total output the smaller the surplus-profits ratio. We manipulate this expression further in order to derive a form which is most useful for further analysis[16]:

$$\alpha = 1 + \frac{(1-s)\theta}{2s(1+m\theta)} \left[1 + \frac{[2+g+m(1+z)]}{[2+g+m\theta\,(g-2z)]} + \frac{(1+s(m+1))}{\nu}\right] \qquad (23)$$

We consider each element of the result in turn and discuss its specific interpretation.

Comparing Cournot and Bertrand competition Here we show that the surplus-profits-differences ratio in our model is almost always smaller under Cournot competition than under Bertrand competition.

The difference between the surplus profits ratios in the two cases can be shown to be:

$$\begin{aligned}
\alpha_B - \alpha_C = &\left(\frac{s}{(2+s(m-2))} - \frac{s(1-s)}{(2+s(m-1))} + \frac{s}{2}\right) + s\,[2+g+m(1+z)] \cdot \\
&\left[\frac{1}{(2+s(m-2))}\frac{1}{[2+g+m\theta_B\,(g-2z)]} - \frac{1}{(2+s(m-1))}\frac{1}{[2+g+m\theta_C\,(g-2z)]}\right]
\end{aligned} \qquad (24)$$

Where the cost disadvantage of the research active firms ex-ante is greater or equal to their cost advantage ex-post ($2z > g$), the surplus profits ratio under Bertrand must be greater than that under Cournot. In this case both brackets in the expression above are positive, as a comparison of the expressions within each of the brackets quickly reveals. Where the cost advantage of the research active firms ex-post is greater than their cost disadvantage ex-ante ($g > 2z$) we can show that $\alpha_B - \alpha_C > 0$ if $m > 1$. The proof is quite messy and is relegated to appendix A.3.

Cournot competition is generally regarded as being less competitive than Bertrand competition on account of the lower price-cost margins that obtain under Bertrand competition. Vives (1999)(Ch 6.3) provides a discussion of the assumptions needed for this characterisation. Boone (2001) employs the switch from Cournot to Bertrand as a device to increase product market competition as we do here.

As Vives (1999) (Ch 5.2) notes Cournot models characterise markets in which firms fix production capacities whereas Bertrand models are more suited to markets in which firms can

[16] The derivation is relegated to the appendix.

commit to a given price and are able to meet any level of demand at that price. Our finding above suggests that ex-ante R&D cooperation should be encouraged in Cournot markets whereas ex-post R&D cooperation should be encouraged in Bertrand markets.

Efficiency of the competitors The surplus-profits-differences ratio is increasing in z:

$$\frac{\partial \alpha}{\partial z} = \frac{(1-s)}{2\nu(\nu+1+s(m-1))}\left[2\nu\left(\frac{s}{1-s}\right)\frac{m(2+g)\left[1+\theta(m+2)\right]}{\left[2+g+m\theta\left(g-2z\right)\right]^2}\right] > 0 \tag{25}$$

z measures the efficiency of the research active firms' competitors relative to the ex-ante cost level of the research active firms: $z \equiv \frac{\bar{c}-\tilde{c}}{a-\bar{c}}$. The derivative shows that lower efficiency of competitors on this measure will lead to a decrease in the surplus-profits-differences ratio.

The implication of this finding is that firms should be encouraged to cooperate on R&D ex-ante more strongly the lower the efficiency of their remaining product market rivals and vice versa.

Size of the innovation The surplus-profits-differences ratio is decreasing in g:

$$\frac{\partial \alpha}{\partial g} = -\frac{(1-s)}{2\nu(\nu+1+s(m-1))}\left[2\nu\left(\frac{s}{1-s}\right)\frac{m(1+z)\left[1+\theta(m+2)\right]}{\left[2+g+m\theta\left(g-2z\right)\right]^2}\right] < 0 \tag{26}$$

g measures the size of the innovation attempted by the research active firms. This innovation is modelled as a reduction in marginal costs. The derivative shows that larger innovations on the part of the research active firms lead to a reduction in the surplus-profits-differences ratio.

Here the implication is that firms should be more strongly encouraged to cooperate ex-ante the larger the innovative step they are seeking to achieve.

It is perhaps interesting to note that we cannot derive clear implications of variation in the degree of product market substitution or the number of outside competitors for changes in the surplus-profits-differences ratio. These variables are often used in symmetric oligopoly models to capture changes in the degree of product market competition.

5 Simulations

In this section we present the results of a simulation [17] of the model presented above. We use these simulations to show that the main predictions of the model as presented in result 2 above hold true. The simulations also provide an illustration of the ancillary claims we have made:

- that firms cooperating ex-ante will not always find it optimal to close a lab , even when this is socially optimal,

- that firms cooperating ex-post may reduce the welfare loss to zero whereas firms cooperating ex-ante always underinvest.

The underlying premise of the following simulations is that all the firms in an industry will face the same degree of technological opportunity (β is constant) and the same competitive environment, whereas they may at different times attempt innovations of very different

[17] The model was simulated using a program written and run under Mathematica

sizes. In other words the size of innovation g is taken to be an exogenously varying parameter whereas other exogenous parameters of our model are taken to be fixed and characteristic of a given industry.

Result 2 predicts that in markets with strong decreasing returns to scale in R&D and with a high surplus-profits-differences ratio (α), the welfare losses in the ex-ante equilibrium exceed those in the ex-post equilibrium. Result 2 also predicts that in markets with weakly decreasing returns to scale and very low competitiveness, the research active firms produce a lower welfare loss in an ex-ante equilibrium than in an ex-post equilibrium.

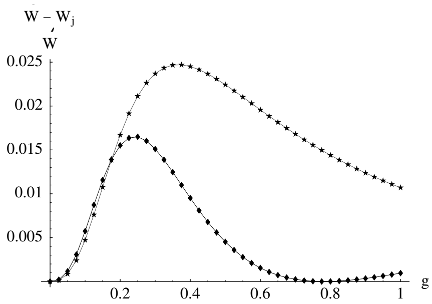

Figure 4: **The case in which the welfare loss under ex-ante cooperation is greater.** Here $A = 2$, $m = 4$, $s = 0.9$, $\boldsymbol{\beta} = 0.95$ and $\delta = 1$, which implies **Bertrand** competition.

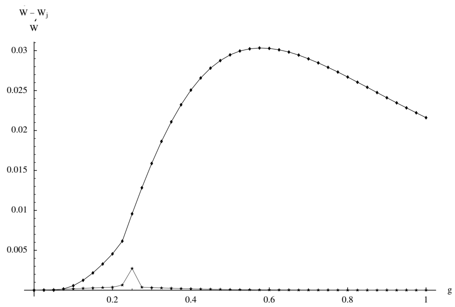

Figure 5: **The case in which the welfare loss under ex-post cooperation is greater.** Here $A = 2$, $m = 2$, $s = 0.9$, $\boldsymbol{\beta} = 0.2$ and $\delta = 0$, which implies **Cournot** competition.

In each of the plots above the percentage welfare losses arising in a ex-post equilibrium are represented by the line joining the $\star$ and the welfare losses in the ex-ante equilibrium are represented by the line joining the $\diamond$.

In the left-hand plot the welfare losses arising under ex-ante cooperation exceed those under ex-post cooperation for innovations of almost every size. We also observe that the welfare loss due to licensing approaches zero as the innovations become large enough.

In the right-hand plot the welfare losses under ex-post cooperation are always greater than those under ex-ante cooperation. The spike in the welfare loss plot for ex-ante cooperation indicates the size of innovation at which it becomes profit maximising to centralise R&D. The spike indicates rising welfare losses due to the socially suboptimal decision to operate two laboratories. This is also predicted by the theory set out above.

In the next set of plots we investigate what happens at parameter combinations for which the model provides no strong conclusions.

We begin by reducing the degree of product market competition whilst maintaining the same high level of decreasing returns to scale which we used in the first plot above. In the left hand plot we simulate Cournot competition.

The plot on the left illustrates clearly how the firms cooperating ex-post move from undervaluation to overvaluation as the innovation becomes more important. The low level of technological opportunity is making it unprofitable and socially suboptimal to centralise R&D so that there is no spike in the plot.

The plot on the right plots we simulate the model for the same high degree of technological opportunity as in the right-hand plot above. Here we assume a high degree of product market competition. The plot shows how initially high welfare losses arising under ex-ante cooperation die out as R&D is centralised. The plot also demonstrates that once R&D is centralised the welfare losses in the ex-post equilibrium can never be reduced to zero, as a consequence

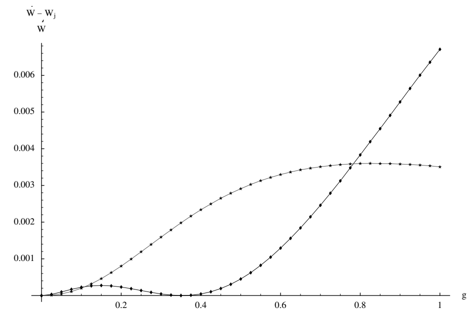

Figure 6: **The first indeterminate case**
Here $A = 2$, $m = 2$, $s = 0.9$, $\boldsymbol{\beta} = 0.85$ and $\delta = 0$, which implies Bertrand competition.

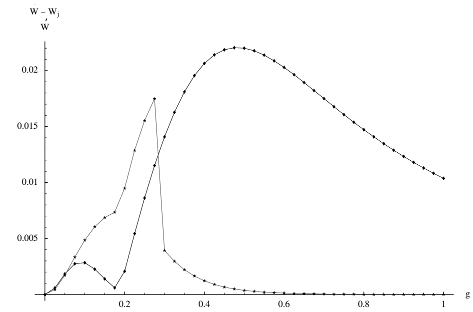

Figure 7: **The second indeterminate case**
Here $A = 2$, $m = 4$, $s = 2$, $\boldsymbol{\beta} = 0.2$ and $\delta = 1$, which implies Bertrand competition.

of the inability of the firms to centralise R&D under ex-post cooperation.

6 Conclusion

In this paper we have compared the welfare losses that arise under ex-ante and ex-post cooperation on R&D. We show that the level of these welfare losses depends on the strength of product market competition and on the degree of technological opportunity in an industry. Welfare losses under ex-ante cooperation will be lower than those under ex-post cooperation where technological opportunity is high and product market competition is weak. The converse result also holds. There are intermediate parameter combinations where the difference of the welfare losses depends on the size of the innovation which firms are pursuing.

In order to make these predictions we introduce the surplus-profits-differences ratio which captures the gulf between the innovation incentives under ex-ante cooperation and the social planner's second best innovation incentives. We show that this ratio can be used to predict how likely it is that ex-ante R&D cooperation produces smaller welfare losses than ex-post R&D cooperation and vice versa. We link this ratio to measures of the intensity of product market competition such as the ex-ante cost differences between firms and the type of product market competition (Cournot/Bertrand).

These findings are derived from a three stage model of R&D cooperation which endogenizes the decision to share innovations. In this model we allow for product market competition by firms not party to the R&D cooperation agreement. We find that such *outside* competition has strong effects on firms' willingness to share technological innovations.

We argue that our findings have implications for existing competition laws especially in Europe. As outlined in the introduction the competition authorities there have adopted a system of block exemptions which determines whether firms are allowed to cooperate freely on R&D or not. These block exemptions apply up to a market share threshold which is laid down in competition law. At present the thresholds for ex-ante cooperation (25%) and ex-post cooperation (20%) indicate that the competition authorities have a preference for ex-ante cooperation. Our model shows that such a preference can be justified where product market competition is weaker (e.g. Cournot competition) and technological opportunity is high. Where the reverse is true (e.g. Bertrand competition) the bias in the threshold levels ought to be reversed to provide welfare enhancing R&D incentives to firms. At present the block exemption regulations as applied to markets characterized by strong product market competition take with one hand what is given with the other.

Matters are further complicated as market shares by themselves are not a very satisfactory statistic for the degree of product market competition and this is widely acknowledged[18]. If the thresholds for R&D cooperation were indeed made contingent on the degree of product market competition and technological opportunity, then product market competition should not be measured by market shares!

Our work raises questions for future research. The link between the relative efficiency of different modes of R&D cooperation and product market competition that emerges from the model is quite robust. Further research is needed to establish how far this finding can be generalised. If competition authorities begin to make stronger use of thresholds as instruments of competition policy in the sense suggested above, more research into the costs and benefits of each mode of R&D cooperation from the point of view of the firms is also required.

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[18] However Motta (2004) argues that market shares are a very reasonable starting point for the analysis of market power.

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A Appendix

A.1 Stage 3: Solutions of the product market competition model

The inverse demand function is:

$$p = a - q_i - s \sum_{j=1;j\neq i}^{m+2} q_j, 0 < s \leq 1 \qquad . \tag{27}$$

The corresponding first order condition for the firms' profit maximisation problem is:

$$\frac{\partial \pi_i}{\partial q_i} = 0 \Leftrightarrow (p - c_i) - q_i + \frac{s \cdot \partial \sum_{j=1;j\neq i}^{m+2} q_j}{\partial q_i} q_i = 0. \tag{28}$$

Defining $\frac{\partial \sum_{j=1;j\neq i}^{m+2} q_j}{\partial q_i} \equiv \delta$ this may be rewritten as: $p = q_i\left(1 - s\delta\right) + c_i$ Notice that δ captures the conjecture of the firm about the output response of its rivals. From the above equation we can derive the following matrix form of the simultaneous equations system that determines the firms' equilibrium outputs:

$$\begin{bmatrix} 2 - s\delta & s & sm \\ s & 2 - s\delta & sm \\ s & s & 2 + s\left(m - 1 - \delta\right) \end{bmatrix} \cdot \begin{pmatrix} q_i \\ q_j \\ \tilde{x} \end{pmatrix} = \begin{pmatrix} a - c_i \\ a - c_j \\ a - \tilde{c} \end{pmatrix}$$

$$\Leftrightarrow \begin{pmatrix} q_i \\ q_j \\ \tilde{q} \end{pmatrix} = \frac{A}{d} \begin{bmatrix} 1 + \theta\left(m + 1\right) & -\theta & -\theta m \\ -\theta & 1 + \theta\left(m + 1\right) & -\theta m \\ -\theta & -\theta & 1 + 2\theta \end{bmatrix} \cdot \begin{pmatrix} 1 + \frac{\bar{c} - c_i}{A} \\ 1 + \frac{\bar{c} - c_j}{A} \\ 1 + z \end{pmatrix} \tag{29}$$

Where we introduce a series of compound parameters to simplify the resulting expressions:

$A \equiv a - \bar{c}, A > 0$ where $\bar{c}$ is the ex ante cost level of the research active firms

$z \equiv \frac{\bar{c} - \tilde{c}}{A}$ where $\tilde{c}$ is the cost level of the outside firms

$\theta \equiv \frac{s}{2 - s\left(1 + \delta\right)}$

$d \equiv 2 + s\left(m + 1 - \delta\right)$

I also use the following definition above:

$g \equiv \frac{\bar{c} - \underline{c}}{A}$ where g is a measure of the size of the innovation which the research active firms achieve

From the solutions to this system of equations we build up expressions for profits, Social surplus and Consumers' surplus.

Output and Profits

$\overline{q} = \left(\frac{A}{d}\right)\left[1 + g\left(1 + m\theta\right) - m\theta z\right],\quad \overline{\pi} = \nu\overline{q}^2 \qquad \tilde{q} = \left(\frac{A}{d}\right)\left[1 + z\left(1 + 2\theta\right) - 2g\theta\right],\quad \tilde{\pi} = \nu\tilde{q}^2$

$\underline{q} = \left(\frac{A}{d}\right)\left[1 - z\theta m\right],\quad \underline{\pi} = \nu\underline{q}^2 \qquad \underline{\tilde{q}} = \left(\frac{A}{d}\right)\left[1 + z\left(1 + 2\theta\right)\right],\quad \underline{\tilde{\pi}} = \nu\underline{\tilde{q}}^2$

Derivation of the social surplus functions Definitions:

$$\nu \equiv \left(1 - s\delta\right) \qquad \left(p_i - c_i\right) = \nu q_i$$

As is well known the social surplus function is derived from the quasi-linear utility function. Given the definitions adopted above it is expressed as follows:

$$S(x,z,c) = a\sum_{k=1}^{n} q_k - \frac{1}{2}\sum_{k=1}^{n} q_k^2 - \frac{s}{2}\sum_{k=1}^{n} q_k \sum_{\substack{l=1 \\ l\neq k}}^{n} q_l - \sum_{k=1}^{n} c_k q_k \tag{30}$$

From this general expression it follows that:

$$\overline{S}(x,z,c) = (a-c)\,2\overline{q} + (a-\tilde{c})\,m\tilde{q} - \frac{1}{2}\left[2\overline{q}^2 + m\tilde{q}^2\right] - \frac{s}{2}\left[2\overline{q}\left(\overline{q}+m\tilde{q}\right) + m\tilde{q}\left(2\overline{q}+(m-1)\,\tilde{q}\right)\right]$$
$$\Leftrightarrow \overline{S}(x,z,c) = 2\overline{q}^2\left[\nu + \frac{1+s}{2}\right] + 2sm\overline{q}\tilde{q} + m\tilde{q}^2\left[\nu + \frac{1+s\,(m-1)}{2}\right],$$

and similarly

$$\underline{S}(x,z,c) = 2\underline{q}^2\left[\nu + \frac{1+s}{2}\right] + 2sm\underline{q}\tilde{\underline{q}} + m\tilde{\underline{q}}^2\left[\nu + \frac{1+s\,(m-1)}{2}\right]$$

A.2 Stage 2: The information sharing decision

The condition for sharing of an innovation is:

$$2\nu\,(q_{11})^2 > \nu\,(q_{10})^2 + \nu\,(q_{01})^2$$

Given this condition the expressions for q_{11}, q_{10} and q_{01} that were derived above can be inserted:

$$2\Bigg[\underbrace{1+g\,(1+m\theta)-m\theta z}_{r}\Bigg]^2 > [r+g\theta]^2 + [r-g\theta-g\,(1+m\theta)]^2$$
$$\Leftrightarrow 2\,(1+m\theta) > g\left[2\theta^2 + (1+m\theta)\left(\theta\,[2-m\,(1-\mu)]-1\right)\right]$$

This expression shows that for all cases in which $m > 1$ there will always be information sharing by the firms in the RJV. In all of the cases in which the term to the right of the inequality in the expression above is negative it can be shown that g must be greater than some negative number. This is always the case so in these cases there will always be information sharing.

In all of the cases in which the term to the right of the inequality in the expression above is positive it can be shown that an upper bound for g exists beyond which the firms would indeed no longer share the innovation. It can also be shown that for all $m > 1$ the non innovating firm would exit the industry in such cases. Thereby all of these cases are ruled out. This conclusion can be arrived at by a comparison of the upper limit for g up to which information is shared and the upper limit for which the non innovating firm can make a positive profit:

$$\frac{2\,(1+m\theta)}{2\theta^2 + (1+m\theta)\left(\theta\,[2-m\,(1-\mu)]-1\right)} > \frac{1}{\theta\,(1+m\mu)}$$
$$\Leftrightarrow\ m > \sqrt{2} - \frac{1}{\theta}$$

which condition is always fulfilled for $m > 1$.

A.3 Stage 1: Deriving the surplus-profits-differences ratio

We can show that the change in Consumers' surplus in this model is just equal to a function of the change in total profits of the industry plus the change in total output of the industry:

$$
\begin{aligned}
\triangle CS &= 2\left(\overline{q}^2 - \underline{q}^2\right)\left[\frac{1+s}{2}\right] + 2sm\left(\overline{q}\tilde{q} - \underline{q}\underline{\tilde{q}}\right) + m\left(\tilde{q}^2 - \underline{\tilde{q}}^2\right)\left[\frac{1+s\,(m-1)}{2}\right] \\
\Leftrightarrow \triangle CS &= \left[\left(2\overline{q}^2 + m\tilde{q}^2\right) - \left(2\underline{q}^2 + m\underline{\tilde{q}}^2\right)\right]\left[\frac{1-s}{2}\right] + \left[(2\overline{q} + m\tilde{q})^2 - \left(2\underline{q} + m\underline{\tilde{q}}\right)^2\right]\frac{s}{2} \\
\Leftrightarrow \triangle CS &= \left[\overline{\Pi} - \underline{\Pi}\right]\left[\frac{1-s}{2\nu}\right] + \left[\overline{Q}^2 - \underline{Q}^2\right]\frac{s}{2} \qquad (31)
\end{aligned}
$$

Using this expression for the consumers' surplus we can show that the surplus-profits ratio becomes:

$$
\alpha = 1 + \frac{\triangle\Pi}{\triangle\Sigma}\frac{(1-s)}{2\nu} + \frac{\triangle(Q^2)}{\triangle\Sigma}\frac{s}{2} \qquad (32)
$$

$$
= 1 + \left[1 + \frac{\triangle\tilde{\Sigma}}{\triangle\Sigma}\right]\frac{(1-s)}{2\nu} + \frac{\triangle(Q^2)}{\triangle(q^2)}\frac{s}{4\nu} \quad . \qquad (33)
$$

Here we make use of the fact that in general $\pi = \nu q^2$ in our model.

From our expressions for outputs given above we derive that:

$$
\triangle Q^2 = \left(\frac{A}{d}\right)^2 4g\,[2 + g + m(1+z)] \qquad \triangle(q^2) = \left(\frac{A}{d}\right)^2 g(1+m\theta)\,[2 + g + m\theta\,(g - 2z)]
$$

$$
\triangle(\tilde{q}^2) = -\left(\frac{A}{d}\right)^2 4g\theta\,[(1+z) - \theta(g-2z)]
$$

Inserting these in our expression for the surplus-profits ratio we can show that:

$$
\begin{aligned}
\alpha &= 1 + \frac{1}{2\nu(1+m\theta)}\left((1-s)\left[(1+m\theta) - \frac{2m\theta\,[(1+z) - \theta(g-2z)]}{[2+g+m\theta\,(g-2z)]}\right] + s\frac{2\,[2+g+m(1+z)]}{[2+g+m\theta\,(g-2z)]}\right) \\
&= 1 + \frac{(1-s)}{2\nu(\nu+1+s(m-1))}\left[\nu\left[1 + 2\Big(\frac{s}{1-s}\Big)\frac{[2+g+m(1+z)]}{[2+g+m\theta\,(g-2z)]}\right] + (1+s(m+1))\right]
\end{aligned}
$$

The surplus-profits ratio under Cournot and Bertrand competition:

$$
\alpha_C = 1 + \frac{1}{2(2+s(m-1))}\left[2s\left[\frac{[2+g+m(1+z)]}{[2+g+m\theta_C\,(g-2z)]} + (1-s)\right] + (1-s)(2+s(m-1))\right] \qquad (34)
$$

$$
\alpha_B = 1 + \frac{1}{2(2+s(m-2))}\left[2s\left[\frac{[2+g+m(1+z)]}{[2+g+m\theta_B\,(g-2z)]} + 1\right] + (2+s(m-2))\right] \qquad (35)
$$

$$\alpha_B - \alpha_C = \Big(\frac{s}{(2+s(m-2))} - \frac{s(1-s)}{(2+s(m-1))} + \frac{s}{2}\Big) +$$
$$\underbrace{s[2+g+m(1+z)]}_{F}\Bigg[\underbrace{\frac{1}{(2+s(m-2))}}_{A}\underbrace{\frac{1}{[2+g+m\theta_B\,(g-2z)]}}_{C} - \underbrace{\frac{1}{(2+s(m-1))}}_{B}\underbrace{\frac{1}{[2+g+m\theta_C\,(g-2z)]}}_{D}\Bigg]$$
$$= s\Big[F\Big(\frac{1}{A}\frac{1}{C} - \frac{1}{B}\frac{1}{D}\Big) + (1-s)\left(\frac{1}{A} - \frac{1}{B}\right) + \frac{s}{B} + \frac{1}{2}\Big] = \frac{s^2}{AB}\Big[\frac{F}{D} + (1-s)\Big] + s\Big[\frac{1}{2} + \frac{s}{B} + \frac{F(D-C)}{DAC}\Big] \tag{36}$$

Here the first term is always positive, but the second may not be. We concentrate on this term to establish when it will be negative:

$$s\Big[\frac{1}{2} + \frac{s}{B} + \frac{F(D-C)}{DAC}\Big] = \frac{s}{ACD}\Big[CDB' - F(C-D)\Big] \tag{37}$$

where $B' = B - 2s^2$ (38)

Here it is the first term that may become negative. We can show that:

$$C - D = m(g-2z)\theta_B\theta_C \text{ and } F(C-D) = (2+g)m(g-2z)\theta_B\theta_C + m^2(1+z)(g-2z)\theta_B\theta_C \tag{39}$$

$$CDB' - F(C-D) = B'(2+g)^2 + m^2(g-2z)\theta_B\theta_C((g-2z)B' - 1) + (2+g)m(g-2z)(\theta_B(2B'-\theta_C) + \theta_C(2B' - mz\theta_B)) \tag{40}$$

At this stage we isolate the only remaining negative expression and establish how large it may become. Note first that we must restrict $1 \geq zm\theta_B$ as we assume that the research active firms do not lose money ex-ante. This implies that only the second term in the last expression will be negative. The term will be most negative where $(g-2z) = \frac{1}{2B'}$. In this case we can show that the entire expression above remains positive for $m > 1$[19]:

$$B'(2+g)^2 + \frac{m}{2}\theta_B\left[(2+g) - \frac{m}{4B'}\theta_C\right] + (2+g)\frac{m}{2B'}(\theta_B(B'-\theta_C) + \theta_C(2B' - mz\theta_B))$$

If $m = 1$ and $s \to 1$ we know by Result 1 above that the research active firms will not share the innovation.

[19]Where $m = 1$ $\lim B'_{s\to 1} = 0$