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STRATEGIC CHOICE OF PARTNERS: RESEARCH JOINT VENTURES AND MARKET POWER

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ABSTRACT

Strategic Choice of Partners: Research Joint Ventures and Market Power*

The literature on research joint ventures (RJVs) has emphasized internalizing spillovers and cost sharing as motives for RJV formation. In this Paper we develop an additional explanation: the incentive to exclude rivals in order to gain market power. We illustrate this effect in a simple model of RJV formation with asymmetric firms. We then test our hypothesis by estimating an endogeneous switching model using data from the US National Cooperative Research Act. The empirical findings support our Hypothesis that RJVs can be used as an instrument by which firms leverage their market power in the product market.

JEL Classification: L00, L60, O30
Keywords: joint ventures, product market competition, research and development

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NON-TECHNICAL SUMMARY

In the early 1980s there was an apparent shift in technology policy in both the US 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). In Japan, 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 US 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, which is currently revised. The overall picture that emerges from these policy developments is that antitrust regulators have generally been quite accommodating towards RJVs. A notable exception to this is when the venture's membership is considered 'over-inclusive'. This sentiment and the conditions under which regulators intervene is expressed in the following quotation:

> Joint R&D ventures generally are pro-competitive, and are condemned by the antitrust laws when they have net negative effect on competition. Generally, R&D joint ventures rarely will raise competitive concerns – [they will do so] only when the venture's membership is 'over-inclusive', because an insufficient number of entities are left outside the venture to perform competitive R&D.
> US Department of Justice News Release, 26 June 1985.

This Paper develops a model that raises the opposite antitrust concern: if RJVs are 'exclusive clubs' they can be used as an instrument by which firms leverage their market power in the product market. In particular, we show that the incentives to choose an RJV partner increase, the more similar in size the partner is. In other words, large firms have less of an incentive to form an RJV with a smaller rival, leading to a more concentrated market structure. The exclusive nature of RJVs may then increase asymmetry in the industry, thereby increasing the market power of those firms inside the RJV at the expense of outsiders.

The goal of this Paper is to test the 'firm-size' hypothesis on US data that became available through the 1984 NCRA. We illustrate the basic argument by extending the model by Kamien, Muller and Zang (1992). Within the context of this model, we show that the incentive to form an RJV is smaller for large firms, since they increase their market share by excluding the smaller rival. When the *ex ante* asymmetry is large, no RJV is formed and the industry becomes even more concentrated. Exclusive RJVs can then be viewed as instruments to leverage market power. In the second part of the Paper, we take the firm-size hypothesis to the data, making use of a rather unique database available through the information made public under the 1984 National Cooperative Research Act. We estimate a two-equation system that endogenizes RJV formation and R&D investments. Our main finding is 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 to exclude smaller rivals in order to leverage their market power in the product market.

We also report on a number of empirical findings regarding R&D spending and RJV formation. In particular, we find that equal-sized RJVs and RJVs with many participants spend more on R&D on a per firm basis. In addition, the econometric estimates imply that firms are less likely to form an RJV, the more RJVs they are engaged in, and i.e. the returns to RJVs are diminishing.

1 Introduction

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The overall picture that emerges from these policy developments is that antitrust regulators have generally been quite accommodating towards RJVs. A notable exception to this is when the venture's membership is considered "overinclusive". This sentiment and the conditions under which regulators intervene is expressed in the following quotation:[1]

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This paper develops a model that raises the opposite antitrust concern: if RJVs are "exclusive clubs" they can be used as an instrument by which firms leverage their market power in the product market. In particular, we show that the incentives to choose an RJV partner increases, the more similar in size the partner is. In other words, large firms have less of an incentive to form an RJV with a smaller rival, leading to a more concentrated market structure. The exclusive nature of RJVs may then increase asymmetry in the industry, thereby increasing the market power of those firms inside the RJV at the expense of outsiders.

The goal of this paper is to test the "firm-size" hypothesis on U.S. data that became available through the 1984 NCRA. We illustrate the basic argument by extending the model by Kamien, Muller, and Zang (1992) to asymmetric firms,

[1] Similar sentiments have been expressed by Canadian regulators (Industry Canada, 1994) and those of the European Commission (Official Journal, 1985)

where firms are differentiated through their initial marginal costs. The effect of an RJV is to reduce marginal costs of the participating firms. Within the context of this simple model, we show that with no RJV large firms have an incentive to spend more on R&D than do small firms.[2] As a result the incentive to form an RJV is smaller for large firms, since they increase their market share by excluding the smaller rival. When the ex-ante asymmetry is large, no RJV is formed and the industry becomes even more concentrated. Exclusive RJVs can then be viewed as instruments to leverage market power.

The empirical implication of the firm-size hypothesis is that RJVs are more likely to be formed between firms of equal size than between smaller and larger firms. Empirical work on RJV formation has focussed on the issue of what the determinants and effects of RJVs are.[3] By contrast, the firm-size hypothesis is about the strategic choice of an RJV partner. We therefore base our empirical analysis on the characteristics of the RJV partners. We assume that the probability of an RJV between any two firms depends on the relative size difference of the two partners.

To identify the impact of size heterogeneity on RJV formation, we control for other factors that affect RJV formation. There has been a considerable amount of economic research on RJVs focussing mainly on free-rider and cost-sharing aspects of RJVs (the most influential papers are Katz, 1986, d'Aspremont and Jacquemin, 1988, and Kamien, Muller, and Zang, 1992).[4] One of the key results of this literature is that when R&D by one firm spills over to other firms, private incentives to conduct R&D are reduced (the 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 for all firms, and raises welfare. Note that contrary to the free-rider scenario, cost-sharing would lead to a decrease in R&D investment for the individual firm. 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

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[2] 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.

[3] Other empirical studies in this area include Link and Bauer (1989), Kogut (1989), Beecy, Link, William and Teece (1994), and Link (1996). For RJV studies with European data sets see Cassiman and Veugelers (1998), Veugelers and De Backer (1999), and Marin et al. (2000).

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

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).[5] 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 the more important factor.

The implications of the above studies for the empirical testing of our firm-size hypothesis are significant. In particular, the probability that two firms would form an RJV should be influenced - in part - by the expected change in R&D spending. The only scenario in which R&D spending is unaffected by RJV formation is when the free-rider and the cost saving affects exactly offset each other. Since this restriction is unlikely to hold in the data, R&D must be included in the analysis of RJV formation. In addition, R&D spending and RJV formation are simultaneously determined as there is causality running both ways: changes in R&D spending affects RJV formation, and vice versa. To account for this endogeneity of R&D spending, we estimate an endogenous switching model proposed by Lee (1978). In this way, we are able to obtain consistent estimates of our firm-size hypothesis.

In the second part of the paper, we take our firm-size hypothesis to the data 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 R&D investments. Our main finding is 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 to exclude smaller rivals in order to leverage their market power in the product market.

We also report on a number of empirical findings regarding R&D spending and RJV formation. In particular, we find that equal-sized RJVs and RJVs with many participants spend more on R&D on a per firm basis. In addition, the econometric estimates imply that firms are less likely to form an RJV, the more RJVs they are engaged in, i.e. the returns to RJVs are diminishing.

The remainder of the paper is organized as follows. Section 2 develops a simple model of RJV formation under asymmetric firms building on one of the more influential papers in this literature. Section 3 describes the data and the results of the empirical model. We conclude in Section 4.

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[5] 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.

2 The KMZ Model under Asymmetry

In this section we illustrate how the duopoly model of Kamien, Muller, and Zang (hereafter KMZ, 1992) can be extended to illustrate the firm-size effect. KMZ show that symmetric firms have an incentive to form a cartelized RJV. We would like to emphasize at this point that we do not claim that the KMZ model is necessarily the most relevant one. Indeed there are other important approaches to modeling RJVs or spillovers.[6]

The purpose of this section is to provide a consistent theoretical argument to show how product market asymmetry affects the incentives to RJV. Following the approach of KMZ we allow for three stages. In the first stage firms decide on RJV participation. In the second stage the partners determine their R&D investment (X) 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, being the sum of the firms' R&D investments when they form an RJV. The third stage entails a Cournot product market game with homogenous products. We assume that the firms indexed by i and j have different *ex ante marginal costs* c_i and c_j, such that $c_i < c_j$. Given that R&D will reduce the marginal costs, we will refer to $c_i - f(X)$ as the *ex post marginal costs of firm i.* We further assume that there are no fixed costs and that there is a linear demand structure given by $p = a - b(q_i + q_j)$. We also assume that profits cannot be negative, such that exit does not occur. To focus on the effect of asymmetry, we set $b = 1$ and 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.[7]

2.1 Product Market Competition

Firms' profit function in stage three (gross of R&D investment costs) are $\pi_i = [p - (c_i - f(X_i))]\, q_i$. 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

$$q_i^* = \frac{1}{3}\left[a - 2\left(c_i - f\left(X_i\right)\right) + \left(c_j - f\left(X_j\right)\right)\right]$$

[6]For further discussion of the information exchange in a noncooperative equilibrium, see Katsoulacos and Ulph (1998) and Beath, Poyago-Theotoky and Ulph (1998).

[7]The R&D production function $f(x)$ is twice differentiable and concave and satisfies the following: $f(0) = 0, f(X) \leq c_i$, for all X, $\lim_{x\to\infty} f(X) < a - 2c_j + c_i$ and $f'(0) > \frac{9}{2}(a - 2c_j + c_i)$ which guarantees that both firms find it optimal to produce output and invest in finite R&D. Also, the profit minus the R&D expenditure is a strictly concave function of X, i.e., $\frac{4}{9}f'(x_i)\left[a - 2\left(c_i - f\left(x_i\right)\right) + c_j - f(x_j)\right]$ is decreasing in X_i (with an analogous condition for firm j).

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

$$\Pi_i^* = (q_i^*)^2 - X_i \tag{1}$$

where X_i is the firm-specific R&D investment 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 effective R&D $(c_i - f(X_i))$ and the larger the ex post asymmetry in marginal costs the larger the difference in quantities and profits. The next section will endogenize costs by considering firms' R&D investments.

2.2 R&D Investment

We first consider the case of R&D competition, in which firms decide on their individual R&D level (X_i) non-cooperatively. The effective level of cost-reducing R&D investment in this case is X_i. In other words, we assume that there are no spillovers.[8] Firms' objectives at this stage are to maximize their respective profit functions (1). The first-order condition for R&D investment derived from (1) for the firm of type i is

$$f'\left(X_i^N\right) q_i^* = 3/4 \tag{2}$$

with an analogous condition for firm j. Differentiating (2) with respect to X_j yields

$$\frac{\partial X_i^N}{\partial X_j} = \frac{f'(X_j)\, f'\left(X_i^N\right)}{3f''\left(X_i^N\right) q_i^* + 2\left[f'\left(X_i^N\right)\right]^2}$$

which is negative under the above assumptions and the second order condition of X_i. This implies that R&D investments are strategic substitutes, which is graphically illustrated in Figure 1.

For the case of symmetric ex ante marginal costs $(c_i = c_j)$ equation (2) simplifies to

$$f'\left(X^A\right)\left[\alpha - c + f\left(X^A\right)\right] = 9/4 \tag{3}$$

which implies that the equilibrium investments are identical, i.e. $X_i^N = X_j^N \equiv X^A$. The symmetric equilibrium is illustrated as point A in Figure 1, which is the equilibrium corresponding to the KMZ model.

2.2.1 The Impact of Asymmetry on R&D Investments

We now address the issue of asymmetry and how it effects the equilibrium R&D investments. Suppose that the equilibrium is symmetric, i.e. at point A. Consider

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

introducing a *mean-preserving* change in the ex ante marginal cost, such that firms' costs are $c_i + \varepsilon = c_j - \varepsilon$. In other words, a larger ε represents a greater asymmetry. To show how the asymmetry affects the reaction function of firm i we need to implicitly differentiate equation (2) with respect to ε, which yields (after some manipulation)

$$\frac{\partial X_i^N(c_i, c_j)}{\partial \varepsilon} = \frac{\partial X_i^N}{\partial c_i} - \frac{\partial X_i^N}{\partial c_j} = \frac{3}{2}\frac{\partial X_i^N}{\partial c_i} \tag{4}$$

where $\frac{\partial X_i^N}{\partial c_i} = 2f'\left(X_i^N\right) / \left[3f''\left(X_i^*\right) q_i^* + 2\left[f'\left(X_i^*\right)\right]^2\right] < 0$, which implies that firm i's reaction function shifts to the right as asymmetry increases. Similarly, firm j's reaction function shifts downwards with increased asymmetry, given that $\frac{\partial X_j^N(c_j,c_i)}{\partial \varepsilon} = -\frac{\partial X_i^N(c_i,c_j)}{\partial \varepsilon}$.

Using these results, we can now analyze the asymmetric equilibrium in R&D investments. Consider an asymmetric equilibrium depicted by point B in Figure 1. We therefore have that low-cost firm investing more in R&D than will the high-cost firm, i.e. $X_i^N > X_j^N$. In addition, note that as ε increases, point B moves further to the bottom-right, which implies that the larger the ex ante asymmetry, the larger the asymmetry in R&D investments, i.e. $\partial X_i^N/\partial\varepsilon > 0$ and $\partial X_j^N/\partial\varepsilon < 0$. We can summarize these results in the following lemma.

Lemma 1 *There is a positive relationship between the ex ante asymmetry in marginal costs and the asymmetry in equilibrium R&D investments, i.e.* $\partial X_i^N/\partial\varepsilon > 0$ *and* $\partial X_j^N/\partial\varepsilon < 0$. *Endogenizing R&D investments magnifies the asymmetric industry structure, i.e. the larger firm becoming even larger and the smaller firm relatively smaller.*

This lemma illustrates that the asymmetry is magnified through the incentives to invest in R&D, yielding an even more asymmetric market structure in which the low-cost firm generates both higher profits and a larger market share. Given that R&D competition has such an impact on market structure, we now consider whether a similar effect exists if firms decide to form an RJV.

Before examining the RJV case, it is useful to consider the mean-preserving symmetric analog to point B, which is denoted by point A in Figure 1. It is important to note that a change in ε does not affect point A, i.e. $\partial X^A/\partial\varepsilon = 0$ (see equation (3)). In other words, a change in ε moves point B, but not point A.

2.2.2 R&D Investment under RJV

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 to be maximized jointly at this stage is $\Pi_i + \Pi_j$, i.e. firms coordinate. The first-order condition for R&D investment can be written as

$$f'\left(X^{JV}\right)\left[a - \frac{(c_i + c_j)}{2} + f\left(X^{JV}\right)\right] = 9/4. \quad (5)$$

The important aspect of the above expression is that R&D investments depend on the *average* ex ante marginal costs. Comparing the first-order conditions for the symmetric case (3) with the RJV case (5) shows that $X^A = X^{JV}$. In other words, we can depict the RJV equilibrium in Figure 1 by the same point A that the mean-preserving symmetric analog is identical in terms of effective R&D investments to the RJV case.[9] However, this does not imply that firms spend equal amounts, since in the RJV case firms can share their R&D expenses. Comparing points A and B yields the following lemma:

Lemma 2 *Firms with higher marginal costs increase their effective R&D investment by participating in an RJV, while firms with lower marginal costs decrease their effective R&D investment, i.e.* $X_i^N > X^{JV} > X_j^N$.

The above two lemmas indicate that while a mean-preserving increase in asymmetry does not change the level of R&D investment in an RJV, i.e. X^{JV} is unaffected by ε, the R&D investments under R&D competition do change with ε. Comparing the equilibria in R&D investments, we find that the ex ante asymmetry in marginal costs is preserved when an RJV is formed, while the ex ante asymmetry is magnified when no RJV is formed. In other words, RJVs tend to keep market structure more symmetric. Since an asymmetric market structure benefits the larger (and more efficient) firm, the larger firm would not want to form an RJV whenever the rival is relatively small. We address this issue in the following section.

2.3 RJV Formation

In this section we compare equilibrium profits between the two cases (R&D competition and RJV). Recall from equation (1) that profits are composed of product market profits minus R&D investments. Let us first focus on the product market. Substituting the solutions for R&D investment decisions into (1), we can compare the product market incentives for firms to participate in an RJV. This leads to the following lemma.

Lemma 3 *The RJV equilibrium yields higher product market profits for the smaller firm, and lower product market profits for the larger firm.*

[9]The reason for this is that we have assumed that the spillovers in the RJV are perfect, that there are no spillovers out side the RJV, and that products are perfectly homogeneous. For instance, if products are allowed to be less than perfect substitutes the effective RJV investments would be larger for the RJV case.

Proof. The difference in equilibrium payoffs in the product market for firm j can be written as, $\pi_j^{JV} - \pi_j^N = \left(q_j^{JV}\right)^2 - \left(q_j^N\right)^2$. Thus there is an incentive for firm j to participate in an RJV whenever $q_j^{JV} > q_j^N$, which implies that $f\left(X^{JV}\right) > 2f\left(X_j^N\right) - f\left(X_i^N\right)$. Given Lemma 2, the first part of this lemma follows. Similarly, the condition for the large firm to have an incentive to join an RJV $\pi_i^{JV} - \pi_i^N > 0$ can be expressed as $f\left(X^{JV}\right) > 2f\left(X_i^N\right) - f\left(X_j^N\right)$, which does not hold by Lemma 2. ■

Lemma 3 indicates that the larger firm's product market profits declines if it participates in an RJV. This creates an incentive for the large firm not to particpate in an RJV.

So far, we have only considered profits in the product market. Whether the larger firm de facto participates in the RJV also depends on its R&D costs. This in turn will depend on the split of R&D costs between the participating members, which needs to be agreed on by the members of the RJV. For our purposes we are not interested in the precise split of the R&D costs. However, since our focus is on whether the large firm will participate in the RJV, we need to investigate how the split affects the incentives to participate. In particular, given Lemma 3, the smaller firm may have an incentive to pay a large share of the R&D costs. In other words, the smaller firm will attempt to induce the larger firm to participate in an RJV by paying a larger share of the R&D costs.

Whether the small firm has a large enough incentive to contribute the larger share of R&D costs depends on whether industry profits are higher under the RJV scenario: whenever industry profits are higher under the RJV case, the small firm is able to compensate the large firm and the RJV will take place. As was first shown by Bergstrom and Varian (1985) (see also Salant and Shaffer, 1998, 2000), industry profits in a Cournot product market are increased with a larger mean-preserving asymmetry. This implies that the RJV equilibrium leads to lower producer surplus (relative to the R&D competition case) whenever there is enough asymmetry. This in turn implies that there is no R&D budget sharing rule that would yield a higher payoff for both firms in an RJV. With respect to the above lemmas, we therefore derive the following result.

Proposition 4 *If the ex ante asymmetry is relatively large no RJV is formed.*

The intuition for this result is the following. If no RJV is formed, ex ante asymmetries are increased by R&D investments. As a result the smaller firm loses market share and has an incentive to pay a larger share of the R&D budget so that the RJV will take place and prevent the asymmetries from rising. On the other hand, the larger firm gains in terms of market share and has an incentive to exclude a smaller rival from an RJV unless it is appropriately compensated. Since industry profits are lower under RJV formation (i.e. the large firm loses more than the small firm gains) whenever the ex ante asymmetry is high, no mutually beneficial RJV formation exists. As a result, the market structure becomes even more asymmetric.

The role of asymmetry in this context is worth emphasizing. Without asymmetry, the RJV equilibrium must lead to higher industry profits, since collusion and cost sharing can only increase payoffs. The only factor leading to lower industry profits under RJV is the asymmetry, which in turn produces the no-RJV equilibrium outcome. The crucial aspect of the model is therefore that an RJV leads to less asymmetry than R&D competition. How robust is this effect? As we have shown in this paper, whenever cost reductions in an RJV affect marginal costs in a symmetric way, an RJV leads to less asymmetry. Furthermore, this is still the case whenever the R&D investment in an RJV lowers marginal costs of the low-cost firm by less than it does for the high-cost firm. The only situation in which the outcome might be reversed is when the low-cost firm benefits relatively more than does the high-cost firm. However, even in this case, this asymmetric impact on marginal costs has to be larger than the one produced under R&D competition.

What are the anti-trust implications of the firm-size hypothesis assuming that the antitrust agency follows a consumer surplus standard.[10] As we have stated above, exclusive behavior may increase concentration in the product market. But this may not lower consumer surplus, as prices might be lower too, due to an increase in R&D investment by the larger firm. More precisely, using the demand specification and the first-order R&D conditions, it can be shown that prices are lower under the RJV equilibrium whenever $2f\left(X^{JV}\right) > f\left(X_i^N\right) + f\left(X_j^N\right)$, i.e. when the total effective cost reduction in marginal costs under RJV is higher. This is intuitive, since prices in Cournot depend only on the sum of the marginal costs (see Bergstrom and Varian, 1985). Whether or not this condition is satisfied will depend on the precise parametrization of our model, in particular on the shape of the R&D investment function and on how the asymmetry affects $f\left(X_i^N\right) + f\left(X_j^N\right)$.[11]

The antitrust implications are also not obvious if we consider the possibility of exit. We have so far assumed that the smaller firm does not exit. Consider the possibility of exit by the smaller firm, leading to a monopoly in the product market. Since excluding a rival from an RJV increases the asymmetry, it increases the ability by the larger firm to induce exit. In other words, excluding a rival from an RJV makes exit more likely. However, the impact on prices are not obvious. On the one hand a monopolist would have more market power, but on the other hand a monopolist has higher R&D investments (relative to the RJV case). Even though exclusive RJVs can be interpreted as predatory behavior, since they force the smaller rival to exit the industry, the antitrust implications need to be considered on a case by case basis.

[10] This is in fact the case in the U.S. and at the European Commision.

[11] Recall that $2f\left(X^{\mathsf{JV}}\right)$ is unaffected by ε.

In general, our analysis suggests that R&D Joint Ventures should raise competition concerns when its membership is "overexclusive". The next section will provide some empirical evidence regarding the firm-size hypothesis in research joint ventures.

3 Empirical Analysis

In this chapter we present econometric evidence regarding the firm-size hypothesis developed in the previous section. The main hypothesis we wish to investigate is that larger firms tend not to form RJVs with smaller firms, such that we would observe RJVs among firms of similar size. We therefore wish to estimate the probability of two firms joining an RJV in terms of the relative difference in firm size.

To test this hypothesis we control for a number of other factors of RJV formation that have been stressed in the literature. Among these are internalizing spillovers (i.e. the free-rider effect), cost-sharing, as well as industry and technology effects. As we mention above, free-riding implies that firms spend less on R&D than if they coordinate their R&D investments. As a result, one would expect the R&D investments at the firm-level to increase in an RJV. Cost-sharing, however, would go in the opposite direction - firms can pool their R&D spending in an RJV. As a result, the net effect of free-riding and cost-sharing on firm level R&D spending is ambiguous. With high spillovers, the free-rider effect dominates, whereas with low spillovers the cost-sharing effect dominates and firms spend less on R&D in an RJV (see for example KMZ).

The focus of this empirical section is not to identify the free-rider effect separately from the cost-sharing effect.[12] Rather, our interest is to test the firm-size hypothesis, controlling for possible changes in R&D investment due to RJV formation. The only scenario in which R&D spending is unaffected by RJV formation is when the free-rider and the cost saving effects exactly offset each other. Since this restriction is unlikely to hold in the data, R&D cannot be excluded from the analysis of RJV formation. To account for changes in R&D investments due to RJV formation, we need to specify the simultaneity as there is causality running both ways: changes in R&D spending affects RJV formation, and vice versa. To account for this endogeneity of R&D spending, we estimate an endogenous switching model proposed by Lee (1978). In this way, we are able to obtain consistent estimates of our firm-size hypothesis.

It is important to emphasize that an RJV is a relatively rare event as far as an industry is concerned. Our data set consists of firm-level and RJV-type information which span a number of industries. Given the sparse occurrence of

[12] Whether the cost-sharing or the free-rider effect dominates is studied by Irwin and Klenow (1996) in the context of SEMATECH.

RJVs in any one industry, it is not possible to perform a more structural industry-specific empirical analysis. In particular, we are not able to estimate a model in which all three stages are endogenized, such as product market competition or demand elasticities.

Nevertheless, we are able to control for other important determinants of RJV formation such as the degree of substitutability or complementarity in the final product market. In the context of the KMZ-like model it is easily shown that RJVs between firms that are in complementary industries are more likely to occur. Besides, our data base appears to consist of a number of RJVs 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. Unable to produce demand cross-elasticities for all the industries, we control for these demand effects by industry dummies. Finally, there may be technological spillovers between RJV partners. For instance, there may be higher spillovers between certain types of product categories. Again, we are able to control for these through industry-pairwise fixed effects.

In summarizing, the empirical analysis below controls for a number of these factors applying an endogenous switching model. Before we discuss the empirical specification in more detail, we briefly describe the data used in the analysis.

3.1 Data Sources: The Joint Ventures Act

Our 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 enabling 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 United States Attorney General and the Federal Trade Commission in order to receive protection from antitrust 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 United States 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 basic data on RJVs runs from January 1985 through July 1994.[13]

[13]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.

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 registered in the period from 1988 to 1994. The number of firms participating in RJVs is 445. The highest frequency is observed in the category of 5-10 participants per RJV. In our sample, each firm participates in an average of about 3 RJVs.

A potential defect of our sample may be that smaller firms are not represented to the same extent as are 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 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 order to investigate the choice of RJV partners, we begin by matching all firms into 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 with no RJV, resulting in a sample of 20,942 observations.[14] We define a variable P_{ij} $(i \neq j)$ as a dummy variable indicating whether the matched pair is participating in a Joint Venture. $DASSET$ is our measure of relative firm size difference defined as

$$DASSET_{ij} = \frac{|ASSET_i - ASSET_{j,}|}{\max\{ASSET_i, ASSET_j\} \cdot MEMBERS}$$

where $ASSET_i$ are the assets of firm i taken one year prior to the RJV whenever $P_{ij} = 1$, while $ASSET_i$ are the average assets over the entire sample period whenever $P_{ij} = 0$. In other 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 propose to control for the size of the RJV by dividing by $MEMBERS$, which is defined as the logarithm of the number of members in the RJV. Given that this variable is not observable for firm pairs that do not

[14]Missing values and too few observations in certain industry-pairs reduced our sample to 20,942 observations.

RJV, we proxy $MEMBERS$ by taking the logarithm of the average size of all other RJVs in which the firms are engaged.

Another control variable is the total RJV activities by the firm-pair. The variable $RJVS$ equals the number of other RJVs the firms are engaged in.

In order to control for cost-sharing and free-riding, we construct a measure of changes in firm-level R&D. We define $r\&d1$ as the change in average firm-level R&D intensities whenever $P_{ij} = 1$ as follows:

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

where $r\&d_i$ is firm-level R&D investment devided by firm-level revenue and t is the year of the RJV formation. In other words, $r\&d1$ measures whether the two firms spend relatively less on average after they form an RJV. It is important to emphasize that the variable $r\&d1$ is observable only 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:

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

where $\Delta r\&d_i$ is the average annual change of firm-level $r\&d$ intensity over the sample period.

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

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

Finally, we use a set of dummy variables to control for intra- and inter-industry effects. 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 ($COMPs$) indicating firms from different industries. In the empirical analysis below we will interpret the $COMP$ dummy as an indicator of how related the products are, either on the demand or technology dimension. Note that SIC classifications are often based on cost-side considerations, i.e. they are technology oriented, and not demand-side oriented.

Table 2 reports the industries in our database and the sample frequencies (mean of the dummies) for each one of the industry pairs. The table shows 6 intra-industry dummies (nonzero elements on the diagonal) and 16 complementarity dummies (nonzero off-diagonal elements). It is noteworthy that in over 50% of all RJVs in our sample one firm is from the industrial machinery and equipment industry. Since machinery and equipment are often inputs for many other industries, this observation is consistent with the hypothesis that RJVs occur more often when products are complementary.[15]

3.3 Econometric Issues, Specification, and Estimation

In order to investigate our firm-size hypothesis we estimate the following probit equation which determines whether a firm-pair forms an RJV:[16]

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

where $R\&D_{ij} = r\&d1_{ij} - r\&d0_{ij}$. As discussed above, the firm-size hypothesis implies that the variable $DASSET$ has a negative impact on the probability of forming an RJV. This is the main hypothesis we wish to test. In addition, we control for the size of the RJV ($MEMBERS$) as well as total RJV activities by the firm-pair ($RJVS$). Finally, the dummies SIC_{ij}^k and $COMP_{ij}^l$ control for intra- and inter-industry effects. In the empirical analysis below we interpret the $COMP$ dummy as an indicator of how related the products are, on either the demand or technology side.

As emphasized by much of the literature on RJVs, the incentive to form an RJV should depend on the expected effect on R&D expenditures. We therefore include the variable $R\&D$ in (6), which measures the impact of the RJV on R&D expenditures. As discussed above, $R\&D$ is positive when the free-rider effect dominates and negative when the cost-sharing effect is larger.

We are not able to obtain consistent estimates of the firm-size hypothesis in (6) unless we address two important issues. First, we observe $R\&D$ only when firms are *actually* engaged in an RJV, i.e. when $P_{ij} = 1$. In this case we can construct

[15] 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 potential 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).

[16] 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 an 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 an 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 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 an RJV depends on which and how many other firms are willing to join.

a measure of the R&D effect from our observed changes in R&D. Whenever a firm-pair is not in an RJV, we have no such measure. We consequently have a missing data problem and need a consistent estimate of the expected effect on R&D expenditures when $P_{ij} = 0$.

A second issue is one of simultaneity between R&D and the decision to form an RJV. As is specified in (6), the decision to RJV is determined by its impact on R&D (i.e free rider and cost-sharing effects). However, R&D investments are in turn also determined by RJV formation, which implies that $R\&D$ is endogenous in (6). Not accounting for this endogeneity in (6) leads to inconsistent estimation of the firm-size hypothesis.

Given these two concerns we estimate the model with a switching model originally suggested by Lee (1978). The endogenous switching model can be written as (6) and

$$r\&d1_{ij} = \alpha_1 MEMBERS_{ij} + \alpha_2 DASSET_{ij} + \sum_{k=1}^{6} \alpha_3^k SIC_{ij}^k + \sum_{l=1}^{16} \alpha_4^l COMP_{ij}^l + \nu_{ij} \qquad \text{if } P_{ij} = 1, \tag{7}$$

$$r\&d0_{ij} = \beta_1 MEMBERS_{ij} + \beta_2 RJVS_{ij} + \sum_{k=1}^{6} \beta_3^k SIC_{ij}^k + \sum_{l=1}^{16} \beta_4^l COMP_{ij}^l + \varepsilon_{ij} \qquad \text{if } P_{ij} = 0. \tag{8}$$

In other words, if $P_{ij} = 1$ (as determined by (6)) R&D expenditures are given by (7), while R&D expenditures are determined through (8), whenever $P_{ij} = 0$.

Note that OLS estimates of (7) and (8) yields inconsistent estimates since $E(\nu_{ij}/P_{ij} > 0) \neq 0$ and $E(\varepsilon_{ij}/P_{ij} \leq 0) \neq 0$. Following Lee, we apply a two-stage probit estimation where we substitute (7) and (8) into (6) which yields a reduced-form probit model. The reduced-form probit model can be consistently estimated by standard probit methods. Using the predicted probabilities $\hat{P}_{ij}$ from the reduced-form probit, we can then get consistent estimates of the R&D equations by least squares as follows:

$$\begin{aligned} r\&d1_{ij} &= \alpha_1 MEMBERS_{ij} + \alpha_2 DASSET_{ij} + \sum_{k=1}^{6} \alpha_3^k SIC_{ij}^k \\ &\quad + \sum_{l=1}^{16} \alpha_4^l COMP_{ij}^l + \rho_1 \sigma_1 \frac{\phi\left(\hat{P}_{ij}\right)}{\Phi\left(\hat{P}_{ij}\right)} + \xi_{ij} \qquad \text{if } P_{ij} = 1, \end{aligned} \tag{9}$$

$$r\&d0_{ij} = \beta_1 MEMBERS_{ij} + \beta_2 RJVS_{ij} + \sum_{k=1}^{6} \beta_3^k SIC_{ij}^k + \sum_{l=1}^{16} \beta_4^l COMP_{ij}^l$$
$$+\rho_0\sigma_0 \left[\frac{-\phi\left(\hat{P}_{ij}\right)}{\left(1-\Phi\left(\hat{P}_{ij}\right)\right)} \right] + \vartheta_{ij} \qquad \text{if } P_{ij} = 0, \qquad (10)$$

where $E[\sigma_{ij} \cdot \xi_{ij}] = \sigma_1^2$, $Corr[\sigma_{ij} \cdot \xi_{ij}] = \rho_1$, $E[\sigma_{ij} \cdot \nu_{ij}] = \sigma_0^2$, and $Corr [\sigma_{ij} \cdot \nu_{ij}] = \rho_0$, where σ_{ij} is the error in the reduced form probit model. The endogeneity is controlled for in the switching regression model through the correction factors, where ϕ and Φ are the PDF and CDF of the standard normal distribution. Using the predicted values of (9) and (10) $r\hat{\&}d1_{ij}$ and $r\hat{\&}d0_{ij}$ yields a consistent estimate of $R\&D_{ij} = r\hat{\&}d1_{ij} - r\hat{\&}d0_{ij}$ which can then be used in (6). The resulting structural probit-estimates are consistent as shown by Lee (1979).

To obtain asymptotically efficient estimates, we have computed the FIML estimates of the above model. [17] The main findings, however, are essentially unchanged regardless of whether the two-stage or the FIML estimates are used. We therefore report only the FIML estimates.

3.4 Results and Interpretation

Before we turn to the probit equation we briefly discuss the R&D equations. The results of the R&D equations (9 and 10) are presented in Table 3. Before interpreting our results, it is important to check whether the truncation terms ρ and σ are significant. As can be seen in Table 3, we find a significant estimate for the correction. This indicates that the selectivity through the endogenous dummy variable is indeed an important issue and justifies our endogenous switching model specification.

Turning to the estimates, we can now report a number of empirical findings regarding R&D spending of RJVs. As can be seen in the table, the number of participating members ($MEMBERS$) is highly significant and negative, indicating that large RJVs spend more per firm on R&D (recall the definition of $r\&d1$). This implies that the free-rider effect becomes more important relative to cost-sharing incentives as the size of the RJV increases. Similarly, the positive sign of $DASSET$ indicates that firms of similar size tend to increase firm-level R&D spending in an RJV. Therefore, we find that equal-sized and large RJVs spend more on R&D on a per firm basis, which is consistent with free-riding incentives being relatively more important than cost-sharing incentives.

[17] See LIMDEP User's Manual (1995), p. 668.

Among the industry dummies we find a considerable amount of heterogeneity in terms of incentives for R&D spending in an RJV.[18] Amongst those industries in which firm-level R&D spending in an RJV is relatively small are the "*Chemicals and Allied Products*" industry (*SIC28*) or the "*Electronic and other Electric Equipment*" industry (*SIC36*). Apparently, the incentives for cost-savings are relativley larger in those cases. 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. 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*) spend relatively less on firm-level R&D.

Estimates of the R&D equation (10) for firm pairs which do not participate in the same RJV are presented in Table 3. 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 in which the firms are engaged. 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, justifying our approach.

We now turn to our main objective. Table 4 presents the structural probit estimates of equation (6). As can be seen, the variable $DASSET$ has a negative impact on the probability of forming an RJV, with a point estimate of -0.114, which implies that RJVs tend to be formed among firms of similar size. In addition, the impact is statistically significant with a t-statistic of -3.54. We therefore find significant evidence for the firm-size hypothesis in our data.

Turning to the other variables, the difference in firm-level R&D (*R&D*) has a positive and statistically significant effect. This finding is consistent with the argument 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 reduction in R&D investment due to forming an RJV increases the likelihood of forming an RJV by some 0.6%. The positive and significant impact of $MEMBERS$ indicates that larger RJVs are more likely. The negative and significant effect of $RJVS$ suggests the more RJVs a firm is engaged in the less likely it will enter additional RJVs, i.e. the returns to RJVs are diminishing.

Turning to the industry dummies, it is interesting to compare the intra-

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

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, implies that firms in $SIC29$ have the highest intra-industry probability to form an RJV. As expected, the complementarity dummies vary substantially according to the industry pairs considered. However, in many cases the $COMP$ dummies are smaller than the SIC dummies, indicating that intra-industry RJVs occur more often than do 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 "*Stone, Clay, and Glass Products*" and the "*Transportation Equipment*" ($COMP3237$) display the highest likelihood of forming RJVs with each other. Not surprisingly, 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 and that the incentive to form an RJV is high.

4 Conclusion

The goal of this paper is to test the firm-size hypothesis on U.S. data that recently became available through the National Cooperative Research Act (NCRA). We illustrate the basic argument by extending the model by Kamien, Muller, and Zang (1992) to asymmetric firms. We show that the more similar in size the potential partner, the greater the incentive to choose the firm as an RJV partner. Thereby, large firms have less of an incentive to form an RJV with a smaller rival, leading to a more concentrated market structure. The exclusive character of RJVs may then increase a given asymmetry in industry structure, increasing market power for those firms inside the RJV at the expense of outsiders. In that sense, exclusive RJVs are instruments to leverage market power.

In the second part of the paper, we take the firm-size hypothesis to the data. We estimate a two-equation system that endogenizes RJV formation and R&D investments through an endogenous switching model. Our main finding is 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 leverage their market power through the strategic choice of RJV partners.

We also report on a number of empirical findings regarding R&D spending and RJV formation. In particular, we find that equal-sized RJVs and RJVs with many participants spend more on R&D on a per firm basis. In addition, the econometric estimates imply that firms are less likely to form an RJV the more

RJVs they are already engaged in, i.e. the returns to RJVs are diminishing.

The welfare implications of the firm-size analysis are less clear, since a more concentrated market structure may lead to lower prices. However, excluding smaller rivals from RJVs can be regarded as an instrument by which firms leverage their market power in the product market. Consequently, antitrust authorities should be wary of why and with whom firms form Research Joint Ventures.

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Appendix: Figures and Tables

Figure 1: R&D Investments in R&D Competition and RJV

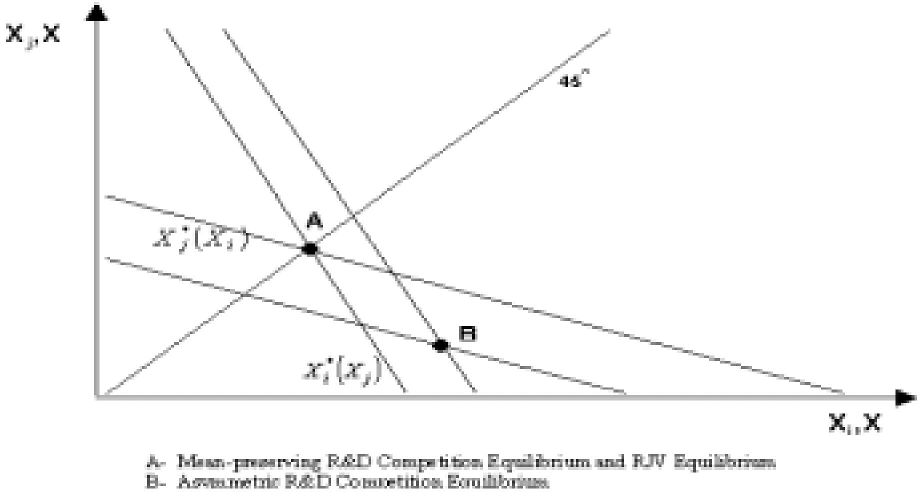

Table 1: Variable definitions and summary statistics
(pair-matches between firm i and firm j)

Variables	Description	N	Mean	Min.	Max.
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 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 form 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 2: 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/ Equipment	36 Electronic and other Electric Equipment	37 Transport. 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, Glass Products	1.36	0.67	0	0				
35 Industrial Machinery/ 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 3: R&D intensities

	Estimates of Equation (9) Dependent Variable: r&d1		Estimates of Equation (10) Dependent Variable: r&d0	
Variables	Estimates	Std. Err.	Estimates	Std. Err.
$MEMBERS$	-1.366	0.332	-0.064	0.005
$DASSET$	11.800	2.070	-	-
$RJVS$	-	-	-0.151	-0.151
$SIC13$	1.975	1.556	0.709	0.030
$SIC28$	7.072	1.739	0.202	0.032
$SIC29$	-0.708	1.735	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	6422	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	0.433	0.022
$COMP3638$	7.899	1.990	0.274	0.151
$COMP3738$	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 4: Sources and complementarities in RJV formation

Probit Estimates of Equation (6): Dependent Variable: P_{ij}		
Variables	Estimates	Std. Err.
$DASSET$	-0.114	0.033
$R\&D$	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 $\alpha_1 f\left(\overline{X}\alpha\right)$, where $\overline{X}$ is the sample mean of the exogenous variables. NOBS=20,942; Log-likelihood: -911.898; Concordant=97.3%; Discordant=1.3%; Tied 1.4%.