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by

Raymond DE BONDT

Changqi WU

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Abstract

The members of a research joint venture (RJV) cartel coordinate strategic R&D investments and improve the transfer of technological information. Outsiders compete against the cartel and against each other. All industry members receive industry-wide spillovers and compete in output.

With linear demand, constant unit production cost and diminishing returns on innovative efforts, it is possible to compute the strategic investments of members and outsiders. Even in industries with small spillovers, RJV members will spend more on R&D than outsiders provided they sufficiently improve information sharing.

Better information sharing enhances investment levels of the RJV members as well as the profitability of joining and staying with the cartel. As a consequence consumer surplus and static welfare is also enhanced

Static welfare and consumer surplus increase with the size of the RJV in industries with few firms and large spillovers. Otherwise they first increase and then decrease as the membership expands.

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° Department of Applied Economics, Katholieke Universiteit Leuven, B-3000 Leuven, Belgium.

°° Department of Economics, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

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1. Introduction

Cooperative arrangements in R&D among otherwise competing firms have evolved as a response to the externalities that accompany such strategic investment activities. The modes of cooperation differ in several ways but particularly in the extent that they allow a more useful information sharing and a better coordination of the efforts. Sometimes firms continue to compete and simply share more information, in other cases they only coordinate efforts and in still other instances they realize both a better coordination of investments and a better sharing of information.

It has been shown in symmetric industry settings that coordinated efforts tend to result in an increase in investment efforts and static welfare if (and only if) spillovers in R&D are important [d'Aspremont and Jacquemin (1988)]¹. But a research joint venture (RJV) cartel that coordinates efforts and succeeds in perfect (or better) information sharing may well yield the highest technological improvements and static welfare [Kamien *et al.* (1992)].

In reality cooperative arrangements tend to involve only part of the suppliers. One relevant industry organisation is that of a group of (large) firms cooperating while other rivals (smaller) continue to compete². This paper argues that in such a setting, even though better

¹ On the relation with first and second-best welfare levels, see Suzumura (1992). For a discussion of policy issues see Jorde and Teece (1990) and Shapiro and Willig (1990) and Geroski (1993).

² For results on symmetric cooperative clusters see Kamien and Zang (1993). On the endogenization of R&D coalitions, see Bloch (1991) and Yi and Shin (1992).

information sharing and coordination improves static welfare, the size of an RJV cartel is likely to differ from the size that maximizes static welfare. Only in industries with otherwise high spillovers and few firms can market forces be trusted to generate a welfare-maximizing RJV cartel.

The framework employed here describes an industry with technological spillovers in which some firms form a cartel to coordinate strategic R&D investments and to enhance information exchange between the members, while they continue to compete against non-participating rivals. In a subsequent section implications for investment levels, profits, and static welfare are also detailed.

2. A Strategic Investment Framework

Consider an industry consisting of n firms, indexed $i=1,2,\dots,n$, competing non-cooperatively in the product market. For simplicity, it is assumed that these n firms face a linear demand function and produce homogenous products

$$P = a - Q$$

where the market size parameter is $a > 0$ and the industry output $Q = q_1 + \dots + q_n$.

The initial unit cost for all the firms is denoted by c and $a > c$. Firms engage in cost-reducing innovation before production starts. Among these n firms, k firms participate in an R&D cooperation. The remaining $n-k$ firms, acting as outsiders, decide their own R&D investment non-cooperatively by taking into account the R&D investments of all other firms. When $k=1$, all firms conduct their research non-cooperatively. When $k=n$, industry-wide R&D cooperation prevails. While this configuration imposes asymmetry on the two groups of firms, all firms within each group are identical.

The actual unit production costs, excluding the R&D expenses, are expressed as the differences between initial unit costs c and the effective cost reductions determined in the R&D stage

$$c_i^c = c - (x_i^c + \beta \cdot \sum_{\substack{s=1 \\ s \neq i}}^n x_s + \epsilon \cdot \sum_{\substack{t=1 \\ t \neq i}}^k x_t^c) \quad i = 1, \dots, k \quad (1)$$

$$c_j^f = c - (x_j^f + \beta \cdot \sum_{\substack{s=1 \\ s \neq j}}^n x_s) \quad j = k+1, \dots, n \quad (2)$$

where all c_i and $c_j \geq 0$, $0 < \beta \leq \beta + \epsilon \leq 1$, $\epsilon \geq 0$. Superscripts c and f identify whether a firm participates in the R&D cooperation or remains in the fringe. The R&D investment, $x_i \geq 0$, represents the individual R&D investment of firm i in its cost-reducing effort.

The unit production costs are not affected by output level. For the members of the R&D cooperation, its effective cost reduction includes its own R&D investment, the R&D spillovers from all other firms, and technical information obtained from other participants of the cooperative agreement. Unlike the members of the cartel, the fringe firms can only benefit from industry-wide spillovers.

The spillover parameter β represents the degree of involuntary industry-wide spillovers or information leakage. The causes of information leakage may include reverse engineering, exchanges between the research scientists and business, and scientific publications. This leakage is assumed to be symmetric and reciprocal.

The information sharing parameter ϵ captures the notion of a better technology sharing among the participants in the R&D cooperation. Its magnitude can be thought of as depending on internal organizational features of the cartel³. Borrowing terminology from Kamien *et al.*

³ The less than perfect information sharing may arise in the real world because of technical difficulties, differences in company culture and

(1992), the case of $\epsilon=0$ applies to an R&D cartel in which the participating firms maximize their joint profits by coordinating their R&D investments without information sharing. When in addition the cooperative firms can share technical information perfectly they belong to an RJV cartel ($\epsilon = 1-\beta$). In this paper this term is also used to designate coordination of investments together with improved, but not perfect, information sharing among the cooperating firms ($0 < \epsilon < 1-\beta$).

Another interpretation for the asymmetry in information sharing is the difference in firms' abilities to absorb information. The industry-wide spillovers β can be understood as the general knowledge that can be absorbed by all firms. The information sharing parameter ϵ can result because the group of cooperating firms possesses specific assets allowing them to absorb more than others and to gain information advantages in the R&D stage.

The net profit (payoff) function of firm i is defined as the difference between its gross profit function $\pi_i = (P - c_i) \cdot q_i$ and its R&D costs

$$V_i = \pi_i - g(x_i) \quad (3)$$

where the R&D cost function, $g(x_i) = (\Gamma/2) \cdot x_i^2$, is quadratic in R&D investment. The parameter Γ , $\Gamma > 0$, is inversely related to the industry-wide R&D efficiency.

The game proceeds as follows. In the first stage, all firms, by perfectly foreseeing what will happen in the second stage, simultaneously choose the R&D investment levels, x_i , which determine their unit production costs. The participants in the R&D cooperation coordinate their R&D efforts to maximize their joint profit; the firms that act as outsiders maximize their own profits. When production costs are known,

organization, and strategic factors. In many situations despite efforts of participating firms to improve information flow, perfect information sharing may not occur.

all firms choose their output in a Cournot-Nash way and then compete in the product market. Details of the resulting equilibrium values are given in Appendix 1.

3. R&D Investments

The differences in equilibrium R&D investments of members of the RJV cartel and outsiders crucially depend on the magnitude of the industry spillovers and the information sharing in the cartel. In Appendix 2 it is verified that :

Proposition 1 : With large spillovers β ($>1/2$), the cooperative firms always invest more in R&D than their outside rivals. Also with small spillovers β ($<1/2$) they make larger R&D efforts than the outsiders, provided that the RJV sufficiently improves on information sharing.

A sufficient condition for the cooperative investment x^c to exceed the effort level x^f of the outsider in sectors with small industry spillovers is

$$\epsilon \geq \frac{1 - 2\beta}{n - k + 1} \quad \beta < 1/2 \quad (4)$$

see Appendix 2. This sufficient condition is satisfied and $x^c > x^f$ in an RJV cartel with perfect information sharing ($\epsilon = 1 - \beta$). But also for less than perfect information sharing the RJV cartel may spend more than the outsiders.

This characterization of the asymmetric effort levels of RJV cartel members and outsiders is reminiscent of earlier reported findings that efforts with industry-wide cooperation are larger (smaller) than those with competition if and only if industry spillovers are large (small). But this last well known tendency is driven by the fact that with small

(large) spillovers the R&D reaction curves are downward (upward) sloping [De Bondt and Veugelers (1991); Vonortas (1993)].

Here, however, the RJV members may spend more on R&D even though their investments are strategic substitutes *vis-à-vis* the efforts of the outsiders. The intuition is that with better information sharing in the cartel, the unit costs are lower and output is higher than it would be otherwise. This tends to increase the profitability of a further decrease in unit costs and consequently it stimulates the cost reducing efforts of RJV members.

4. Profitability of the RJV cartel

Obviously a key question is whether firms are willing to join and stay with the RJV cartel. Following d'Aspremont *et al.* (1983), the cartel coalition is considered to be stable if both internal and external stability conditions are met⁴. The **internal stability** condition states that no insider has an incentive to leave. It means that for $k \geq 2$:

$$V^C(k) \geq V^F(k-1) \quad (5)$$

where $V^C(k)$ and $V^F(k)$ are the profits of the cooperative firms and outsiders respectively, and k denotes the number of firms in the RJV cartel.

The cooperation is **externally stable** if for $k \leq (n-1)$:

$$V^F(k) \geq V^C(k+1) \quad (6)$$

so that no outsider has an incentive to join. By convention, the industry-wide cooperation ($k=n$) is externally stable and the competitive setting ($k=1$) is internally stable. A stable RJV of size k^* , $2 \leq k^* \leq (n-1)$ satisfies both $V^C(k^*) \geq V^F(k^* - 1)$ and $V^F(k^*) \geq V^C(k^*+1)$. The present setting, although simple, because of the quadratic payoffs, still appears

⁴ See Veugelers and Kesteloot (1993) and Kesteloot and Veugelers (1993) for somewhat different approaches to stability in a duopoly setting.

to be too complicated to produce an analytical solution. By means of numerical simulation, however, it is possible to detect a number of tendencies.

The case in which cooperation results only in coordinated investments and no better information transfer ($\epsilon = 0$) can be characterized as an R&D cartel (Kamien *et al.* (1992)). In such a setting it can be shown that the profits of outsider firms are lower than those of cartel members, while levels of profits for both tend to increase as the size k of the cartel increases (see Appendix 3). The intuitive explanation for why outsiders perform better is that, with low industry spillovers, they benefit from lower R&D levels of the cartel. This is similar to effects that apply with an output cartel and fringe firms [see Salant *et al.* (1983)⁵]. With large spillovers, outsiders enjoy a free ride on the larger investment levels and knowledge transfer of the cartel members; also in this case they perform better than cartel members.

It is hard to envisage how such an R&D cartel would come about, since it is more profitable for firms to sit back and wait until others cooperate. One interpretation may be that external circumstances - for example, a participation in a government sponsored project - can result in the coalition of size k . The question then is whether that coalition will remain stable if they coordinate their cost-reducing investments. Extensive computer simulations⁶ indicate that with small spillovers only very small sizes of $k=2$ or 3 are stable. With large spillovers and sufficiently high R&D efficiency it appears that two cartel sizes are stable, i.e. one which comprises all firms in the industry, and another with only a few firms⁷.

⁵ There is a sequel to this observation, see e.g. Farrell and Shapiro (1990), Martin (1990) and Schaffer (1993).

⁶ Details are available from the authors.

⁷ These tendencies are reminiscent of findings by Donsimoni *et al.* (1986) concerning price leadership cartels. Using a similar analytical

In an RJV cartel information sharing improves ($0 < \epsilon \leq 1 - \beta$), and simulations indicate that sharing tends to produce large stable coalition sizes (see Table 1). It is interesting to notice how important the presence of the information sharing parameter is for the stability of the RJV size. In the illustrated parameter ranges, an industry-wide cooperation quickly becomes stable when the information-sharing parameter is still relatively small, $\epsilon < 0.1$. The basic reason is that the improvement in information sharing results in higher profits for member firms [see also Baumol (1992)]. In addition it tends to also increase the profitability of further increases in these strategic investment activities, as explained above. This in turn improves the competitive position of the RJV vis-à-vis the outsiders, and everybody prefers to be a member of the RJV.

The employed stability conditions assume a free membership, but clearly the RJV cartel may have incentives to limit membership in order to maximize the profits per member⁸. In the present framework these tendencies are strongest when industry spillovers and the improvements in information sharing are modest [see also Poyago-Theotoky (1993)].

5. Welfare Implications

Even though the RJV cartel may improve innovative investment efforts, it still remains to be seen whether or not the size of the RJV cartel is appropriate from the viewpoint of static welfare. Static welfare W , by definition, is the sum of consumer surplus and producer surplus, and can be written as

definition of a stable cartel they showed that unique stable sizes exist, as long as firms are not too cost-efficient relative to the market demand. If they are efficient then two cartel sizes exist, one of which comprises all industry members.

⁸ Yi and Shin (1992) discuss both open and closed membership R&D coalitions with reciprocal spillovers, but then do not look at improved information sharing.

$$W = Q^2 + \sum_{i=1}^n V_i \quad (7)$$

with Q the total industry output and V_i the profit of industry member i .

The

complex expression of this welfare function in terms of spillovers, information sharing and size of cooperation again prevents an analytical characterization. But extensive numerical simulations clearly reveal a number of inferences, provided R&D efficiency is not too high (Γ sufficiently high, so that all investment and profits levels are positive and second-order conditions are met).

A first result concerns the effect of the larger cartel spillovers :

Proposition 2 : Better information sharing in the RJV cartel results in a higher consumer surplus and static welfare.

While this result is perhaps not surprising, it is not trivial either, since it is the net effect of two opposing tendencies. On the one hand the innovative investment activities and the profitability of the RJV cartel tend to increase, as information sharing among the members captured by ϵ increases. But the opposite tendency applies for outsiders. They reduce their investment levels and their profitability also diminishes as the RJV members improve on their information sharing. The positive effects on the investment and profitability of the RJV dominate in the present setting, and consumer surplus and static welfare benefit from the enhanced spillovers within the RJV.

The relation between static welfare and the size of the R&D cartel that only coordinates efforts without additional information sharing ($\epsilon = 0$) is given in Figure 1 a.1. and b.1. Welfare decreases (increases) with the size of the R&D cartel if industry spillovers are small ($<1/2$) (large ($>1/2$)).

Figure 1 : Static welfare and the size (k) of the RJV cartel

But this inference is strongly dependent on the absence of additional information sharing. Simulations suggest that in an RJV cartel that allows better information sharing ($0 < \epsilon \leq 1-\beta$) a different pattern emerges, summarized by :

Proposition 3 : In industries with a small number of firms and large industry spillovers, consumer surplus and static welfare tend to increase as the size of the RJV cartel increases.

In other settings with more numerous suppliers and smaller industry spillovers, consumer surplus and static welfare first increase and then decrease as the size of the RJV cartel increases.

Numerical analysis indicates that the indicated pattern of static welfare closely resembles the pattern of consumer surplus. In essence it reflects the investment and resulting output of the RJV cartel members. As the size of the RJV cartel increases, the tendency for cartel members to restrict output begins to dominate incentives to expand resulting from better information sharing. For some large cartel sizes outsiders may in response operate with larger output⁹, but this is not sufficient to compensate for the decrease of the RJV cartel member output. Consequently a tendency exists for consumer surplus and static welfare to decrease as well. All of this tends to have especially strong effects in industries with many firms and low industry spillovers. In other settings larger sizes improve static welfare.

These tendencies are reminiscent of earlier findings that in some cases innovative activities are highest in industries with an intermediate degree of rivalry, while in others a monopoly may be most conducive to technological change [Kamien and Schwartz (1976); and De Bondt *et al.* (1992)]. Even though the discussion of Baumol (1992) of technology sharing cartels is sympathetic towards such modes of cooperation, he noted after a discussion of the welfare gains :

⁹ This discussion is based on additional simulations, details of which are available from the authors.

"Still, none of this is certain. ...if innovation is undertaken by firms purely for its competitive advantage a cartel may adopt a truce committing all of its members to reduce R&D outlays severely or eliminate them altogether. The cartel can, then, harm welfare by discouraging innovation .."(p.136)

The findings reported here highlight circumstances in which this is most likely to happen for an RJV cartel : large membership in industries with smaller spillovers and moderate enhancement of information flows¹⁰.

These results contradict what is reported in Poyago-Theotoky (1993). She states that the equilibrium size of an RJV cartel is less than the optimum size which requires all firms to participate in a cooperative agreement. Poyago-Theotoky's model is very similar to our model, but she defines social surplus as the payoff of the innovative firms. Our findings also differ from those of Combs (1993) who considers a model in which the probability of success in innovation depends on whether or not the innovative firms can share information. She argues, also on the basis of numerical simulations, that the equilibrium size of cooperation never exceeds the size which maximizes total surplus.

The possible reduction in output of the RJV members also tends to result in a decrease in the profit of any cartel member. Hence the RJV members have an incentive to limit membership. The simulations indicate that if the RJV cartel with perfect information sharing were to maximize the profits per member, it will be smaller than the size that maximizes consumer surplus and static welfare. For less than perfect information sharing the cartel may comprise all companies in the industry; this is larger than the more limited size that maximizes welfare. This result strongly suggests that any welfare analysis of stable coalitions in R&D will depend strongly on the properties of information sharing.

¹⁰ Another concern is that the RJV cartel may use the agreement to facilitate cartel like production.

6. Conclusions

To date most of the analytical work suggests that pre-competitive R&D improves on consumer surplus and static welfare if and only if industry spillovers are large. This paper qualifies this inference for industries in which a research joint venture cartel both coordinates investments and improves information sharing. Consumer surplus and static welfare tends to increase and then decrease as the size of the cartel increases, especially in industries with many rivals and smaller spillovers. This result applies even though better information sharing in the RJV cartel results in a larger consumer surplus and static welfare.

Although public policy instruments may be called in to correct the wedge between the welfare maximizing size and the stable size of R&D cooperation, it seems that an easier route would be to attempt to stimulate policies that facilitate voluntary information transfers¹¹. The analysis indicates that these improved transfers tend to improve the profitability of the RJV members, albeit at the expense of outsiders. These redistribution effects may result in political support of RJV members for government programs that improve information sharing, while at the same time the non-participating fringe firms may argue for an adapted special treatment.

Extensions of the analysis may test for robustness of findings with other cost and demand specifications. In addition the assumption of a constant spillover parameter β and information sharing parameter ϵ can be relaxed, since one could expect for example such transfer effects to diminish as the number of transmitting and recipient firms increases. A

¹¹ Contrary to popular belief, the amount of direct R&D subsidies provided to private firms by the Japanese government is much smaller in relative as well as absolute terms than that in both the European Community and the United States. R&D policies in Japan are characterised by the encouragement and coordination of R&D collaboration among large Japanese firms [see Suzumura and Goto (1993)].

full endogenisation of stable coalitions taking, into account possibilities for better information sharing that is also at least partly endogenous, still needs to be accomplished. Firms may, in addition, through their internal organisational architecture and the choice of product characteristics, influence spillovers. The impact of these aspects on profitability and welfare in asymmetric industry settings also await further clarification.

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Appendix 1

A two-stage setting is presented. In the second stage all firms compete à la Cournot Nash. In the first stage they choose the level of R&D investments that reduce the constant unit cost of production. The first-order conditions are :

$$\frac{\delta \pi_i}{\delta q_i} = a - c_i - 2 \cdot q_i - \sum_{\substack{j=1 \\ j \neq i}}^n q_j = 0 \quad i=1, \dots, n \quad (A1)$$

which imply $\pi_i = q_i^2$.

After substituting c_i and c_j equations given by equations (1) and (2) of the text into (A1) and solving for q_i , the Nash equilibrium outputs in the product market follow :

$$q_i^c = Z + (A-D) \cdot x_i^c + B \cdot \sum_{\substack{s=1 \\ s \neq i}}^n x_s + (C-D) \cdot \sum_{\substack{t=1 \\ t \neq i}}^k x_t^c \quad i = 1, \dots, k \quad (A2)$$

$$q_j^f = Z + A \cdot x_j^f + B \cdot \sum_{\substack{s=1 \\ s \neq i}}^n x_s - D \cdot \sum_{t=1}^k x_t^c \quad j = k+1, \dots, n \quad (A3)$$

where

$$A = \frac{n-(n-1)\beta}{n+1}, \quad B = \frac{2\beta-1}{n+1}, \quad C = \frac{(n+1)\epsilon}{n+1}, \quad D = \frac{(k-1)\epsilon}{n+1}, \quad Z = \frac{a-c}{n+1}.$$

Subsequently, the payoff for insiders of the RJV cartel V_i^c and for outsiders V_i^f can be written as

$$V_i^c = [Z + (A-D) \cdot x_i^c + B \cdot \sum_{\substack{s=1 \\ s \neq i}}^n x_s + (C-D) \cdot \sum_{\substack{t=1 \\ t \neq i}}^k x_t^c]^2 - \Gamma \cdot (x_i^c)^2 / 2 \quad (A4)$$

$$V_j^f = [Z + A \cdot x_j^f + B \cdot \sum_{\substack{s=1 \\ s \neq i}}^n x_s - D \cdot \sum_{t=1}^k x_t^c]^2 - \Gamma \cdot (x_j^f)^2 / 2 \quad (A5)$$

The investment strategies in the first R&D stage satisfy :

$$\frac{\delta \sum_{i=1}^k V_i^c}{\delta x_1^c} = Z \cdot S + [S^2 - \Gamma'] \cdot x^c + (n-k) \cdot B \cdot S \cdot x^f = 0 \quad (A6)$$

$$\frac{\delta V_j^f}{\delta x_j^f} = Z.A + k.A.(B-D).x^c + [A^2 + (n-k-1)OAB - \Gamma'] . x^f = 0 \quad (A7)$$

in which $\Gamma' \equiv \Gamma/2$ and $S \equiv A + (k-1).(B+C) - k.D > 0$.

Second-order conditions require $\Gamma' > S^2$ and $\Gamma' > A^2 + (n-k-1)AB$.

The best response functions of the RJV cartel members and outsiders in the R&D stage are

$$x^c = \frac{Z.S + (n-k).B.S.x^f}{\Gamma' - S^2} \quad (A8)$$

$$x^f = \frac{Z.A + k.A.(B-D).x^c}{\Gamma' - A^2 - (n-k-1).A.B} \quad (A9)$$

Equations (A8) and (A9) reveal the nature of strategic interactions among the rival firms. The best response functions of the RJV firms and outsiders all slope downward when $0 \leq \beta < 1/2$ and the R&D investments of rival firms are strategic substitutes. When spillovers are large ($\beta > 1/2$), the outcomes are not so clear-cut. Although the best response function of the RJV members still slopes upward, the slope of the best response function for the outsiders is determined by B and D, which depends on β and ϵ . The best response function of the outsiders is downward sloping when $\epsilon > (2\beta - 1)/(k-1)$ and is upward sloping otherwise. Hence, it becomes possible for the slopes of the best response functions to have opposite signs. If this happens, we cannot simply characterize the interactions as strategic substitutes or complements. Such an outcome is more likely when k and/or ϵ become larger¹².

The R&D investments follow from solving equations (A8) and (A9)

$$x^c = \frac{Z.S.[A.(B-A) + \Gamma']}{T} \quad (A10)$$

$$x^f = \frac{Z.A.\{S.[B-A-(k-1).C] + \Gamma'\}}{T} \quad (A11)$$

where $T \equiv (S^2 - \Gamma').[A^2 + (n-k-1).AB - \Gamma'] - (n-k).k.A.B.S.(B-D) > 0$, because of $Z.S.[A.(B-A) + \Gamma'] > 0$ and the positivity requirement of the R&D investment.

The equilibrium profits of the RJV members V^c and of the outsiders V^f can be computed as

$$V^c = \left(\frac{\Gamma'}{S^2} - 1 \right) . (x^c)^2 \quad (A12)$$

¹² When slopes of the best response curves differ, De Bondt and Henriques (1993) show that a Stackelberg equilibrium, where the firm with upward sloping best-response curve (in our case, the cooperative firms) acts as a leader, may produce a superior solution to a Cournot-Nash equilibrium in the sense that all firms are better off.

$$V^f = \left(\frac{\Gamma'}{A^2} - 1 \right) \cdot (x^f)^2 \quad (A13)$$

Appendix 2

Starting from the R&D investment levels defined in equations (A10) and (A11) it is possible to verify that $(x^c - x^f)$, has the same sign as

$$(k-1) \cdot A \cdot C \cdot S + (S-A) \cdot \Gamma' \quad (A14)$$

The first term in expression (A14) is greater than (equal to) zero when the information sharing parameter ϵ is positive (zero) because of C as defined in (A3). The second term has the same sign as $[2 \cdot \beta - 1 + (n-k+1) \cdot \epsilon]$. When $\beta > 1/2$, it is clear that $(S-A)$ is positive and $x^c > x^f$. When $\beta < 1/2$, the positivity of $(S-A)$ requires that

$$\epsilon \geq (1 - 2 \cdot \beta) / (n - k + 1)$$

which is the sufficient condition (4) for $x^c > x^f$.

Appendix 3

From the definition of the profits of the RJV cartel members and outsiders given above by (A12) and (A13) with $\epsilon=0$ and thus $C=D=0$ it is possible to verify that $(V^f - V^c) > 0$ for $\beta \neq 1/2$ and $V^f = V^c$ for $\beta = 1/2$. Tedious manipulation reveals

$$\text{sign}(V^f - V^c) = \text{sign}[(k-1) \cdot B^2 \cdot \{ (k+1) \cdot \Gamma' + ((k+1) \cdot A + (k-1) \cdot B \cdot (B-A)) \}] \quad (A15)$$

The result for $\beta = 1/2$ follows immediately since it means that $B=0$. The expression between square brackets can be rewritten as :

$$[(k+1) \cdot (\Gamma' + A \cdot (B-A)) + (k-1) \cdot B \cdot (B-A)] > 0 \text{ for } \beta < 1/2,$$

since for such small spillovers $B < 0$. Use is also made of the positivity of A and $(\Gamma' + A \cdot (B-A))$ which is needed in any case to assure positive investments and profits.

For $\beta > 1/2$ and $B > 0$ it is likewise possible to use the restriction $(\Gamma' + S \cdot (B-A)) > 0$ which follows from $x^f > 0$ and (A11), to give

$$0 < [\Gamma' + (A + (k-1) \cdot B) \cdot (B-A)] = [(k+1) \cdot \Gamma' + ((k+1) \cdot A + (k-1) \cdot B) \cdot (B-A)] < (k+1) \cdot \Gamma' + (A + (k-1) \cdot B) \cdot (B-A)$$

noting $S = (A + (k-1) \cdot B) > 0$, $(A-B) < 0$ and $k \geq 2$.

The stated dependence of profits on k follows in part from

$$\text{sign}(\delta V^c / \delta k) = \text{sign} B^2 \cdot [k \cdot (n-k) \cdot A \cdot B + (k-1) \cdot (\Gamma' - S^2)] > 0 \text{ for } \beta > 1/2 \quad (A16)$$

$$\text{sign}(\delta V^f / \delta k) = \text{sign} B^2 \cdot [(B-A) \cdot A + \Gamma'] \cdot k + ((B-A) \cdot S + \Gamma') \cdot (k-1) > 0 \quad (A17)$$

for $\beta \neq 1/2$. The first inequality (A16) uses $B > 0$ for $\beta > 1/2$ and $(\Gamma' - S^2) > 0$ by second-order condition. Simulations indicate that $(\delta V^c / \delta k)$ may be negative for small k in industries with very small β and low Γ . The second inequality (A17) again uses restrictions that are necessary for the positivity of investment and profits. ■