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ABSTRACT

The Incentives to Form Research Joint Ventures: Theory and Evidence

by Lars-Hendrik Röller, Mihkel M. Tombak and Ralph Siebert*

The literature on research joint ventures (RJVs) has emphasized internalizing spillovers and cost-sharing as motives for RJV formation. In this paper we develop two additional explanations: product market complementarities and firm heterogeneity. We analyze a model of RJVs with asymmetric firms and differentiated products. We then test these various explanations for RJV formation by estimating an endogenous switching model using data now available through the U. S. National Cooperative Research Act.

ZUSAMMENFASSUNG

Anreize, ein Forschungs-Joint Venture zu gründen

Die Literatur über Forschungs-Joint-Ventures (FJV) hat bisher die Internalisierung von Spillovers und die Kostenaufteilung als primäre Motive, ein FJV zu gründen, hervorgebracht. In diesem Beitrag werden zwei weitere Gründe angeführt: Produktmarktkomplementaritäten und Unternehmensheterogenitäten. Wir analysieren ein Modell über FJV mit asymmetrischen Unternehmen und differenzierten Produkten. Anschließend testen wir die verschiedenen Erklärungen, ein FJV zu gründen. Hierbei wird ein endogenes „switching“ Modell geschätzt, in dem Daten von „U.S. National Cooperative Research Act“ benutzt werden.

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1 Introduction

In the early 1980s there was an apparent shift in technology policy in both the U.S. and in Europe. This was seemingly motivated by increased international competition, particularly from the Japanese in high technology sectors. Many scholars, policy makers and industrialists identified the more cooperative business environment in Japan as a factor yielding competitive advantage (e.g., Jorde and Teece, 1990, Shapiro and Willig, 1990, Branscomb, 1992). The 1961 Act on the Mining and Manufacturing Industry Technology Research Association and the proactive efforts of MITI encouraging joint ventures were identified as policy tools by which the Japanese created such a cooperative atmosphere. The response by U.S. policy makers was to enact the 1984 National Cooperative Research Act (NCRA) and to provide government support for ventures such as SEMATECH. In Europe, a block exemption for research joint ventures (RJVs) was provided for under EU Competition Law. In addition, the EU embarked on a series of framework programs where billions of ECU were earmarked for subsidizing many research joint ventures.

As a result of these developments, there has been a considerable amount of economic research on RJVs. In particular, there is a relatively large body of theoretical work in this area. In contrast, the contribution of this study is primarily empirical. Using U.S. data now available through the 1984 NCRA we examine the rationales for RJV formation.[1]

In principle, there are several incentives for firms to engage in an RJV. Among the reasons prevalent in the economics literature are: (i) internalizing the spillovers associated with R&D (i.e., overcoming free-rider problems) and (ii) cost savings through sharing of R&D costs. Internalizing spillovers through RJVs is beneficial because firms would otherwise spend less on RJV due to free-rider behavior. Cost-sharing is a powerful incentive as it allows firms to pool their resources and avoid wasteful duplication. In the theoretical section of this paper, we formalize two other factors that determine firms' decisions to form an RJV: (iii) product market complementarities and (iv) firm heterogeneity. As we will see, all the above factors influence not only firms' decisions to form an RJV, but also their investments in R&D.

Amongst the incentives to RJV which are not studied in this paper are asset complementarities (see Hamel, Doz and Prahalad, 1989, and Teece, 1986, 1992). In this case, RJV partners have complementary capabilities and would benefit from one another to develop and commercialize new technologies. To the extent that these asset complementarities are not captured by asymmetries in firm size or by product complementarities, they are excluded from the analysis below. We also do not consider the incentives by firms to share risks through RJVs, as well as the possibility of overcoming financial constraints. The reason these explanations are not included is the lack of data and measurement difficulties, and not that we consider these explanations less relevant.

Much of the theoretical economics literature has focused on internalizing technological spillovers as well as cost-sharing as the primary reason for RJV formation (the most

[1] Other empirical studies in this area include Link and Bauer (1989), Kogut (1989), and Beecy, Link, William and Teece (1994).

influential papers are Katz, 1986, d'Aspremont and Jacquemin, 1988, and Kamien, Muller, and Zang, 1992).[2] One of the key results from this literature is that when R&D by one firm spills over to other firms, private incentives to conduct R&D are reduced (a free-rider effect). If firms were to form an all-inclusive RJV and choose R&D investment levels cooperatively, spillovers are internalized. This results in an increase in the effective R&D investments, and raises welfare. Note that contrary to the free-rider argument, cost-sharing would lead to a decrease in R&D investment at the firm-level. For example in the model of Kamien, Muller, and Zang (1992), firm-level R&D spending is reduced in an RJV when spillovers are low. In this case the free-rider problem is relatively small, leading to little increase in firm-level R&D spending by internalizing the spillover. The reverse is the case for high spillovers.

Whether the cost-sharing or the free-rider effect dominates in terms of their combined impact on firm-level R&D spending is ultimately an empirical question. It is claimed that R&D cost-sharing can be quite substantial when it reduces "excessive duplication of effort": firms within an industry may be pursuing the same invention, using the same methods and thus replicating effort. For instance W. Norris, CEO of Control Data Corp. refers to a "shameful and needless duplication of effort", as quoted in David (1985).[3] Whether cost-sharing or R&D coordination dominates within the context of the formation of SEMATECH is studied by Irwin and Klenow (1996). They find a reduction in R&D spending by SEMATECH members relative to the rest of the semiconductor industry and conclude that cost-sharing seems to be a more important factor.

The interactions between product market competition and its effects on organizational decisions is a recently emerging literature (see for example Hart, 1983 and Vickers, 1995). In this paper we analyze the effect of product differentiation (the degree of substitutability or complementarity) on the incentives to form an RJV.[4] We allow products to range from perfect complements to perfect substitutes. In particular, if firms are producing complementary products one would expect incentives for RJV formation to be quite different relative to when firms produce substitutable products. For example, the transportation equipment and stone, glass and clay industries have a complementary product and we observe an RJV between aerospace and ceramics companies to enhance the development of composite materials (Composite Materials Characterization, Inc.).

R&D has been studied as a mechanism to obtain or retain market power (Reinganum, 1983). Since RJVs influence R&D levels for those firms inside differently to those firms outside the RJV, it appears reasonable to conjecture that RJVs affect market structure and market power. The exclusive character of RJVs may then increase a given asymmetry

[2] The theoretical literature on RJVs is too extensive to cite here. For a survey see DeBondt (1997).

[3] This argument, however, does not consider a salient feature of R&D - that it is uncertain. Many independent trials can raise the probability of an invention occurring. In particular, Nalebuff and Stiglitz (1983) argue that the gains from competition in the form of lower risk and better incentives may more than offset the cost of duplicate research.

[4] See Scherer (1980, 1986) for a discussion of product market competition and incentives to innovate. More specifically, Zhang (1997) addresses the issue of product market competition and RJV formation in a strategic delegation game.

in industry structure further, increasing market power for those firms inside the RJV at the expense of outsiders. As we mention above, antitrust regulators have generally been quite lenient towards RJVs. However there has been some concern when the venture's membership is "overinclusive" (U.S. Department of Justice, 1985, EU, 1985). On the other hand, if RJVs are "exclusive clubs" the benefits of R&D accrue to only a few firms. This, in turn, may pronounce the initial asymmetries, leading to a more concentrated market structure. In general, given an initial asymmetric market structure, R&D joint ventures might raise competitive concerns, and it is important to examine which firms participate in RJVs and what the conditions for membership are.

Our paper contributes to the above literature by examining both theoretically and empirically several of the above motives for RJV formation simultaneously. We begin by specifying a framework that extends the model by Kamien, Muller, and Zang (1992) to asymmetric firms and complementary products. This allows us to investigate the effect of heterogeneous firms and product market complementarities. We show (theoretically) that large firms have less incentive to form an RJV with smaller firms in order to increase market power. As a consequence the industry might become increasingly asymmetric through RJVs. These results suggest that joint ventures between different sized firms are less likely to happen. Regarding the second extension, our model predicts that RJVs tend to be formed amongst firms selling complementary products.

The second part of the paper tests and quantifies the various incentives developed by the theoretical literature on RJV formation making use of a rather unique data base available through the information made public under the 1984 National Cooperative Research Act. We estimate a two-equation system that endogenizes RJV formation and its impact on R&D investments. Our results indicate that a significant factor in determining whether two firms join together in an RJV is that they are similar in size. This finding is consistent with the theoretical model that predicts that large firms tend not to participate with small firms in RJVs. In addition, we find that whether cost-sharing or free-rider effects dominate in terms of firm-level R&D depend on the industry and the size of the RJV under consideration. However, as an incentive to form an RJV, there is evidence that cost-sharing is more important. Finally, we find that there are certain industry-pairs (possibly vertically related) where complementarities significantly increase RJV formation. It appears reasonable that the technology involved in these industries is similar, yet product market competition between firms in these two sectors is somewhat complementary. This empirical finding that firms producing complementary products are more likely to RJV is consistent with the theoretical model developed in the paper.

The remainder of the paper is organized as follows. Section 2 develops and analyzes a model of RJV formation, R&D investment, and Cournot competition allowing for asymmetric firms and complementary products. Section 3 describes the data and the empirical model that test the various motives for RJV participation. We conclude in Section 4.

2 The Model

We consider a duopoly game of three stages similar to that of Kamien, Muller, and Zang (hereafter KMZ, 1992). KMZ show that symmetric firms producing substitutable products have an incentive to form a cartellized RJV. In what follows we show that asymmetry will reduce this incentive while producing complementary products will increase the motivation. In the first stage firms decide on RJV participation. In the second stage the R&D investment (X) is determined which reduces marginal costs by a function of the effective R&D investment f(X). The effective R&D is the firm's own R&D investment when it is engaged in R&D competition and it is the sum of the firms' R&D investments when they form an RJV. The third stage is a Cournot product market game. We assume that the firms indexed by i and j have different initial marginal costs ci and cj, such that ci < cj. We further assume that there are no fixed costs and a linear demand structure given by $p_i = a - bq_i - b\gamma q_j$ where $-1 \leq \gamma \leq 1$. Thus our analysis encompasses substitutable (> 0), totally differentiated ($= 0$), and complementary products (< 0). Without loss of generality we set $b = 1$. As we focus on product market complementarities and firm heterogeneities as motives of RJVs, we abstract from spillovers when firms are in R&D competition. Our assumptions regarding the R&D production function and the profit functions that guarantee existence and uniqueness of the equilibrium are analogous to KMZ taking into consideration the asymmetry of firms and product complementarities.[5]

2.1 Product Market Competition - Stage 3

Firms profit function in stage three are $\pi_i = [p_i - (c_i - f(X_i))]\, q_i$. Note that profits depend upon the R&D investment X_i, which is determined in the second stage as a function of the organization of R&D chosen in the first stage. Solving the third stage Cournot game for a given X_i and X_j the equilibrium quantities are given by,

$$q_i^* = \frac{[(2-\gamma)\, a - 2\,(c_i - f(X_i)) + \gamma\,(c_j - f(X_j))]}{(4-\gamma^2)}$$

$$q_j^* = \frac{[(2-\gamma)\, a - 2\,(c_j - f(X_j)) + \gamma\,(c_i - f(X_i))]}{(4-\gamma^2)}$$

It can be seen that under asymmetric costs the firm with lower effective marginal costs will have larger equilibrium quantities. The equilibrium profit function for firm i, is

[5] First, the R&D production function $f(x)$ is twice differentiable and concave, with $f(0) = 0, f(X) \leq c_i$, $f\prime(X) > 0$ for all X. Secondly, the R&D production function satisfies: $\lim_{x\to\infty} f(X) < a - 2c_j + c_i$ and $f'(0) > (4-\gamma^2)^2 / [2((2-\gamma)\, a - 2c_j + \gamma c_i)]$
which guarantees that both firms find it optimal to produce output and invest in finite R&D. Thirdly, the profit minus the R&D expenditure is a strictly concave function of X, i.e., $\frac{4}{(4-\gamma^2)^2} f'(x_i)\,[(2-\gamma)\, a - 2\,(c_i - f(x_i)) + \gamma\,(c_j - f(x_j))]$
is decreasing in X_i (with an analogous condition for firm j).

$$\pi_i^* = q_i^2 - x_i. \tag{1}$$

and there is an analogous payoff for firm j. Note that the equilibrium quantities and Cournot payoffs are determined by firm i's marginal costs ex post of R&D $(c_i - f(X_i))$ and the larger the ex post asymmetry in marginal costs the larger is the difference in quantities and profits. The next section will endogenize costs by considering R&D investment.

2.2 R&D Investment - Stage 2

In order to solve for the R&D investment decisions, we now consider the case of R&D competition. In this scenario firms decide on their individual R&D level (X_i) given the R&D investment of the other firm. The effective level of cost-reducing R&D investment is then X_i. In other words we assume that in this case there are no spillovers.[6] Firms' objectives at this stage are then to maximize their respective functions (1). The first-order condition for R&D investment derived from (1) for the firm of type i is,

$$f'(X_i^*)\, q_i^* = \left(4 - \gamma^2\right)/4 \tag{2}$$

Analogously, the condition for firm j is,

$$f'\left(X_j^*\right) q_j^* = \left(4 - \gamma^2\right)/4 \tag{3}$$

Using these conditions we obtain the following lemma.

Lemma 1 *R&D investments are strategic substitutes (complements) when products are substitutes (complements).*

Proof.

Taking the derivative of (2) with respect to X_j yields

$$\frac{\partial X_i^*}{\partial X_j} = \frac{\gamma f'(X_j)\, f'(X_i^*)}{f''(X_i^*)\,(4-\gamma^2)\, q_i^* + 2\left[f'(X_i^*)\right]^2}.$$

The numerator is positive when the products are substitutes (γ is positive) as the marginal costs decrease with an increase in investment in R&D. Similarly, the numerator is negative when products are complements. The denominator is the derivative of (2) with respect to X_i which by the second order condition must be negative. ■

Figure 1 illustrates the stage 2 reaction functions when products are substitutes and Figure 2 shows the case when products are complements. In the product substitute case, since R&D investments are strategic substitutes the reaction functions slope downwards. For the case of symmetric initial marginal costs ($c_i = c_j$) (2) and (3) both simplify to,

[6] This implies that the spillover parameter $\beta = 0$ in the KMZ model.

$$f^{'}\left(X^{A}\right)\left[\alpha - c + f\left(X^{A}\right)\right] = \frac{\left(4-\gamma^{2}\right)^{2}}{4\left(2-\gamma\right)} \tag{4}$$

which implies that the equilibrium investments are identical. The symmetric equilibrium is illustrated as point A in Figures 1 and 2.

To show how the asymmetry in the initial marginal costs affects the reaction functions we implicitly differentiate (2) with respect to c_i yielding

$$\frac{\partial X_i^*}{\partial c_i} = \frac{2f^{'}\left(X_i^*\right)}{\left[f^{''}\left(X_i^*\right) q_i^*\left(4-\gamma^2\right) + 2\left[f^{'}\left(X_i^*\right)\right]^2\right]} < 0. \tag{5}$$

A lower c_i therefore implies a larger X_i^* for a given X_j which means that firm i's reaction function shifts to the right. Similarly, implicit differentiation of (2) with respect to c_j yields $\frac{\partial X_i^*}{\partial c_j} = -\frac{\gamma}{2} \cdot \frac{\partial X_i^*}{\partial c_i}$ which indicates that the own cost effect dominates the cross cost effect in absolute terms. Consider a mean-preserving change in the initial cost asymmetry, such that firms' costs are $c_i + \varepsilon = c_m = c_j - \varepsilon$. Suppose the products are substitutes ($\gamma > 0$), which means that the cross cost effect is positive. Consequently, an increase in ε shifts firm i's reaction function to the right and firm j's reaction function down as illustrated in Figure 1. If, however, the products are complements ($\gamma < 0$) then the cross cost effect is negative. Since the own cost effect dominates the cross cost effect, an increase in ε shifts the reaction functions as shown in Figure 2. The asymmetric equilibrium is therefore at point B in Figures 1 and 2. Comparing investments at point A to point B yields the following lemma.

Lemma 2 *When no RJV is formed, then the low cost firm invests more in R&D than the high cost firm, i.e.* $X_i > X_j$.

Lemma 2 states that there is an inverse relationship between the initial marginal costs and the equilibrium R&D investments. As shown above, introducing asymmetric costs yields an asymmetric market structure where the low cost firm has higher profits and a larger market share. The above analysis shows that by incorporating R&D investments, the asymmetric industry structure is magnified, i.e. the larger firms becomes even larger and the smaller firm relatively smaller.[7]

We now consider the R&D investment decisions when the two firms form an RJV. In this scenario firms coordinate their R&D investments. The effective level of cost-reducing R&D investment is then $X = X_i + X_j$, which implies perfect spillovers. The industry profit function at this stage is then $\pi_i + \pi_j$ where the equilibrium payoffs incorporate the same cost reduction from R&D. The first-order condition for R&D investment is,

$$f^{'}\left(X\right)\left[q_i^{*JV} + q_j^{*JV}\right] = \frac{4-\gamma^2}{2\left(2-\gamma\right)}$$

[7] Rosen (1991) studies how firm sizes affect the size of R&D budget and also finds that larger (in our model, low cost) firms invest more in R&D.

or, equivalently,

$$f'(X)\left[a-\frac{(c_i+c_j)}{2}+f(X)\right]=\frac{(4-\gamma^2)^2}{4(2-\gamma)^2} \tag{6}$$

Note that R&D investments depend on the average (across firms) of the initial marginal costs. This implies that a mean-preserving increase in asymmetry between the initial marginal costs does not change the level of R&D investment in an RJV. Comparing this to the above finding, we get that the ex post asymmetry in marginal costs are preserved when an RJV is formed, whereas the ex post asymmetry is magnified when no RJV is formed. In other words, RJVs tend to make market structure more symmetric. The next lemma compares the equilibrium R&D investment under the two regimes.

Lemma 3 *Firms with higher marginal costs increase their effective R&D investment by participating in an RJV, i.e.* $X > X_j$. *Firms with lower marginal costs decrease their effective R&D investment with RJV membership if products are highly substitutable and asymmetries are large, e.g.,* $X_i > X$ *if* $\gamma = 1$ *and* $c_i \neq c_j$.

Proof.

We need to compare the R&D investment levels under RJV formation (X) with those under no RJV formation (X_i and X_j). Consider any R&D competition equilibrium depicted at point B in Figures 1 and 2. The symmetric analog is depicted by point A. Comparing the first-order conditions for the symmetric case (4) with (6) shows that $X^A = X$ if $\gamma = 1$. When $\gamma < 1$ then $X^A < X$. Thus the RJV effective investment level is given by point C which lies on or above point A. Comparing point B (the R&D competition outcome under asymmetry) to points A and C (the RJV outcome under asymmetry) yields the lemma. ■

The above lemma shows that at least one of the firms would increase its effective R&D investment by participating in an RJV. Since the R&D investment by each firm would be a portion of the effective RJV investment, it may be that both firms invest less in R&D. Lemma 3 also illustrates the interaction between product substitutability and cost asymmetries on the R&D investment effects of RJVs. Product complementarity increases the ability of RJVs to raise effective R&D investment while cost asymmetries decrease this effect of RJVs for the larger firms.

2.3 RJV Formation - Stage 1

Whether RJV formation is an equilibrium depends on equilibrium profits under R&D competition compared to those under RJV. Substituting the solutions for R&D investment decisions into (1), we can compare the incentives for firms to participate in an RJV. As we concentrate on asymmetries and complementarities we examine profits in the product market only. The incentive for firm j to participate in the RJV is then $\pi_j^{CJ} - \pi_j^N$, where the superscript denotes the regime (cartelized joint venture, CJ, or noncooperative, N) of the equilibrium profits gross of R&D investment. When $c_j > c_i$, using Lemma 3, we have $X > X_j$. This implies that firm j maintains market share in the product market by participating in the RJV, since the asymmetry is preserved. This leads to the following proposition.

Proposition 4 *The higher cost firm always has an incentive to participate in an RJV. The low cost firm does not have an incentive to participate in the RJV whenever products are highly substitutable and the asymmetry is large.*

Proof.

The difference in payoffs for j is

$$\pi_j^{CJ} - \pi_j^N = \left(q_j^{CJ}\right)^2 - \left(q_j^N\right)^2.$$

Thus there is an incentive for firm j to participate in an RJV so long as $q_j^{CJ} > q_j^N$. Which implies that $2f\left(X^{CJ}\right) - \gamma f\left(X^{CJ}\right) > 2f\left(X_j^N\right) - \gamma f\left(X_i^N\right)$, which holds under Lemma 3. Similarly, the condition for the large firm to have an incentive to join an RJV $\pi_i^{CJ} - \pi_i^N > 0$ can be expressed as

$$q_i^{CJ} > q_i^N \Leftrightarrow 2f\left(X^{CJ}\right) - \gamma f\left(X^{CJ}\right) > 2f\left(X_i^N\right) - \gamma f\left(X_j^N\right),$$

which holds under the conditions in the lemma, i.e. it does not hold for $\gamma = 1$ and when there are asymmetries. ■

Asymmetries change the strategic incentives to invest in R&D. By Lemma 2 the R&D investment magnifies the asymmetry and reduces the share of the producers surplus of the smaller firm. Thus the smaller firm has an incentive to join the RJV to prevent the asymmetries from increasing. As a consequence firm j may be in a weak bargaining position in the allocation of R&D expenditures in research joint ventures.

The incentive for firm i to join an RJV is $\pi_i^{CJ} - \pi_i^N$. With perfectly substitutable products, the effective marginal cost for the larger firm is lower and the marginal cost differential is larger under R&D competition. Thus profits in the product market are higher for the large firm under R&D competition. In sum, the large firm gains in terms of market share and profits from the asymmetry and has an incentive to exclude a smaller rival from an RJV. As a result, the market structure becomes even more asymmetric. RJVs that exclude smaller rivals might exhibit anti-competitive effects over the long run. Contrary to the view expressed by the U.S. Department of Justice (1985), our model suggests that R&D joint ventures should raise competitive concerns when its membership is "overexclusive". Thus, it could be that large firms form RJVs to obtain more market power.

Whether the theoretical arguments for RJV formation presented above are important reasons for RJV participation is an ultimately empirical issue. For this purpose we summarize the theoretical section with the following empirically testable hypotheses.

Hypotheses: Research joint ventures will tend to be formed:

(i) when R&D spillovers create free-rider problems,

(ii) when duplicative R&D efforts create opportunities for cost-sharing,

(iii) by firms producing complementary products,

(iv) among similar sized firms.

3 Empirical Analysis

In this section we present some econometric evidence regarding the incentives to form an RJV: (i) internalizing spillovers (i.e. the free-rider effect), (ii) cost-sharing, (iii) complementary products, and finally (iv) firm heterogeneity. As we mention above, the free-rider effect (i) implies that firms spend less on R&D than if they could coordinate their R&D investments. The reason for this is spillovers. According to the free-rider effect, one would expect the R&D investments at the firm-level to increase in an RJV. In addition, the effect is larger, the greater the spillover. Cost-sharing (ii), however, would go in the opposite direction - firms can pool their R&D spending in an RJV. As a result, the combined effect of the free-rider and cost-sharing effects on firm level R&D spending is ambiguous. As the spillover parameter increases, the free-rider effect increases relative to the cost-sharing effect and firms spend relatively more on R&D in an RJV (see KMZ). Our empirical analysis below will not be able to identify the free-rider effect separately from the cost-sharing effect. Rather, we empirically track the net effect (NE) on firm-level R&D spending, that is,

$$NetEffect = \underset{(-)}{CostSharing} + \underset{(+)}{FreeRider} \tag{7}$$

where cost-sharing has a negative effect on firm-level R&D spending and free-riding a positive effect. When the net effect in (7) is negative we refer to this scenario as the cost sharing effect being dominant. Otherwise the free-rider effect dominates.

The third determinant of RJV formation (iii) is the degree of complementarity in the final product markets. Under this hypothesis we would expect a large proportion of RJVs between firms that are in complementary industries. An example of this is an RJV between firms in vertically related industries such as *Composite Materials Characterization, Inc.* which is an RJV between aerospace (transportation equipment) and ceramics (stone, glass, and clay) companies to enhance the development of composite materials. Finally, hypothesis (iv) implies that larger firms tend to not form RJVs with smaller firms and we would expect RJVs among firms of similar size.

The empirical analysis below simultaneously assesses all four determinants of RJV formation. Instrumenting on the estimated change of R&D expenditures, we assess the effects of the various factors on the probability of RJV formation. Before we discuss the empirical specification in more detail, we briefly describe the data used in the analysis.

3.1 Data Sources: The National Cooperative Research Joint Ventures Act

The analysis requires data from a variety of sources. On October 11, 1984, President R. Reagan signed the National Cooperative Research Act of 1984 with the purpose that cooperative research and development efforts may improve productivity and bring better products to the consumers sooner and at lower costs, and enable American business and industry to keep pace with foreign competitors. Under the National Cooperative

Research Act firms are required to file a notification with the U.S. Attorney General and the Federal Trade Commission in order to receive protection from anti-trust penalties. By filing a notification firms may limit their possible antitrust damage exposure to actual, as opposed to treble, damages and the rule of reason for evaluating antitrust implications is applied. Notifications are made public in the Federal Register. Using a report published by the U.S. Department of Commerce (1993) and additional filings published in the Federal Register, we obtain the identities of the firms involved in the RJV, the date of the RJV, as well as the general nature of the proposed research. Our data on RJVs runs from January 1985 through July 1994.[8]

The identity of the RJV firms is then used to crosslink the RJV database with other firm-specific data obtained from Moody's (1995) company database, which has information on 17,785 firms based on financial reports and the business press. Since the company data we require is complete from 1988 onwards, we are able to use a total of 174 RJVs. The number of firms participating in RJVs is 445. The highest frequency is in the category of 5-10 participants per RJV. In our sample, each firm participates in about 3 RJVs on average.

A potential defect of our sample may be that smaller firms are not represented to the same extent as large firms. There are two reasons for this. First, firms participating in an RJV are not required to file under the National Cooperative Research Act. Since smaller firms are less likely to be the subject of an anti-trust investigation, it may be that an RJV consisting entirely of small firms is less likely to file. Secondly, smaller firms are often not reported in our Moody's Global Company Database or may not report R&D expenditures. Therefore our data may overemphasize larger firms. This possible sample selection bias, however, may only serve to make our estimates more conservative (e.g. we observe that firm size differences are important among the large firms).

3.2 Variable Definitions and Descriptive Statistics

In this section we will define the variables used in our econometric specification given in the following sections. Initially, in order to investigate whether firms form an RJV and with whom, we match all firms into firm pairs. There are a total of 502 cases where a firm pair is engaged in an RJV with each other, and there are 20,440 firm pairs where firms are not in an RJV, leading to a sample of 20,942 observations. As a result, we define a variable $P_{ij}\,(i \neq j)$ as a binary variable indicating whether the matched pair is participating in a joint venture.

$DASSET$ is the variable that measures the relative difference in firm size. In addition to firm size, we like to control for the size of the RJV: if the number of participating firms in the RJV is large, one would expect the size difference in firms' assets to be larger as well. Accordingly we define $DASSET$ as follows,

[8] For a more detailed description of the RJV-filings, see Link (1996). It is worth emphasizing that according to the classification done by Link (1996), 59% of the RJV filings are concerned with process innovation, whereas only 36% are product oriented.

$$DASSET_{ij} = \frac{|ASSET_{i,t-1} - ASSET_{j,t-1}|}{\max\{ASSET_{i,t-1}, ASSET_{j,t-1}\} \cdot \ln(\#RJV)} \; whenP_{ij} = 1,$$

$$DASSET_{ij} = \frac{\left|\overline{ASSET}_i - \overline{ASSET}_j\right|}{\max\left\{\overline{ASSET}_i, \overline{ASSET}_j\right\} \cdot 0.6} \; whenP_{ij} = 0,$$

where $\overline{ASSET}_i$ is the average of firm i's assets over the sample period and #RJV is the number of members in the RJV. In words, whenever the two firms form an RJV, we define DASSET as the absolute value of the difference in the firms' assets as a proportion of the larger firm's assets one year prior to the RJV formation. Whenever the firms are not engaged in an RJV, we define $DASSET$ as the absolute value of the difference of the firms' average assets as a proportion of the larger firm. In addition, we control for the size of the research joint ventures by dividing through by #RJV, where we set $ln(\#RJV) = 0.6$ when the two firms are not in an RJV.

In order to assess possible cost-sharing and free-rider effects, we need to construct a measure of how firm-level R&D changes. We define $r\&d1$ as the change in average firm-level R&D intensities after an RJV takes place. For the firm pairs that are involved in an RJV, the variable $r\&d1$ is constructed as follows,

$$r\&d1_{ij} = \frac{1}{2}\left(\frac{r\&d_{i,t-1}}{tr_{i,t-1}} - \frac{r\&d_{i,t}}{tr_{i,t}} + \frac{r\&d_{j,t-1}}{tr_{j,t-1}} - \frac{r\&d_{j,t}}{tr_{j,t}}\right) * 100$$

where $r\&d_i$ is firm level R&D investment, tr_i is total revenue at the firm-level, and t is the year of the RJV formation. In other words, $r\&d1$ measures whether the two firms spend relatively less on averge after they form an RJV. It is important to emphasize that the variable $r\&d1$ is only observable for firms that are actually engaged in an RJV.

For those firms that *do not* form an RJV with each other, the following variable $r\&d0$ can be constructed,

$$r\&d0_{ij} = \frac{1}{2}\left(\Delta\frac{r\&d_i}{tr_i} + \Delta\frac{r\&d_j}{tr_j}\right) * 100$$

where $\Delta\frac{r\&d_i}{tr_i}$indicates the average annual change of firm-level $r\&d$ intensity over the sample period.

In addition we define two control variables that should have an impact on RJV formation. $MEMBERS$ is the logarithm of the number of participants in the RJV and controls for the size of the RJV. Given that this variable is not observable for firm pairs that do not RJV, we proxy $MEMBERS$ by taking the logarithm of the average size of all other RJVs that the firms are engaged in. The logarithm is used to allow for a non-linear relationship between the change in R&D expenses and the size of the RJV. Total RJV activities by the firm-pair is measured through the variable $RJVS$ and equals to the number of other RJVs the firms are engaged in.

The definitions of the variables used in the estimation below, as well as some summary statistics, are given in Table 1a.

INSERT TABLE 1a ABOUT HERE

It is interesting to note from Table 1a that firm-level R&D expenditures as percentage of firm-level revenues are lower prior to forming an RJV, i.e. the variable $r\&d1$ has a negative mean. This seems to suggest that the free-rider effect dominates the cost-sharing effect. We will return to this in the empirical analysis below.

Finally, we use a set of dummy variables to control for intra- and inter-industry effects. Accordingly, we define industry dummies ($SICs$) which take on a value of one if two firms under consideration are in the same major industry group and zero otherwise. In addition, we define inter industry dummies ($COMPs$) which indicate whether firms are from different industries. In the empirical analysis below we will interpret the $COMP$ dummy as an indicator of whether firms produce related products. Note that SIC classifications are often based on cost-side considerations, i.e. they are technology oriented, and not demand-side oriented. In such a case, the precise complementarities we are capturing would be in production rather than product market complementarities. Given that the theoretical model developed above focuses on demand-side complementarities and the fact that currently there is no alternative industry classification, we use the SIC codes as a proxy for product market complementarities.

Table 1b reports the industries in our database and the sample frequencies (mean of the dummies) for each one of the industry pairs. As can be seen there are 6 intra-industry dummies (nonzero elements on the diagonal) and 16 complementarity dummies (nonzero off-diagonal elements).

INSERT TABLE 1b ABOUT HERE

It is noteworthy that over 50% of all RJVs in our sample occur with at least one firm being from the industrial machinery and equipment industry. Since machinery and equipment are often inputs for many other industries, it appears that this observation is consistent with the complementarity hypothesis.

As usual, there may be relevant variables for the formation of RJVs which have been excluded from the empirical analysis due to a lack of measures or data. In addition to financial risk and organizational variables already mentioned, there are potentially other factors. KMZ, for example, have identified the organization of the RJV as an important variable. Geographic location of the partners may be another variable affecting RJV formation. These variables may be correlated with some of the variables that have been included (e.g., the organization of the RJV may be correlated with the number of members).

3.3 Econometric Specification

In order to investigate our four hypotheses (i)-(iv) mentioned above we ultimately wish to estimate the following probit equation which determines whether or not the firms form an RJV[9]

$$
\begin{aligned}
P_{ij} &= \delta_1 DASSET_{ij} + \delta_2 R\&D_{ij} + \delta_3 MEMBERS_{ij} + \delta_4 RJVS_{ij} \\
&\quad + \sum_{k=1}^{6} \delta_5^k SIC_{ij}^k + \sum_{l=1}^{16} \delta_6^l COMP_{ij}^l + \varpi_{ij} \qquad (8)
\end{aligned}
$$

where $R\&D_{ij} = r\&d1_{ij} - r\&d0_{ij}$, i, j represents the firm pair $(i \neq j)$, k the industry dummy and l the inter-industry dummy. As already mentioned above, the variable $DASSET$ tests whether an RJV is formed among firms of similar size. Under hypothesis (iv) we expect that $DASSET$ has a negative impact on the probability of forming an RJV. Our hypothesis regarding product complementarities in RJV formation (iii) can be tested through the relative effect of the SIC and $COMP$ variables. The variable $R\&D$ tests whether the free-rider (i) or the cost-sharing effect (ii) dominates as an incentive to form an RJV. This is further discussed below. If complementarities across several different industries are important factors in RJV formation one would expect the coefficients for the corresponding $COMP$s to be larger than that of the SICs. In addition we include the two RJV control variables, one for the size of the RJV ($MEMBERS$), and the other for the number of RJVs that the firms are already engaged in ($RJVS$).

The incentive to RJV should depend on the expected effect on R&D expenditures as measured by $R\&D$ which is the effect of forming an RJV on the change in R&D spending (see section 3.2 for the variable definition). However, we only observe the variable $r\&d1$ (and consequently the variable $R\&D$) whenever the firms are *actually* engaged in an RJV, that is whenever the dependent variable is equal to one (i.e. $P_{ij} = 1$). We therefore have a missing data problem and need to somehow estimate the expected effect on R&D expenditures. A second econometric issue is that there may be considerable amount of simultaneity between R&D expenditures and the decision to form an RJV: the decision to RJV is determined by the R&D effect, but conversely the impact on R&D expenditures has an effect on the decision to RJV (as postulated in 8). Consequently, simultaneity between RJV participation and a change in R&D expenditures is a concern.

We take these issues into account by estimating an switching model proposed by Lee (1978). Lee solves the problem of missing data by estimating the omitted variable which then can be used as a regressor in obtaining consistent estimates of (8). Furthermore, this model takes into account the simultaneous effects between RJV participation and the R&D expenditures. The endogeneous switching model is given by:

[9] The decision process by which firms choose their RJV partners may be more complicated than a simple probit model suggests. Clearly, the probability of forming a RJV with a particular firm is not independent of the alternatives available. In other words, if there are many similar firms available, the probability of doing a RJV with one particular firm is lower than if there were no real alternatives. This would suggest a conditional probit approach. However, firms may be (and often are, see section 3.1) engaged in many RJVs at the same time. Therefore, the number of feasible alternatives are not impacting on any particular choice, which justifies our probit specification. Furthermore, the fact that RJVs are composed of many firms suggests a more sophisticated model, where the decision to participate in a RJV depends on which and how many other firms are willing to join.

$$r\&d1_{ij} = \alpha_1 MEMBERS_{ij} + \alpha_2 DASSET_{ij} + \sum_{k=1}^{6} \alpha_3^k SIC_{ij}^k + \sum_{l=1}^{16} \alpha_4^l COMP_{ij}^l + \nu_{ij} \quad (9)$$

if $P_{ij} = 1$.

$$r\&d0_{ij} = \beta_1 MEMBERS_{ij} + \beta_2 RJVS_{ij} + \sum_{k=1}^{6} \beta_3^k SIC_{ij}^k + \sum_{l=1}^{16} \beta_4^l COMP_{ij}^l + \varepsilon_{ij} \quad (10)$$

if $P_{ij} = 0$, where P_{ij} are given by equation (8). Equation (9) is the R&D equation for firms which form an RJV together, while equation (10) is the R&D equation for firms which do not RJV. Whenver $P_{ij} = 1$ (as endogeneously determined by (8) R&D expenditures are themselves determined by equation (9). Alternatively, when $P_{ij} = 0$ (as endogeneously determined by 8) R&D expenditures are determined by equation (10).

Following Irwin and Klenow (1996) our specification for RJV firms (9) controls for revenue effects. In addition, we include the variables $MEMBERS$ and $DASSET$ since both the cost-sharing and the free-rider effects are likely to vary with the size of the RJVs as well as the difference in size between the two firms. Finally, we include dummy variables to control for industry fixed-effects. Recall that the R&D expenditures for firms that do not form an RJV are the average R&D expenditures over the sample. Specification (10) postulates that average R&D spending is a function of the average number of members in other RJVs and the average number of other RJVs.

3.4 Estimation Procedure

Estimating equations (9) and (10) by OLS gives inconsistent estimates since $E\left(\nu_{ij}/P_{ij} > 0\right) \neq 0$ and $E\left(\varepsilon_{ij}/P_{ij} \leq 0\right) \neq 0$. Following Lee, we apply a two-stage estimation procedure where we first substitute (9) and (10) into (8) and obtain a reduced-form probit model as follows,

$$\begin{aligned} P_{ij} &= \gamma_1 MEMBERS_{ij} + \gamma_2 RJVS_{ij} + \gamma_3 DASSET_{ij} + \\ &\quad \sum_{k=1}^{6} \gamma_4^k SIC_{ij}^k + \sum_{l=1}^{16} \gamma_5^l COMP_{ij}^l + \sigma_{ij} \end{aligned} \quad (11)$$

which can be estimated consistently by standard probit methods. Using the predicted probabilities $\hat{P}_{ij}$ obtained from (11) we can then get consistent estimates of the R&D equations by OLS as follows,

$$\begin{aligned} r\&d1_{ij} &= \alpha_1 MEMBERS_{ij} + \alpha_2 DASSET_{ij} + \sum_{k=1}^{6} \alpha_3^k SIC_{ij}^k \\ &\quad + \sum_{l=1}^{16} \alpha_4^l COMP_{ij}^l + \rho_1 \sigma_1 \frac{\phi\left(\hat{P}_{ij}\right)}{\Phi\left(\hat{P}_{ij}\right)} + \xi_{ij} \end{aligned} \quad (12)$$

if $P_{ij} = 1$, and where $E\left[\sigma_{ij} \cdot \xi_{ij}\right] = \sigma_1^2$ and $cov\left[\sigma_{ij} \cdot \xi_{ij}\right] = \rho_1$.

$$
\begin{aligned}
r\&d0_{ij} &= \beta_1 MEMBERS_{ij} + \beta_2 RJVS_{ij} + \sum_{k=1}^{6} \beta_3^k SIC_{ij}^k \\
&+ \sum_{l=1}^{16} \beta_4^l COMP_{ij}^l + \rho_0 \sigma_0 \left[\frac{-\phi\left(\hat{P}_{ij}\right)}{\left(1 - \Phi\left(\hat{P}_{ij}\right)\right)} \right] + \vartheta_{ij} \qquad (13)
\end{aligned}
$$

if $P_{ij} = 0$, where $E\left[\sigma_{ij} \cdot \nu_{ij}\right] = \sigma_0^2$ and $cov\left[\sigma_{ij} \cdot \nu_{ij}\right] = \rho_0$. Note that ϕ is the standard normal density function and Φ the standard normal distribution function, which controls for the endogeneity in the switching regression model.

The final step is to take the consistent estimates of the R&D equations (12) and (13) and to compute the predicted values for $\hat{r\&d1}_{ij}$ and $\hat{r\&d0}_{ij}$ for the entire sample of firm-pairs. This gives us a consistent estimate of $R\&D_{ij} = \hat{r\&d1}_{ij} - \hat{r\&d0}_{ij}$ which can then be used in the following probit estimation,

$$
\begin{aligned}
P_{ij} &= \delta_1 MEMBERS_{ij} + \delta_2 RJVS_{ij} + \delta_3 DASSET_{ij} + \delta_4 R\&D_{ij} \\
&+ \sum_{k=1}^{6} \delta_5^k SIC_{ij}^k + \sum_{l=1}^{16} \delta_6^l COMP_{ij}^l + \varpi_{ij} \qquad (14)
\end{aligned}
$$

The resulting structural probit-estimates are consistent as shown by Lee (1979). To obtain asymptotically efficient estimates, FIML is performed, where the two-stage probit estimates are used as starting values (see Limdep (1995), p. 668). The main results reported in the next section are essentially unchanged regardless of whether the two-stage or the FIML estimates are used.

3.5 Results and Interpretation

The results of the ML-estimates of R&D equation (12) for firm pairs which form an RJV are presented in Table 2. Since the dependent variable $r\&d1$ measures how R&D spending changes when firms form an RJV, we can now address whether the free rider or the cost sharing effect dominates.

INSERT TABLE 2 ABOUT HERE

Before interpreting our results, it is important to check whether the truncation term (ρ and σ) in our R&D equation is significant. As can be seen in Table 2, we find a significant estimate for the correction. This indicates that the selectivitiy through the enodgeneous dummy variable is indeed an important issue and justifies our endogeneous switching model specification.

Turning to the other estimates, it can be seen in the table that the number of participating members ($MEMBER$) is highly significant and negative, indicating that large RJVs increase firm-level R&D spending (recall the definition of $r\&d1$). This implies that the free-rider effect becomes more important as the size of the RJV increases. Apparently the free-rider problem is mitigated by including many firms from an industry. In other words, large RJVs leave fewer firms outside, reducing the free-rider problem, resulting in higher R&D investments. The positive sign of $DASSET$ indicates that firms of equal size tend to better internalize the free-rider effect, while firms of different size tend to reduce R&D spending, indicatig that the cost-sharing effect dominates. In sum, we find that homogeneous and large RJVs tend to favour the free-rider hypothesis.

Among the industry dummies we find a considerable amount of heterogeneity.[10] Comparing the relative magnitude of the intra-industry dummies reveals that cost-sharing is relatively large if both firms are in the "*Chemicals and Allied Products*" industry (*SIC28*) or the "*Electronic and other Electric Equipment*" industry (*SIC36*).[11] On the other hand, in the "*Oil and Gas Extraction*" industry (*SIC13*) and the "*Petroleum and Coal Industry*" (*SIC29*) R&D savings are relatively small, indicating that free-rider problems are rather significant. Turning to complementary industry effects, we find that firm-pairs from the "*Oil and Gas Extraction*" and the "*Chemicals and Allied Products*" (*COMP1328*), and the "*Oil and Gas Extraction*" and the "*Industrial Machinery and Equipment*" (*COMP1335*), as well as firm-pairs from the "*Industrial Machinery and Equipment*" and "*Transportation Equipment*" industries (*COMP3537*) are subject to significant cost sharing. By contrast, cost sharing-effects for firm-pairs from "*Oil and Gas Extraction*" and "*Petroleum and Coal Industry*" (*COMP1329*), and from the "*Industrial Machinery and Equipment*" and the "*Electronic and other Electric Equipment*" industry (*COMP3536*) are relatively small.

We next compute the net effect of whether cost-sharing or free-riding dominates. For tractability, we compute these net effects by differentiating between two categories of RJVs: small and large RJVs. We classify RJVs with less than or equal to 7 members[12] as small RJVs, otherwise they are classified as large RJVs. In addition, we set the variable $DASSET$ equal to the sample mean.[13] Consequently, cost-sharing dominates for firm pairs in industry k whenever $NE = \hat{\alpha}_1 MEMBERS + \hat{\alpha}_2 \overline{DASSET} + \hat{\alpha}_3^k > 0$. Analogously, cost-sharing dominates for firm-pairs from different industries denoted by l when $NE = \hat{\alpha}_1 MEMBERS + \hat{\alpha}_2 \overline{DASSET} + \hat{\alpha}_4^l > 0$. Table 3 reports the net effects for the various industries, whereby the lower triangle reports the total effect for small RJVs

[10] Aggregating the industry dummies to SIC and COMP (i.e. only two dummies) yields no statistically significant difference between them.

[11] Note that this finding is consistent with Irwin and Klenow (1996) who conclude that participation in SEMATECH (consisting of firms in the "Electronic and other Electric Equipment" industry) resulted in significant reductions in R&D spending.

[12] The highest frequency of members per RJV between 5 and 10 participants is 7 (see Section 3.1).

[13] For values other than the sample mean, results are virtually unchanged. In fact, since the cost-sharing effect dominates (see Table 3) the most likely case for free-riding to overturn the cost-sharing effect is the case when $DASSET$=0, i.e. when the RJV is perfectly homogeneous. However, even in this scenario all but three cases yield stronger cost-sharing.

and the upper triangle for large RJVs.

INSERT TABLE 3 ABOUT HERE

As can be seen in the table, it is the cost-sharing effect that dominates, whether the RJV is between firms from the same industry or across two different industries. In addition, this finding is robust with respect to the size of the RJV - and the amount of heterogeneity amongst members. Moreover, our finding is consistent with that of Irwin and Klenow (1996) who also find that cost-sharing is more pronounced in SEMATECH. Recall from Table 1 that the dependent variable $r\&d1$ has a negative mean. This seems to suggest that the free-rider effect dominates the cost-sharing effect. However, due to the correction resulting from the endogeneity of the switching model, we find that this result is overturned. Accounting for the endogeneity in our sample makes an important difference: what appears to be a free-rider effect at first sight is shown to be a cost-sharing incentive; and that result is robust.

Consistent estimates of the R&D equation (13) for firm pairs which do not RJV are presented in Table 2.[14] Recall that in this case the dependent variable ($r\&d0$) is the average annual change of firm-level $r\&d$ intensity over the sample period, $MEMBERS$ is defined as the average size of all other RJVs that the firms are engaged in, and $RJVS$ is the number of other RJVs that the firms are engaged in. As can be seen in the table, $MEMBERS$ and $RJVS$ are negative and significant, indicating that the size and frequency of RJVs generally favor firm-level R&D spending. As before, we find that the correction term is statistically significant.

We now turn to our main objective, namely the estimation of the structural probit model of (14), the results of which are presented in Table 4.

INSERT TABLE 4 ABOUT HERE

As can be seen, the variable $DASSET$ has a negative and significant impact on the probability of forming an RJV, with a point estimate of -0.114. This implies that RJVs tend to be formed among firms of similar size, which is consistent with the theoretical model developed above and hypothesis (iv). Using the definition of $DASSET$, this estimate implies that a firm is 2.48% less likely to form an RJV with another firm half its size, assuming that there are a total of 10 firms in the RJV.[15] Analogously, the estimated probability of RJV formation is reduced by some 3.71% if the two firms differ in size by a factor of four. The effects of the size differences are even more pronounced when the RJV has fewer members. Our estimate in Table 4 implies that the likelihood of RJV formation

[14]The results in this table should be interpreted as an average effect firms benefit by forming a RJV in general by not with a specific partner since all firms in this regresssion have been involved in a RJV as well but not with this specific partner they are matched with. This is contrary to the estimation from equation (7) where firms were forming a RJV with the specific partner under consideration.

[15] To compute this let $ASSET_i = k \cdot ASSET_j$, i.e. firm i is k times larger than firm j. Then, $\frac{\partial P_{ij}}{\partial DASSET_{ij}} = \alpha_1 \frac{k-1}{k} / \ln(RJV)$, where α_1 is the point estimate given in Table 4.

with another firm half its size is some 3.54% lower if there are only 5 firms in the RJV. The probability that two firms of equal size participate in a 5 member RJV is some 5.31% higher than two firms that differ in size by a factor of four.

The difference in firm-level R&D intensities ($R\&D$) has a positive and statistically significant effect, which implies that the difference in R&D expenditures has a significant effect on the probability of forming an RJV. More precisely, one of the incentives to form an RJVs is a potential reduction in R&D expenses. This finding is consistent with the hypothesis that the cost-sharing effect (net of the free-rider effect) is an important determinant of RJV formation. However, the effect is rather small in magnitude. The point estimate of $R\&D$ is 0.006, which implies that a one percent increase in R&D savings (from forming an RJV) increases the likelihood of forming an RJV by some 0.6%. However, the fact that this effect is so small is not surprising at all, given that we only measure the *net effect* of free-riding and cost-sharing incentives.

Regarding the control variable $MEMBERS$ we find a positive and significant impact on probability of forming an RJV, which indicates that larger RJVs are more likely to be formed than smaller once. The negative and significant parameter estimate of $RJVS$ suggests that firms have a lower incentive to form an RJV the more RJVs they are otherwise engaged in.

In order to test the complementarity hypothesis (iii) we compare the intra-industry dummies ($SICs$) to the inter-industry dummies ($COMPs$). As can be seen in Table 4, the point estimate for the "*Petroleum and Coal Products*" industry ($SIC29$) is 0.027, which is the largest significant estimate for an industry, followed by the estimate for the instruments industry ($SIC38$). This implies that firms in $SIC29$ have the highest probability to form an RJV. As expected the complementarity dummies vary substantially according to the industry pairs considered. Our estimates for the inter-industry dummies ($COMPs$) range from -0.090 (for $COMP3537$) to 0.021 (for $COMP3237$). In many cases the $COMP$ dummies are smaller than the SIC dummies, indicating that intra-industry RJVs occur more often than inter-industry RJVs. This is not surprising, in light of the fact that many of the industries in our sample are too different in their technologies and/or products in order to engage in an RJV.

However, we do find large statistically significant complementarities between some industry groups. In particular, the "*Oil and Gas Extraction*" and the "*Petroleum and Coal Industry*" ($COMP1329$), the "*Stone, Clay, and Glass Products*" and the "*Transportation Equipment*" ($COMP3237$), and the "*Industrial Machinery and Equipment*" and "*Electronic and other Electric Equipment*" ($COMP3536$) display relatively strong complementarities between two different industries. Complementarities are strongest between "*Stone, Clay, and Glass Products*" and the "*Transportation Equipment*" ($COMP3237$). These two industries appear to be subject to vertical relationships, for example, ceramics manufacturers provide composite materials to aerospace firms. Given those vertical relationships, one would expect that firms in these industries produce complementary products. The finding that firms producing complementary products are more likely to RJV is consistent with the theoretical model developed above.

4 Conclusion

In this paper we investigated the determinants of RJV formation. In addition to the free-rider and cost-sharing explanations already prominent in the literature, we developed a theoretical model which focuses on firm heterogeneity and product market characteristics as a factor in firms decisions to form RJVs. We show that large firms have less incentive to form an RJV with smaller firms in order to increase market power. Our theoretical model also predicts that RJVs tend to be formed amongst firms selling complementary products. The second part of the paper empirically tests these hypothesis of RJV formation by making use of a rather unique data base available through information made public under the 1984 National Cooperative Research Act.

Our results can be broken into two parts: according to the simultaneous specification explaining R&D expenditures and RJV formation. Regarding R&D expenditures, we find that accounting for the endogeneity between changes in R&D expenditures and RJV formation in our sample makes an important difference: what initially appears to be a free-rider effect is shown to be a cost-sharing effect; and that result is robust. In terms of the incentives to form an RJV we find that a significant factor in determining whether two firms form an RJV is that they are similar in size. This finding is consistent with the theoretical model that predicts that large firms tend not to participate with small firms in RJVs. In addition, we provide some evidence that cost-sharing is more important as an incentive mechanism in RJV formation. Finally, there is no evidence that complementarities exist for all industry pairs. However, we find that there are certain industry-pairs (possibly vertically related) where such complementarities significantly increase RJV formation. It appears reasonable that the technology involved in these industries is similar, yet product market competition between firms in these two sectors is somewhat complementary. This empirical finding that firms producing complementary products are more likely to form an RJV is consistent with the theoretical model developed in the paper.

While RJVs between firms in complementary industries would seem to have positive welfare implications, the welfare impacts of cost-sharing and symmetric (large) sized firms in the same industry are less clear. Cost-sharing may reduce the investment required for a particular outcome, however, as R&D is uncertain a successful outcome may be less likely. Also, RJVs with a small number of members between the large firms in an industry may pronounce asymmetries in firm size leading to a more concentrated market structure. Consequently, antitrust authorities should be wary of why firms form research joint ventures.

REFERENCES

Beecy, L., Link A., William F., and Teece D., 1994, "Quantifying Private Rates of Return to Collaborative Research: The Case of SEMATECH", mimeo.

Branscomb. L., 1992, "Does America Need a Technology Policy¿, Harvard Business Review, March-April, pp. 24-31.

d'Aspremont, C., and A. Jacquemin, 1988, "Cooperative and Noncooperative R&D in Duopoly with Spillovers", American Economic Review, 78, (Dec.), pp. 1133-1137.

David, D., 1985, "R&D Consortia", High Technology, October, pg. 42.

DeBondt, R., 1997, "Spillovers and innovative activities", International Journal of Industrial Organization, 15, No. 1, pp. 1-28.

EU Official Journal, 1985, No. L 53, February 22, Extract from the fourteenth EC Report on Competition Policy, pp. 38-39.

Hamel, G., Y., Doz, and C. Prahalad, 1989, "Collaborate with Your Competitors - and Win", Harvard Business Review, Jan.-Feb., pp. 133-139.

Hart, O. D., 1983, "The Market Mechanism as an Incentive Scheme", The Bell Journal of Economics, 14, pp. 366-382.

Irwin, D., and P. Klenow, 1996, "High Tech R&D Subsidies: Estimating the effects of SEMATECH", Journal of International Economics, 40, No. 3-4, pp 323-344.

Jacquemin, A., 1988, "Cooperative Agreements in R&D and European Antitrust Policy", European Economic Review, 32, pp. 551-560.

Jorde, T., and D. Teece, 1990, "Innovation and Cooperation: Implications for Competition and Antitrust", Journal of Economic Perspectives, 4, No. 3, (Summer), pp. 75-96.

Kamien, M., E. Muller, and I. Zang, 1992, "Research Joint Ventures and R&D Cartels", American Economic Review, 82, No. 5, pp. 1293-1306.

Kamien, M., and I. Zang, 1993, "Competing Research Joint Ventures", Journal of Economics and Management Strategy, 2, No. 1, (Spring), pp. 23-40.

Katz, M., 1986, "An Analysis of Cooperative Research and Development", Rand Journal of Economics, 17, No. 4, pp. 527-543.

Katz, M., and J. Ordover, 1990, "R&D Cooperation and Competition", Brookings Papers on Economic Activity, Microeconomics, pp. 137-191.

Kogut, B., 1989, “The Stability of Joint Ventures: Reciprocity and Competitive Rivalry“, Journal of Industrial Economics, 38, pp. 183-198.

Lee, L.-F., 1978, “Unionism and Wage Rates: A Simultaneous Equations Model with Qualitative and Limited Dependent Variables“, International Economic Review, 19, no. 2, pp. 415-433.

Lee, L.-F., 1979, “Identification and Estimation in Binary Choice Models with Limited (Censored) Dependent Variables“, Econometrica, 47, pp. 977-996.

Limdep User’s Manual, 1995, Version 7.0, Econometric Software, Australia.

Link, A., and Bauer L., 1989, Cooperative Research in U.S. Manufacturing, Lexington, MA: D.C: Heath.

Link, A., 1996, “Research Joint Ventures: Patterns from Federal Register Filings“, Review of Industrial Organization, 11, pp. 617-628.

Moody’s Investors Service, 1995, “Moody’s Global Company Data“, USA.

Nalebuff, B., and J. Stiglitz, 1983, “Information, Competition and Markets“, American Economic Review Papers and Proceedings, May, 72, pp. 278-284.

OECD, 1994, “Basic Science and Technology Statistics“, Paris, France.

OECD, 1995, “Research and Development Expenditure in Industry“, Paris, France.

OECD, 1994, “The OECD Stan Database (1970-1993)“, Paris, France.

Reinganum, J., 1983, “Uncertain Innovation and the Persistence of Monopoly“, American Economic Review, 83, pp. 741-748.

Rosen, R., 1991, “Research and development with asymmetric firm sizes“, RAND Journal of Economics, 22, No. 3, pp.411-429.

Scherer, F. M., 1980, Industrial Market Structure and Economic Performance, Rand McNally, Chicago.

Scherer, F. M., 1986, Innovation and Growth, MIT Press.

Shapiro, C., and R. D. Willig, 1990, “On the Antitrust Treatment of Production Joint Ventures“, Journal of Economic Perspectives, 4, No. 3, (Summer), pp. 113-130.

Teece, D., 1986, “Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy“, Research Policy, 15, No. 6, pp. 285-305.

Teece, D., 1992, “Competition, Cooperation and Innovation“, Journal of Economic Behavior and Organization, 18, pp. 1-25.

U.S. Department of Commerce, 1993, "Research and Development Consortia Registered under the National Cooperative Research Act of 1984", The Technology Administration, Office of Technology Commercialization, Washington, D.C.

U.S. Department of Justice, News Release with accompanying letter by Charles F. Rule, Acting Assistant Attorney General, June 26, 1985.

Vickers, J., 1995, "Concepts of Competition" Oxford Economic Papers, 47, pp. 1-23.

Zhang, J., and Z. Zhang, 1997, "Ownership Structure, R&D and Product Market Competition", Managerial and Decision Economics, 18, No. 5, pp.391-398.

Tables and Figures

Table 1a: Variable Definitions and Summary Statistics

(pair-matches between firm *i* and firm *j*)

Variables	Description	N	Mean	Minimum	Maximum
P_{ij}	Binary Variable indicating a RJV between firm *i* and firm *j*.	20,942	0.024	0	1
MEMBERS	Number of members in a RJV (see the text for precise definition)	20,942	3.101	0.693	4.927
RJVS	Number of further RJVs undertaken by firms.	20,942	14.213	0	35.5
DASSET	Measure of firms' difference in assets prior to forming an RJV.	20,942	1.242	0	1.667
r&d1	The change in firm-level R&D intensities by forming an RJV.	502	-0.359	-19.050	8.936
r&d0	The average change in firm-level R&D intensities (see the text for precise definition).	20,440	0.095	-2.006	3.804

The Standard Industrial Classifications refer to the 1987 SIC-Revision. The monetary data are measured in million $-US in current prices and are deflated by the producer price index taken from the Main Economic Indicators (OECD).

Table 1b: Sample Frequencies of Industry-Pairs (in percent)

INDUSTRIES (2-digit SIC-Codes)	13 Oil and Gas Extraction	28 Chemicals and Allied Products	29 Petroleum and Coal Products	32 Stone, Clay, and Glass Products	35 Industrial Machinery and Equipmt.	36 Electronic and other Electric Equipment	37 Transportation Equipment	38 Instruments and Related Products
13 Oil and Gas Extraction	**4.24**							
28 Chemicals and Allied Products	7.62	**1.70**						
29 Petroleum and Coal Products	12.06	5.88	**1.31**					
32 Stone, Clay, and Glass Products	1.36	0.67	0	**0**				
35 Industrial Machinery and Equipment	19.08	0	14.71	1.68	**11.0**			
36 Electronic and other Electric Equipment	0	0	0	0	5.96	**0.76**		
37 Transportation Equipment	2.72	0	0	0.24	3.36	0	**0**	
38 Instruments and Related Products	0	0	0	0.26	3.74	0.90	0.53	**0.21**

Table 2: R&D Intensities

	Estimates of Equation (12) Dependent Variable: ***r&d1***		Estimates of Equation (13) Dependent Variable: ***r&d0***	
Variables	**Estimates**	**Standard Errors**	**Estimates**	**Standard Errors**
MEMBERS	-1.366	0.332	-0.064	0.005
DASSET	11.800	2.070	-	-
RJVS	-	-	-0.151	0.008
SIC13	1.975	1.556	0.709	0.030
SIC28	7.072	1.739	0.202	0.032
SIC29	-0.708	1.739	0.448	0.109
SIC35	5.738	1.563	0.483	0.022
SIC36	6.131	1.765	0.646	0.023
SIC38	0.794	5855	0.254	0.155
COMP1328	10.791	2.667	0.401	0.022
COMP1329	3.095	1.391	0.508	0.023
COMP1332	11.197	4644	0.468	0.064
COMP1335	10.244	1.744	0.559	0.021
COMP1337	5.201	4.685	0.479	0.038
COMP2829	9.743	2.528	0.322	0.025
COMP2832	6.326	6.717	0.270	0.050
COMP2935	7.972	2.226	0.497	0.022
COMP3235	8.582	19.433	0.424	0.031
COMP3237	0.544	5450	0.369	0.627
COMP3238	9.792	6422	0.259	0.150
COMP3536	4.803	1.645	0.577	0.022
COMP3537	12.295	2.068	0.404	0.026
COMP3538	6.703	1.592	0.359	0.025
COMP3638	7.899	1.990	0.433	0.022
COMP3738	8.702	9245	0.274	0.151
SIGMA (1)	4.073	0.122	-	-
RHO (1)	-0.975	0.007	-	-
SIGMA (0)	-	-	0.342	0.0007
RHO (0)	-	-	-0.102	0.055
	NOBS=502; F-Value: 1.78; Adj. R-square: 0.036.		NOBS=20,440; F-Value: 67.57; Adj. R-square: 0.073.	

Table 3: Cost-Sharing versus Free-Rider (Net Effect)

INDUSTRIES **(2-digit SIC-Codes)**	13 Oil and Gas Extraction	28 Chemicals and Allied Products	29 Petroleum and Coal Products	32 Stone, Clay, and Glass Products	35 Industrial Machinery and Equipmt.	36 Electronic and other Electric Equipment	37 Transportation Equipment	38 Instruments and Related Products
13 Oil and Gas Extraction	**0.21** **(2.31)**							
28 Chemicals and Allied Products	9.03 (7.09)	**5.31**** **(2.94)**						
29 Petroleum and Coal Products	1.33 (1.86)	7.98 (6.37)	**-2.47**** **(2.98)**					
32 Stone, Clay, and Glass Products	9.43 (1576E05)	4.56 (45.10)						
35 Industrial Machinery and Equipment	8.48** (2.92)		6.21 (4.91)	6.82 (379.20)	**3.97**** **(2.30)**			
36 Electronic and other Electric Equipment					3.04 (2.56)	**4.37*** **(2.98)**		
37 Transportation Equipment	3.44 (21.93)			-1.22 (1084E04)	10.53** (4.19)			
38 Instruments and Related Products				8.02 (8577E05)	4.94** (2.44)	6.13* (3.89)	6.94 (1072E05)	**-0.97** **(5122E05)**

Standard errors are given in parentheses. **- significant at 5%-level. *- significant at a 10%-level.

Table 4: Sources and Complementarities in RJV Formation

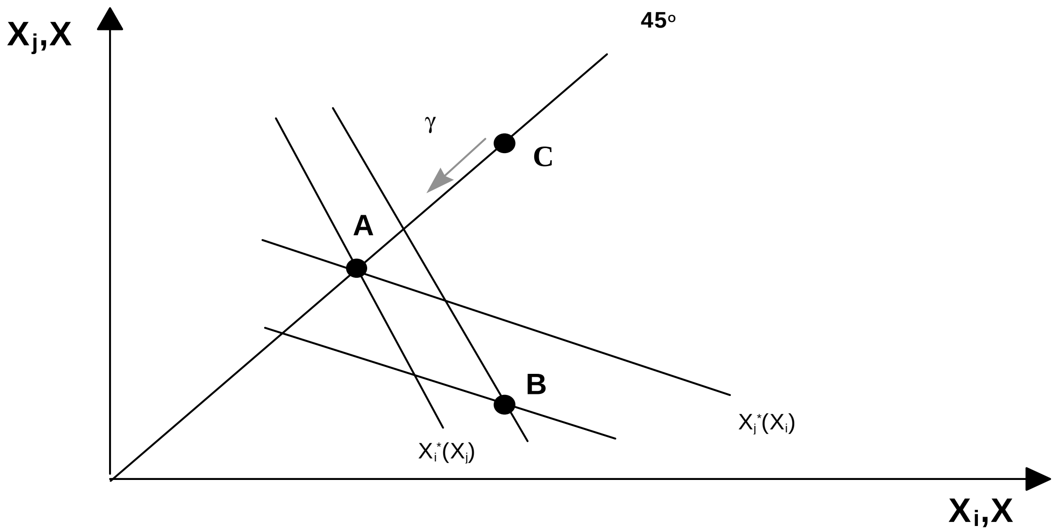
Probit Estimates of Equation (14): Dependent Variable: P_{ij}

Variables	Estimates	Standard Errors
DASSET	-0.114	0.033
r&dh	0.006	0.003
MEMBERS	0.010	0.004
RJVS	-0.0002	0.0006
SIC13	0.004	0.005
SIC28	-0.040	0.014
SIC29	0.027	0.012
SIC35	-0.028	0.009
SIC36	-0.015	0.012
SIC38	0.023	0.014
COMP1328	-0.078	0.023
COMP1329	-0.014	0.004
COMP1332	-0.081	0.025
COMP1335	-0.069	0.021
COMP1337	-0.023	0.010
COMP2829	-0.072	0.020
COMP2832	-0.032	0.012
COMP2935	-0.054	0.015
COMP3235	-0.053	0.017
COMP3237	0.021	0.012
COMP3238	-0.065	0.022
COMP3536	-0.011	0.008
COMP3537	-0.090	0.027
COMP3538	-0.034	0.012
COMP3638	-0.041	0.017
COMP3738	-0.055	0.019

The reported estimates are converted such that they represent the increase in probability for a given variable. For example, for *DASSET* the number in the above table is $\alpha_1 f(\bar{X}\alpha)$, where $\bar{X}$ is the sample mean of the exogenous. NOBS=20,942; Log-likelihood: -911.898. Concordant=97.3%, Discordant=1.3%, Tied 1.4%.

Figure 1

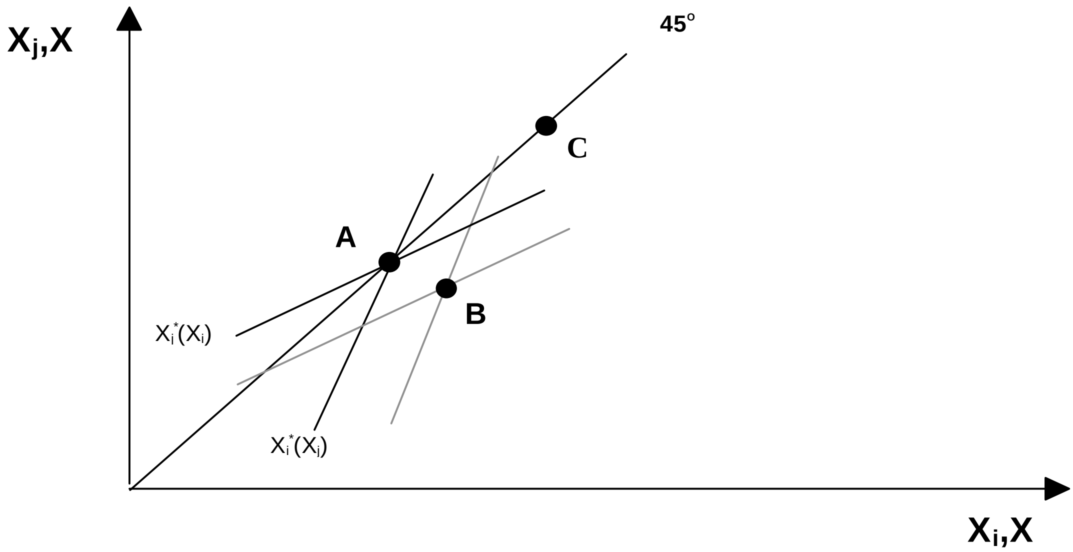
Effective R&D Investments: Substitutable Product Markets



A- Symmetric R&D Competition Equilibrium
B- Asymmetric R&D Competition Equilibrium
C- RJV Equilibrium

Figure 2

Effective R&D Investments: Complementary Product Markets



A- Symmetric R&D Competition Equilibrium
B- Asymmetric R&D Competition Equilibrium
C- RJV Equilibrium