GOVERNANCE AND THE EFFICIENCY
OF ECONOMIC SYSTEMS
GESY

Discussion Paper No. 35

Integrating competition policy and innovation policy: the case of R&D cooperation

Georg von Graevenitz*

February 2005

*Georg von Graevenitz, University of Munich, Kaulbachstr. 45, D-80539 Munich, Germany,
graevenitz@bwl.uni-muenchen.de

Financial support from the Deutsche Forschungsgemeinschaft through SFB/TR 15 is gratefully acknowledged.

Sonderforschungsbereich/Transregio 15 · www.gesy.uni-mannheim.de
Universität Mannheim · Freie Universität Berlin · Humboldt-Universität zu Berlin · Ludwig-Maximilians-Universität München
Rheinische Friedrich-Wilhelms-Universität Bonn · Zentrum für Europäische Wirtschaftsforschung Mannheim

Speaker: Prof. Konrad Stahl, Ph.D. · Department of Economics · University of Mannheim · D-68131 Mannheim,
Phone: +49(0621)1812786 · Fax: +49(0621)1812785

Integrating competition policy and innovation policy: the case of R&D cooperation. *

G. v. Graevenitz†

28.02.2005

Abstract

I develop a model of R&D cooperation with uncertain research outcomes. In this model asymmetric outcomes of R&D competition emerge naturally. Therefore ex-ante and ex-post R&D cooperation can be studied as alternatives for firms. Using this model I compare welfare losses under ex-ante and ex-post R&D cooperation as the degree of product market competition varies. It emerges that the relative size of these welfare losses is monotonically related to the degree of product market competition and the degree of technological opportunity. The implications of these results for the interaction of competition policy and innovation policy are discussed.

JEL Classification: L13, L49, O31 .

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

---

*Earlier versions of this paper have been presented at seminars at LMU , WZB, EARIE, and UCL. The author thanks seminar and conference participants for their comments. I would particularly like to acknowledge the helpful comments and suggestions of Malcolm Pemberton, David Ulph, John Beath, Sanjeev Goyal, Lars Hendrik Röller and Dietmar Harhoff. Financial assistance on the part of the DFG is gratefully acknowledged.

†Institute for Innovation Research and Technology Management, Munich School of Management, Ludwig Maximilians Universität München (LMU), University of Munich, Kaulbachstrasse 45, D-80539 Munich, Germany, *email: graevenitz@bwl.uni-muenchen.de*

1 Introduction

R&D cooperation between firms takes place either through ex-ante cooperation such as the formation of a research joint venture or through ex-post cooperation such as licensing of technology. Ex-ante and ex-post R&D cooperation are separately regulated in competition law in Europe and the United States. Economic research mirrors this state of affairs: there is an extensive literature on licensing and another on research joint ventures. This separation of thinking on and regulation of ex-ante and ex-post R&D cooperation raises several questions: how do the regulations of R&D cooperation interact to determine how firms cooperate? At the level of economic theory the corresponding question is: how do ex-ante and ex-post R&D cooperation compare when we consider economic welfare?

A firm deciding on the formation of an ex-ante alliance with a rival firm faces a clear alternative: to compete with this firm. The existing literature on ex-ante R&D cooperation is based on this counterfactual[1]. However it is plain that R&D competition holds out the prospect of owning a licenseable technology as well as the concomitant threat of becoming a licensor. This suggests that the correct counterfactual will often be the possibility of ex-post R&D cooperation. Recent empirical research shows that licensing and research joint venture formation are particularly prevalent in key high technology industries[2]. In spite of this the determinants of the choice between ex-ante and ex-post R&D cooperation are not well studied[3]. How firms should choose between these options if the objective is to maximise welfare is not studied at all.

This paper is an attempt to answer the latter question. It compares the welfare losses that arise under ex-ante and ex-post R&D cooperation[4] . The relative performance of these two

[1] This counterfactual is appropriate if the question being asked is whether ex-ante R&D cooperation raises welfare at all and should be permitted. It is less compelling once regulation permitting such cooperation is in place.

[2] Anand and Khanna (2000b,a) study licensing and the formation of strategic alliances using data supplied by the SDC (Securities Data Corporation). They find that R&D cooperation is prevalent in the following industries: Chips (SIC 367), Drugs (SIC 283), Communications (SIC 366) and Computers (SIC 357).

[3] In part the choice between ex-ante and ex-post R&D cooperation will depend on the relative levels of transactions costs. The interaction between transactions costs and the forms of contract governing R&D cooperation has so far been studied by Oxley (1997). Her study focuses on ex-ante R&D cooperation.

[4] This paper contrasts the main innovation incentives at work under ex-ante and ex-post R&D cooperation. The results derived below do not depend on specific details of how R&D cooperation ex-ante and ex-post are organised. Distinctions between various forms of ex-ante R&D cooperation such as those made by Kamien et al.

modes of R&D cooperation is shown to depend on the ratio of the change in social surplus to the change in joint profits as firms innovate. I relate this "surplus-profits-differences ratio" to the degree of product market competition and find that the relationship is monotonic. This finding has implications for the design of competition policy rules on R&D cooperation. At a positive level it throws light on whether existing regulation tends to promote comparatively inefficient forms of R&D cooperation. At a normative level it suggests how regulations might be improved to raise economic welfare by strengthening R&D incentives.

Competition between oligopolists is regulated both by innovation- and competition policy. While both forms of regulation aim to increase economic welfare it is frequently noted that tensions between them arise[5]. Incentives for innovative activity usually derive from some form of market power, for instance the monopoly conferred upon the holder of a patent, whereas competition policy rules are set to curb or prevent the development of excessive market power. Judging where the market power of an innovating firm becomes excessive is very challenging. At present competition authorities tolerate R&D cooperation[6] within certain bounds because it is assumed that this raises welfare[7]. This is in spite of the risk that R&D cooperation may engender collusion in the product market[8]. Taking this policy stance as given I pursue the question whether differences in welfare losses between ex-ante and ex-post R&D cooperation depend systematically on the strength of product market competition. I find that a monotonic

(1992) do not affect my results. Therefore I maintain the distinction between ex-ante and ex-post R&D cooperation throughout the paper.

[5]The paper by Encaoua and Hollander (2002) and the book byScotchmer (2005) discuss the sources of these tensions.

[6]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). In April 2000 the DOJ and FTC issued their Collaborations Guidelines. These explain the antitrust treatment of strategic alliances. 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.

[7] Compare the discussion of R&D cooperation by Motta (2004). Recently Shapiro (2001) argues that R&D cooperation is increasingly important in the context of the patent thickets emerging in several key industries.

[8] This point is made by Shapiro and Willig (1990), Leahy and Neary (1997) and Scotchmer (2005).

relationship between observable measures of product market competition and relative welfare losses exists. In particular ex-ante R&D cooperation is preferable to ex-post R&D cooperation where technological opportunity is high and product market competition is weak and vice-versa. These results suggest that a better integration of competition policy and innovation policy in the realm of R&D cooperation is possible.

This paper links two strands of research in applied economics: research on R&D cooperation and research on the effects of the competition in product markets on the strength of R&D incentives. In the latter literature the argument over whether greater competition in the product market strengthens R&D incentives goes back to Schumpeter (1942). Recent work suggests that the effect of product market competition on innovation incentives of oligopolistic firms is non-monotonic [Boone (2001), Aghion et al. (2004)] and that it may depend on the relative competitive positions of competing firms ex-ante [Boone (2000)]. These findings suggest that it is unlikely that the strength of product market competition will have clear effects on R&D incentives where firms cooperate on R&D. Surprisingly the relative strength of R&D incentives under ex-ante and ex-post R&D cooperation does depend monotonically on some measures of product market competition.

In order to model the possibility of ex-post licensing I allow for uncertainty in the success of R&D [9] . In this setting firms that will cooperate ex-post face an R&D incentive akin to the "competitive threat" which arises in patent race models[10]. Firms cooperating ex-ante do not face this incentive. As product market competition weakens, the competitive threat can be shown to grow and so the probability of over-investment by firms cooperating on R&D ex-post grows too. At the same time weaker product market competition lowers under-investment by firms cooperating on R&D ex-ante. These effects both contribute to lower welfare losses under ex-ante cooperation below those under ex-post cooperation when competition in the product market is weak.

The model developed below is most closely related to the literature on ex-ante R&D cooperation. This literature has consistently shown that there is under-investment in R&D under ex-ante R&D cooperation[d'Aspremont and Jacquemin (1988); Kamien et al. (1992);

[9] This is a departure from the standard literature on ex-ante R&D cooperation discussed below. That literature generally ignores uncertainty in R&D and focuses mainly on symmetric outcomes as a result.

[10] The terms "competitive threat" and "profit incentive" for the innovation incentives arising in patent race models derives from Beath et al. (1989).

Leahy and Neary (1997)] but that cooperation may still improve on non-cooperative outcomes if spillovers are large enough. My model of ex-ante R&D cooperation focuses on an alternative source of welfare gains from ex-ante R&D cooperation: the eradication of duplicative R&D efforts. Therefore the effects of R&D spillovers are not considered here. It emerges that ex-post R&D cooperation may outperform ex-ante R&D cooperation in spite of gains from elimination of duplication. The model employed in this paper also differs from most of the existing literature on R&D cooperation by endogenizing the sharing of innovations[11]. This leads me to consider the effects of outside competition on the firms undertaking R&D cooperation.

As a consequence of these modelling choices I study a model that allows for uncertainty in R&D and captures R&D cooperation between two firms in the context of product market competition by further oligopolists. The basic model of R&D competition from which the main results are derived is quite general. In order to study how the "surplus-profits-differences" ratio relates to the degree of product market competition I employ a general linear demand model of the product market. This model generates surprisingly clear predictions about the relative efficiency of ex-ante and ex-post R&D cooperation under variation in the degree of product market competition. It is possible to study the effects of several parameters used in the previous literature to capture changes in the strength of product market competition. It is shown that salient measures of product market competition in this context are the type of competition (Cournot/Bertrand), the ex-ante efficiency of the cooperating firms relative to their industry and the size of the innovation being attempted by the firms.

Comparing existing regulations of R&D cooperation important differences between U.S. and European regulations emerge[12]. In the United States the National Cooperative Research Act (NCRA) lowers the costs of being found in breach of competition law if firms register an agreement to cooperate on R&D ex-ante. Ex-post R&D cooperation is regulated through the Antitrust Guidelines for the Licensing of Intellectual Property. In their recent Collaborations Guidelines the federal antitrust agencies set out a "safety zone" of 20% joint market share of each relevant market for ex-ante R&D cooperation. At the same time the Antitrust Guidelines for the Licensing of Intellectual Property provide for a "safety zone" from antitrust scrutiny which is also set at this level. Therefore on the face of it it seems that the U.S. guidelines at-

[11] In this I follow the approach suggested by Katsoulacos and Ulph (1998).

[12] An in depth comparison of U.S. and European competition regulations is undertaken by Hemphill (2003).

tempt to treat ex-ante and ex-post R&D cooperation equally. In case of the European antitrust framework it is clearer that the antitrust rules are biased in favour of ex-ante R&D cooperation.

The European Commission has adopted a system of block exemptions from the prohibitions of competition law[13]. These block exemptions impose limits on firms that wish to license technologies ex-post[14] and on firms that seek to collaborate on future R&D [15]. The block exemptions apply as long as certain market share thresholds are not overstepped.

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[16]. The results derived below suggest that both the U.S. and the European regulations of R&D cooperation may be further improved upon.

The structure of this paper is as follows: in the next section I discuss the model. Section 3 contains two central analytical results . In section 4 analyses how variation in product market competition affects the second of these results. The fifth section provides an illustration of the analytical predictions of the paper using simulation. Section 6 concludes.

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

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

[14] 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).

[15] 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).

[16] 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.

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. I model the inverse of technological opportunity as decreasing returns to scale in R&D which I 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. I include further product market competitors in the model as I find their presence to have important effects for my results.[17].

The model is based on the linear demand specification:

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

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. I rely on this specification to derive some of my 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 $\tilde{c}$[18]. I 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

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

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

by g. Their objective functions at the first stage are:

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

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

The expected revenue $\mathbf{\Pi}$ 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 $\boldsymbol{P}$ and to firms cooperating ex-ante by $\boldsymbol{A}$. As the firms in the RJV may centralise research in one laboratory I introduce the parameter $\Lambda \in \{1, 2\}$ to capture this fact.

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 $\boldsymbol{F}$.

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 going on to derive the solution of the game I 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.

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. 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[19] 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[20] 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. I 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 $2\frac{\partial\gamma(\rho_X,\beta)}{\partial\rho_X} > \frac{\partial\gamma(\varrho_X,\beta)}{\partial\varrho_X}$.

[19] 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 $\tilde{\varrho} > 0$

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

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. I go on to show when firms will share an innovation with their rival. Finally I compare the welfare losses that arise under ex-ante R&D cooperation with those that arise under ex-post R&D cooperation.

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

Here I 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. 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

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

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

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

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 to ex-ante and ex-post R&D cooperation. The license fee payed where firms license 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 anticompetitive effects. The analysis below demonstrates that this finding is rather special. In the context of the linear demand function I introduced above it holds for duopolies and in rare cases triopolies.

I show in appendix A 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 $\mu \equiv \frac{\bar{c} - \tilde{c}}{\bar{c} - \underline{c}} = \frac{z}{g}$

Firms will share knowledge as long as this expression is positive. 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 duopolists 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. I 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 I 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 I restrict the analysis of those cases in which the firms cooperating ex-ante will share the innovation.

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 I derive here do not depend on the specific model of product market competition I have derived above.

I begin by setting out the main result of the paper. To prove it I develop my model and derive an intermediate result regarding the kind of welfare losses that arise when firms chose to centralise R&D. I then go on to prove my 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:*

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

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 I 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 I are able to prove the result outlined above I describe how the size of the innovation under consideration determines which of these possibilities applies. I 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). I 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. I 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 I 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 I derived previously:

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

First of all I find that firms in ex-ante R&D agreements will always *under-invest* in R&D relative to the social optimum[21]. It follows from the under-investment 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.

I consider each case in turn.

Decentralised R&D

Here I 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. I showed above that the firms in an RJV will always under-invest relative to the social optimum. This gives rise to a welfare loss which I 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:

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

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

[21] This is the result is analogous to the under-investment result derived by Arrow (1962)

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

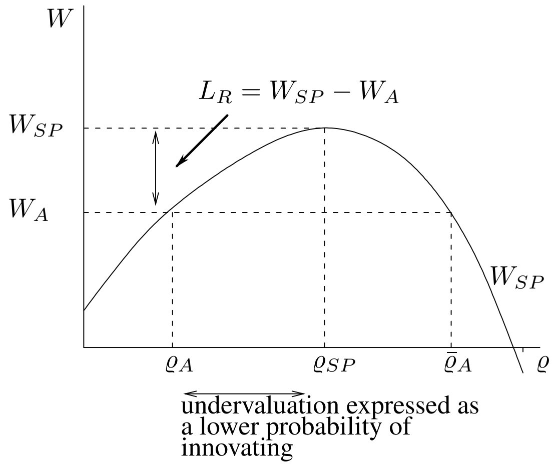

Figure 1: **The welfare function under decentralised R&D**

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.

Now 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.

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 compare the firms' R&D incentives in both equilibria. These are set out in Table 1 below.

Following Beath et al. (1989) I 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 under-investment arises because firms fail to take account of the social surplus created by their innovations. I 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 under-investment 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 over-investment 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

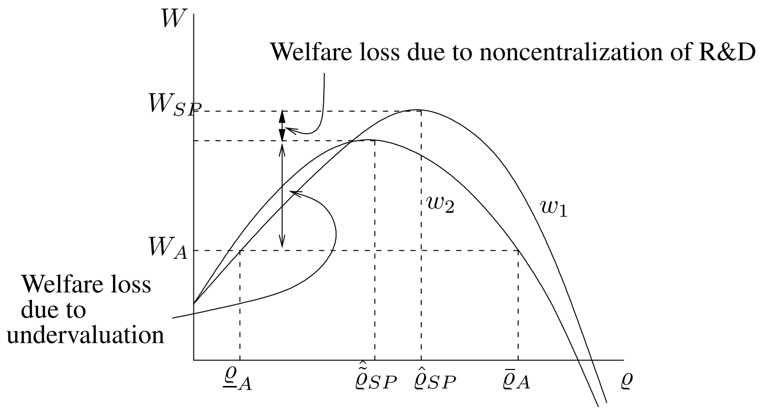

Figure 2: **The welfare function when the RJV does not centralise R&D but this is socially efficient.**

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 $\hat{\hat{\varrho}}$ as that probability at which w_2 is maximised. The question whether firms over- or under-invest can then be restated with respect to this probability $\hat{\hat{\varrho}}$. 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 I 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

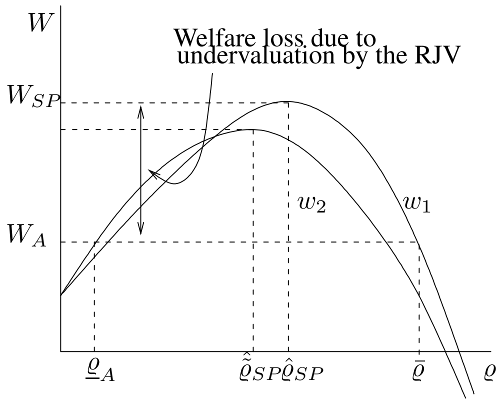

Figure 3: **The welfare function when the RJV centralises R&D and this is socially efficient**

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 I obtain the probability of innovation for firms cooperating ex-ante under centralised R&D:

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

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

$$W_R^c \equiv S_{11} - (1 - \varrho_A^c)\,[S_{11} - S_{00}] - \gamma(\varrho_A^c, \beta) \qquad\qquad l_A^c = \frac{\hat{W}_{SP} - W_A^c}{\hat{W}_{SP}} \tag{21}$$

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.

I have now demonstrated that Result 2 holds independently of the precise organisation of R&D. In the following section this result is interpreted.

4 Competition and the surplus-profits ratio

The previous analysis demonstrated 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. I 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* $m > 1$ [22],
- *the more inefficient are the outside competitors of the* research active *firms,*
- *when innovations undertaken by the* research active *firms are larger.*

[22] 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.

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 I have developed above.

There I 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 I 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 I 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 my 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. I discuss this argument at length in the conclusion. Here I turn to the derivation of the last result.

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. I show this in appendix A. I 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. I manipulate this expression further in order to derive a form which is most useful for further analysis[23]:

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

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

Comparing Cournot and Bertrand competition Here I show that the surplus-profits-differences ratio in my 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:

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

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 ($g > 2z$) I can show that $\alpha_B - \alpha_C > 0$ if $m > 1$. The proof is quite messy and is relegated to appendix A.

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 I 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 commit to a given price and are able to meet any level of demand at that price. My 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.

[23]The derivation is relegated to the appendix.

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

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

z measures the efficiency of the research active firms' competitors relative to the ex-ante cost level of the research active firms: $z \equiv \frac{\bar{c}-\tilde{c}}{a-\tilde{c}}$. 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:

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

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 I 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 I present the results of a simulation [24] of the model presented above. I 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 I have made:

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

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

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

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 sizes. In other words the size of innovation g is taken to be an exogenously varying parameter whereas other exogenous parameters of my 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.

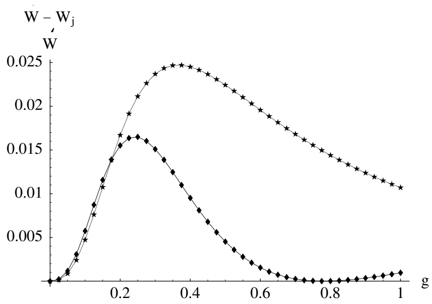

Figure 4: **The case in which the welfare loss under ex-ante cooperation is greater.** Here $A = 2$, $m = 4$, $s = 0.9$, $\boldsymbol{\beta} = 0.95$ and $\delta = 1$, which implies **Bertrand** competition.

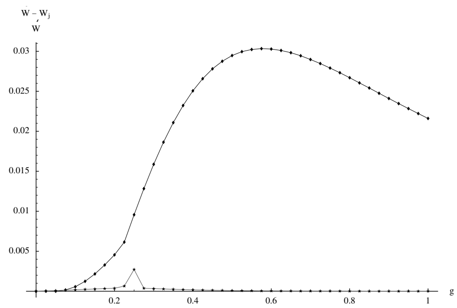

Figure 5: **The case in which the welfare loss under ex-post cooperation is greater.** Here $A = 2$, $m = 2$, $s = 0.9$, $\boldsymbol{\beta} = 0.2$ and $\delta = 0$, which implies **Cournot** competition.

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. I 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.

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

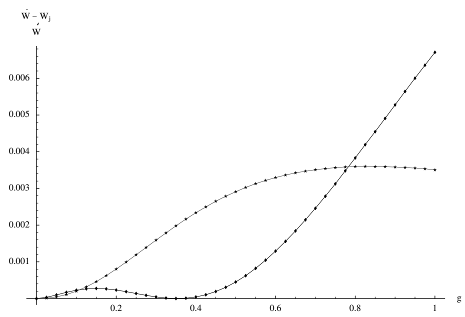

Figure 6: **The first indeterminate case**
Here $A = 2$, $m = 2$, $s = 0.9$, $\boldsymbol{\beta} = 0.85$ and $\delta = 0$, which implies Bertrand competition.

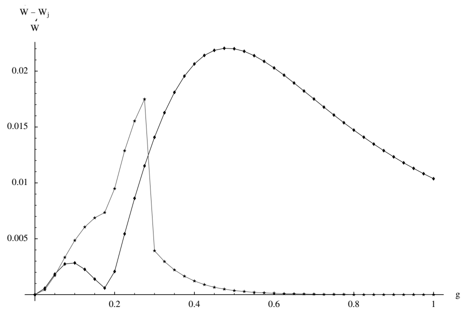

Figure 7: **The second indeterminate case**
Here $A = 2$, $m = 4$, $s = 2$, $\boldsymbol{\beta} = 0.2$ and $\delta = 1$, which implies Bertrand competition.

The plot on the left illustrates clearly how the firms cooperating ex-post move from undervaluation to over-valuation 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 I simulate the model for the same high degree of technological opportunity as in the right-hand plot above. Here I 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 of the inability of the firms to centralise R&D under ex-post cooperation.

6 Conclusion

In this paper I have compared the welfare losses that arise under ex-ante and ex-post cooperation on R&D. I 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 I 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. 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. The ratio can be linked 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. I find that such *outside* competition has strong effects on firms' willingness to share technological innovations.

I argue that my 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. The model analysed in this paper 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 characterised 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[25]. If the thresholds for R&D cooperation were indeed made contingent on the degree of product market competition and technological opportunity, then the intensity of product market competition should not be measured by market shares!

This paper 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.

A Appendix

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: $p = q_i (1 - s\delta) + c_i$ Notice that δ captures the conjecture of the firm about the output response of its rivals. From the above equation one can derive the following matrix form of the simultaneous equations system that determines the firms' equilibrium outputs:

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

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

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

The following compound parameters 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

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

$\theta \equiv \dfrac{s}{2 - s\,(1+\delta)}$

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

I also use the following definition above:

$g \equiv \dfrac{\bar{c}-\underline{c}}{A}$ 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 I build up expressions for profits, Social surplus and Consumers' surplus.

Output and Profits

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

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

Derivation of the social surplus functions Definitions:

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

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:

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

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

and similarly

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

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:

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

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:

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

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

Stage 1: Deriving the surplus-profits-differences ratio

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:

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

Using this expression for the consumers' surplus the surplus-profits ratio becomes:

$$\begin{aligned}
\alpha &= 1 + \frac{\triangle\Pi}{\triangle\Sigma}\frac{(1-s)}{2\nu} + \frac{\triangle(Q^2)}{\triangle\Sigma}\frac{s}{2} \qquad (32) \\
&= 1 + \left[1 + \frac{\triangle\tilde{\Sigma}}{\triangle\Sigma}\right]\frac{(1-s)}{2\nu} + \frac{\triangle(Q^2)}{\triangle(q^2)}\frac{s}{4\nu} \qquad . \qquad (33)
\end{aligned}$$

Note that in general $\pi = \nu q^2$ above.

From my expressions for outputs given above one may derive that:

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

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

Inserting these in my expression for the surplus-profits ratio one can show that:

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

The surplus-profits ratios under Cournot and Bertrand competition are:

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

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

$$\alpha_B - \alpha_C = \Big(\frac{s}{(2+s(m-2))} - \frac{s(1-s)}{(2+s(m-1))} + \frac{s}{2}\Big) +$$

$$s\underbrace{[2+g+m(1+z)]}_{F}\left[\frac{1}{\underbrace{(2+s(m-2))}_{A}\underbrace{[2+g+m\theta_B(g-2z)]}_{C}} - \frac{1}{\underbrace{(2+s(m-1))}_{B}\underbrace{[2+g+m\theta_C(g-2z)]}_{D}}\right]$$

$$= s\Big[F\Big(\frac{1}{A}\frac{1}{C} - \frac{1}{B}\frac{1}{D}\Big) + (1-s)\left(\frac{1}{A} - \frac{1}{B}\right) + \frac{s}{B} + \frac{1}{2}\Big] = \frac{s^2}{AB}\Big[\frac{F}{D} + (1-s)\Big] + s\Big[\frac{1}{2} + \frac{s}{B} + \frac{F(D-C)}{DAC}\Big] \tag{36}$$

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

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

$$\text{where } B' = B - 2s^2 \tag{38}$$

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

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

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

At this stage I isolate the only remaining negative expression and establish how large it may become. Restrict $1 \geq zm\theta_B$ on the assumption 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 the entire expression above remains positive for $m > 1$[26]:

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

If $m = 1$ and $s \to 1$ it follows from Result 1 above that the research active firms will not share the innovation.

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

References

Aghion, P., Bloom, N., Blundell, R., Griffith, R., and Howitt, P. (2004). Competition and innovation: An inverted u relationship. Technical Report 007, Advanced Institute of Management Research.

Anand, B. and Khanna, T. (2000a). The structure of licensing contracts. *The Journal of Industrial Economics*, XLVIII(1):103–135.

Anand, B. N. and Khanna, T. (2000b). Do firms learn to create value: the case of alliances. *Strategic Management Journal*, 21(3):295–315.

Arrow, K. J. (1962). Economic welfare and the allocation of resources for invention. In Nelson, R. R., editor, *The Rate and Direction of Inventive Activity*. Princeton University Press, Princeton.

Beath, J., Katsoulacos, Y., and Ulph, D. (1989). Strategic R&D policy. *The Economic Journal*, 99(395):74–83. Conference Papers.

Boone, J. (2000). Competitive pressure: the effects on investments in product and process innovation. *RAND Journal of Economics*, 31(3):549–569.

Boone, J. (2001). Intesity of competition and the incentive to innovate. *International Journal of Innovation*, 19:705–726.

d'Aspremont, C. and Jacquemin, A. (1988). Cooperative and non-cooperative R&D in a duopoly with spillovers. *American Economic Review*, 78:1133–1137.

Encaoua, D. and Hollander, A. (2002). Competition policy and innovation. *Oxford Review of Economic Policy*, 18(1):63–79.

Gilbert, R. and Shapiro, C. (1997). Antitrust issues in the licensing of intellectual property: The nine no-no's meet the nineties. In *Brookings Papers: Microeconomics*, volume 1997, pages 283–349. Brookings Institution, Washington D.C.

Hemphill, T. (2003). Cooperative strategy, technology innovation and competition policy in the united states and the european union. *Technology Analysis& Strategic Management*, 15(1):93–101.

Kamien, M., Mueller, E., and Zang, I. (1992). Research joint ventures and R&D cartels. *American Economic Review*, 82:1293–1306.

Katsoulacos, Y. and Ulph, D. (1998). Endogenous spillovers and the performance of research joint ventures. *Journal of Industrial Economics*, 46:333–357.

Katsoulacos, Y. and Ulph, D. (1999). Innovation spillovers and the welfare performance of RJV's. mimeo.

Korah, V. (2004). *An Introductory Guide to EC Competition Law and Practice*. Hart Publishing, Oxford - Portland Oregon, eighth edition.

Leahy, D. and Neary, P. (1997). Public policy towards R&D in oligopolistic industries. *American Economic Review*, 87(4):642–662.

Majewski, S. E. and Williamson, D. V. (2004). How do consortia organize collaborative R&D ? Evidence from the National Cooperative Research Act. Mimeo.

Motta, M. (2004). *Competition Policy*. Cambridge University Press.

Oxley, J. E. (1997). Appropriability hazards and governance in strategic alliances: A transactions cost approach. *The Journal of Law, Economics & Organization*, 13(2):387–409.

Schumpeter, J. A. (1942). *Capitalism, Socialism and Democracy*. Routledge, New York.

Scotchmer, S. (2005). *Innovation and Incentives*. MIT Press, Cambridge, Massachusetts.

Shapiro, C. (2001). Navigating the patent thicket: Cross-licenses, patent pools, and standard-setting. In Jaffe, A., Lerner, J., and Stern, S., editors, *Innovation Policy and the Economy*. NBER.

Shapiro, C. and Willig, R. (1990). On the antitrust treatment of production joint ventures. *Journal of Economic Perspectives*, 4(3):113–130.

Vives, X. (1999). *Oligopoly Pricing, Old Ideas and New Tools*. MIT Press, Cambridge, Massachusetts and London, England.

Whish, R. (2001). *Competition Law*. Butterworths.