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Why Firms Form Research Joint Ventures: Theory and Evidence

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ABSTRACT

Why Firms Form Research Joint Ventures: Theory and Evidence

by Lars-Hendrik Röller, Mikhel 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 using data now available through the U.S. National Cooperative Research Act.

ZUSAMMENFASSUNG

Warum Unternehmen Forschungs-Joint Ventures gründen:
Theorie und Empirie

Die Literatur über Forschungs-Joint Ventures (FJVs) hat die Internalisierung von Spillovers und die Kostenaufteilung als Motive für das Entstehen von FJVs hervorgehoben. In dieser Studie werden zwei weitere Erklärungen mitaufgenommen: die Produktmarktkomplementarität und die Unternehmensheterogenität. Diese Motive werden mit Hilfe von Daten, die aufgrund des U:S:-amerikanischen "National Cooperative Research Act" verfügbar sind, getestet.

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NON-TECHNICAL ABSTRACT

Why firms Form Research Joint Ventures: Theory and Evidence

In the early 1980s there was an apparent shift in technology policy in both the U.S. and in Europe. This was apparently 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. 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.

This paper analyzes the motives for firms to engage in research cooperatives, by putting forward various explanations emphasizes in the literature, and then testing them empirically. Amongst the reasons most emphasized 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. 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 (or 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. 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 duplicating one anothers' effort. For instance W. Norris, CEO of Control Data Corp. refers to a "shameful and needless duplication of effort". 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 and will be tested in the second part of this paper in the context of a newly available data base.

In addition to (i) and (ii), we formalize two other factors that determine firms decision to form an RJV: (iii) *product market complementarities* and (iv) *firm heterogeneity*. We begin by specifying a framework which 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 specify a three-stage game where firms decide in stage one whether or not to join an RJV, in stage

two they decide on R&D investments, and in stage three they compete in the product market. In particular, we analyze the effect of product differentiation (the degree of substitutability or complementarity) on the incentives to form an RJV. We allow products to range from perfect complements to perfect substitutes. If firms are producing complementary products one would expect incentives for RJV formation to be quite different relative to when firms produce substitutable products (since firms compete more closely in the product market). For example, the electronic equipment and communications industries have complementary products and is an area in which many RJVs are observed.

To analyze (iv) our models allows for firms to be different in their marginal costs, which introduces exogenous asymmetry, and an insider-outsider problem. Since RJVs influence R&D levels for those firms inside differently from those firms outside the RJV, it is shown that RJVs affect market structure and market power. The exclusive character of RJVs may then increase a given asymmetry in industry structure further, increasing market power for those firms inside the RJV at the expense of the outsiders. We show (in the context of our model) that large firms have less incentive to form an RJV with smaller firms in order to increase market power. As a consequence the industry becomes increasingly asymmetric. 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.

The second part of the paper tests 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 which 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 which 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, 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 RJV is consistent with the theoretical model developed in the paper.

ZUSAMMENFASSENDER ÜBERBLICK

Warum die Unternehmen Forschungs-Joint Ventures gründen: Theorie und empirischer Beweis

In den frühen 80er Jahren war in den USA und in Europa eine prägende Veränderung in der Technologiepolitik zu verzeichnen. Diese war hauptsächlich aufgrund eines härteren internationalen Wettbewerbs entstanden, der besonders von den Japanern im Hochtechnologiesektor vorangetrieben wurde. Viele Wissenschaftler und Wettbewerbshüter identifizierten die kooperativere Unternehmenslandschaft als Ursache für die Erlangung des kompetitiven Vorteils in Japan. Das 1961 erlassene Gesetz für Technologie- und Forschungsvereinigungen im Bereich des Bergbaus und des produzierenden Gewerbes und die Bemühungen des MITI waren politische Instrumente, mit denen die Japaner zur Joint Venture-Bildung ermutigten und eine kooperative Atmosphäre erzeugten. Die Antwort der U.S. Wettbewerbshüter war die Erlassung des „National Cooperative Research Act (NCRA)“ von 1984 und die staatliche Unterstützung von Forschungsprojekten, wie z.B. SEMATECH. In Europa ist unter EU-Wettbewerbsgesetzgebung eine Ausnahmeregelung für Forschungsgemeinschaften geschaffen worden. Zusätzlich ist in der EU eine Reihe von Rahmenprogrammen geschaffen worden, in denen Milliarden von ECU bereitgestellt wurden, um Forschungs-Joint Ventures (FJVs) zu subventionieren.

Diese Studie analysiert die Motive für Unternehmen, den Forschungskooperationen beizutreten, indem verschiedene Erklärungen aus der bisherigen Literatur weiterentwickelt und anschließend empirisch getestet werden. Die in der einschlägigen Literatur am häufigsten erwähnten Gründe sind: i) die Internalisierung von Spillovers verbunden mit F&E-Investitionen (z.B. die Überwindung des Freifahrerproblems) und ii) die Kostenersparnisse durch die Aufteilung der F&E-Kosten. Die Internalisierung von Spillovers durch FJVs ist wünschenswert, da die Unternehmen sonst aufgrund des Freifahrerverhaltens weniger in die F&E investieren würden. Die Kostenaufteilung stellt für die Unternehmen einen starken Anreiz dar, da er es erlaubt, Unternehmenressourcen zu vereinen und verschwenderische Mehrfachaufwendungen zu vermeiden. Eines der Schlüsselergebnisse in der Literatur ist der Freifahrereffekt, der aufgrund des kostenlosen Übergangs von F&E Investitionen eines Unternehmens auf andere Unternehmen, die privaten Anreize in die F&E zu investieren, reduziert.

Wenn die Unternehmen ein *inklusives* FJV gründen (oder die F&E-Investitionen kooperativ festsetzen), werden die Spillovers internalisiert. Dies führt zu einer Erhöhung der unternehmensbezogenen F&E-Investitionen und erhöht die Wohlfahrt. Entgegengesetzt zu dem Freifahrerargument führt der Kostenaufteilungseffekt zu einer Verringerung der unternehmensbezogenen F&E-Investitionen. Es ist festgestellt worden, daß der Kostenaufteilungseffekt sehr bedeutsam wird, wenn es zu einer exzessiven Reduzierung von Mehrfachaufwendungen kommt: Unternehmen innerhalb einer Industrie mögen dieselben Innovationen verfolgen und benutzen dieselben Methoden, was zu Mehrfachaufwendungen führt. Zum Beispiel verweist W. Norris von der Control Data Corp. auf „beschämende und unsinnige Mehrfachaufwendungen.“ Ob der Kostenaufteilungs- oder

der Freifahrereffekt die unternehmensbezogenen F&E-Investitionen dominiert, ist eine ultimativ empirische Frage und wird im zweiten Teil der Studie im Kontext einer neuen Datenbank getestet.

Zusätzlich zu i) und ii) formalisieren wir zwei weitere Faktoren, die die Unternehmensentscheidung, ein FJV zu gründen, entscheidend mitbestimmen: iii) die Produktmarktkomplementaritäten und iv) die Unternehmensheterogenität. Wir spezifizieren ein Modell, welches das Modell von Kamien, Muller und Zang (1992) in Bezug auf asymmetrische Unternehmen und komplementäre Produkte erweitert. Somit erhalten wir die Möglichkeit, die Effekte der heterogenen Unternehmen und Produktmarktkomplementaritäten zu untersuchen. Wir spezifizieren ein dreistufiges Spiel, in dem die Unternehmen in Stufe eins entscheiden, ob sie an einem FJV teilnehmen oder nicht. In der zweiten Stufe entscheiden die Unternehmen über die F&E-Investitionshöhe und in Stufe drei stehen sie im Produktmarkt untereinander im Wettbewerb. Im besonderen analysieren wir den Effekt der Produktdifferenzierung (das Ausmaß der Substitutionalität oder der Komplementarität von Produkten) auf den Anreiz, ein FJV zu gründen. Wenn die Unternehmen komplementäre Produkte produzieren, sind andere FJV-Formationsanreize zu erwarten, als wenn die Unternehmen substitutionale Produkte produzieren würden, da die Unternehmen im letzteren Fall härtere Konkurrenten im Produktmarkt darstellen. Zum Beispiel stellen die Elektronik- und die Kommunikationsindustrie Produkte her, die untereinander in komplementärer Beziehung stehen. Zudem kommen aus diesen Industriebranchen viele Unternehmen, die miteinander ein FJV eingehen.

Um iv) zu analysieren, nehmen wir in unserem Modell Unternehmen mit unterschiedlichen Grenzkosten an, was zu einer exogenen Asymmetrie und zu einem Insider-Outsider Problem führt. Da Unternehmen innerhalb eines FJVs andere F&E-Investitionen tätigen als Unternehmen außerhalb des FJVs, kann gezeigt werden, daß FJVs die Marktstruktur und die Marktmacht beeinflussen. Der exklusive Charakter der FJVs könnte eine gegebene Asymmetrie in der Industriestruktur vergößern und die Marktmacht der kooperierenden Unternehmen auf Kosten der nichtkooperierenden Unternehmen erhöhen. Wir zeigen in unserem Modell, daß große Unternehmen weniger Anreize besitzen mit kleineren Unternehmen gemeinsam ein FJV zu gründen, da sie sich dadurch eine Erhöhung der Marktmacht versprechen. Als Konsequenz ergibt sich eine zusätzlich asymmetrische Industriestruktur. Wie oben erwähnt, sind die Wettbewerbsbehörden recht begünstigend mit der Bewertung von FJVs umgegangen. Es wurde jedoch vor Wettbewerbsgefahren gewarnt, wenn das FJV zu umfassend (*"overinclusive"*) ist (U.S. Department of Justice, 1985 und EU, 1985). Auf der anderen Seite würden die F&E-Erfolge nur einigen wenigen Unternehmen zufallen, wenn die FJVs *„exklusive Clubs"* darstellen. Dieser Effekt würde eine anfängliche Asymmetrie in der Industriestruktur verstärken, was zu einer konzentrierteren Marktstruktur führt. Im allgemeinen können F&E Joint Ventures dazu führen, eine anfänglich asymmetrische Marktstruktur zu vergrößern und dadurch Wettbewerbsgefahren auslösen.

Der zweite Teil der Studie testet mit Hilfe einer Datenbank, die als Folge des „National Cooperative Research Act (1984)“ erstellt werden konnte, die verschiedenen Anreizstrukturen, die aus dem theoretischen Modell abgeleitet wurden. Wir schätzen ein Zwei-Gleichungssystem, welches die FJV-Formation und die Auswirkungen auf die F&E-Investitionen endogenisiert. Unsere Resultate bestätigen, daß eine ähnliche Unternehmensgröße, bei der Entscheidung, ob zwei Unternehmen ein FJV eingehen, ein signifikanten Faktor darstellt. Dieses Ergebnis ist konsistent mit dem theoretischen Modell, welches vorhersagt, daß große Unternehmen nicht dazu tendieren, mit kleinen Unternehmen an einem FJV zu partizipieren. Darüber hinaus finden wir, daß weder der Kostenaufteilungseffekt noch der Freifahrereffekt bei der Untersuchung der unternehmensbezogenen F&E-Investitionen dominiert, sondern diese von der Industrie und der Größe des FJVs abhängig sind. Als Anreiz ein FJV zu gründen, stellt sich der Kostenaufteilungseffekt jedoch als relevante Bestimmungsgröße heraus. Schließlich erhalten wir keinen Beweis dafür, daß Komplementaritäten zwischen *allen* Industriepaarungen existieren. Es zeigt sich vielmehr, daß bestimmte Industriepaarungen (möglicherweise in vertikale Beziehungen) existieren, die die Wahrscheinlichkeit einer FJV-Gründung aufgrund von Komplementaritätseffekten signifikant erhöhen. Es erscheint vernünftig anzunehmen, daß die Technologie die in diesen Industrien vorherrscht, sehr ähnlich ist, obwohl der Produktmarktwettbewerb zwischen den Unternehmen von komplementärer Natur ist. Dieses empirische Resultat verdeutlicht, daß die Unternehmen, die untereinander komplementäre Produkte produzieren, eher ein FJV gründen und ist damit konsistent mit dem theoretischen Modell dieser Studie.

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 considerable 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 decision 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.

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

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 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 and cost-sharing occurs. 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 set-up 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. Hence, cost-sharing dominates. On the other hand, 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

[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.

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 electronic equipment and communications industries have complementary products and are areas in which many RJVs are observed.

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 from 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 in industry structure further, increasing market power for those firms inside the RJV at the expense of the 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 are the conditions for membership.

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

[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.

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 becomes increasingly asymmetric. 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 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, 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 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 c_i and c_j, such that $c_i < c_j$. 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 $-1 \le \gamma \le 1$. Thus our analysis encompasses substitutable ($\gamma>0$), totally differentiated ($\gamma=0$), and complementary products ($\gamma<0$). 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 $\pi_i = \left[p_i - (c_i - f(X_i))\right]q_i$. 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,

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[5] First, the R&D production function *f(x)* is twice differentiable and concave, with $f(0)=0$, $f(X) \le c_i$, $f'(X)>0$ for all X. Secondly, the R&D production function satisfies: $\lim_{X\to\infty} f(X) < a - 2c_j + c_i$ and $f'(0) > (4-\gamma^2)^2 \big/ \left[2\left((2-\gamma)a - 2c_j + \gamma c_i\right)\right]$ 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., $\frac{4}{(4-\gamma^2)^2} f'(x_i)\left[(2-\gamma)a - 2(c_i - f(x_i)) + \gamma(c_j - f(x_j))\right]$ is decreasing in x_i (with an analogous condition for firm *j*).

$$q_i^* = \left[(2-\gamma)\alpha - 2\left(c_i - f(X_i)\right) + \gamma\left(c_j - f(X_j)\right)\right] \big/ \left(4-\gamma^2\right)$$
$$q_j^* = \left[(2-\gamma)\alpha - 2\left(c_j - f(X_j)\right) + \gamma\left(c_i - f(X_i)\right)\right] \big/ \left(4-\gamma^2\right)$$

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

$$\pi_i^* = q_i^2 - x_i \,. \qquad (1)$$

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,

$$f'\left(X_i^*\right)q_i^* = \left(4-\gamma^2\right)\big/4 \qquad (2)$$

Analogously, the condition for firm *j* is,

$$f'\left(X_j^*\right)q_j^* = \left(4-\gamma^2\right)\big/4 \qquad (3)$$

Using these conditions we obtain the following lemma.

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

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

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. *q.e.d.*

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 $\left(c_i = c_j\right)$ (2) and (3) both simplify to,

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

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

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

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 (γ>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,

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

or, equivalently,

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

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,

[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.

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 (5) 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. *q.e.d.*

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 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 1: *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

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

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

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

which holds under the conditions in Lemma 3, i.e. it does not hold for $\gamma = 1$ and when there are asymmetries.

q.e.d.

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.

To test this argument together with the previously mentioned determinants of RJV formation we summarize the theoretical section with the following 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 empirically investigate the reasons for RJV formation: (i) internalizing spillovers (i.e. the free-rider effect), (ii) cost-sharing, (iii) complementary products, and finally (iv) firm heterogeneity. The free-rider effect (i) implies that firms spend less on R&D than what they would do if they could coordinate their R&D investments. The reason for this is that there may be spillovers. Therefore, taking the free-rider effect alone, one would expect the R&D investments at the firm-level to increase in an RJV. This effect is larger the larger the spillover. Cost-sharing (ii) would go in the opposite direction - firms can pool their R&D spending in an RJV and save expenses. 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,

$$\textit{Net Effect} = \underset{(-)}{\textit{Cost-Sharing}} + \underset{(+)}{\textit{Free-Rider}} \qquad (6)$$

where cost-sharing has a negative effect on firm-level R&D spending and free-riding a positive effect. When the *net effect* in (6) 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 that we assess empirically is the degree of complementarity between products. This hypothesis would imply that one observes a large proportion of RJVs between firms that are in different and complementary industries. An example of this is an RJV between firms in vertically related industries such as instruments and industrial machinery or communications and electronic equipment. It is worth emphasizing again that besides product market complementarities there are other types of complementarities, like asset or organizational complementarities. To the extent that they are not measurable by product market heterogeneities we are unable to test these determinants.

Finally, hypothesis (iv) implies that: larger firms do not participate in RJVs with smaller firms in order to increase industry concentration. If this aspect is important, one would expect firms of equal size forming RJVs.

The empirical analysis below simultaneously assesses all four determinants of RJV formation. We will first discuss the effect of RJVs on R&D expenditures. Instrumenting on the estimated change of R&D we then 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 different 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 consumer 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 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 supplied. Notifications are made public in the

Federal Register. Using a report published by the U.S. Department of Commerce (1993), 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 smaller firms are 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).

R&D data have been obtained from the Basic Science and Technology Statistics, OECD (1994) and the Research and Development Expenditure in Industry, OECD (1995) which publishes industry-level R&D expenditures[9]. Industry-level production data have been taken from the OECD STAN Database (1994)[10].

[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.

[9] The industry codes were converted from ISIC into SIC.

[10] The industry-level R&D and production data are aggregated for the OECD since the participating firms in RJVs are mostly international firms.

3.2 Variable Definitions and Descriptive Statistics

In order to investigate the determinants of RJV formation between firms we consider firm pairs and whether both firms belong to the same RJV. We find a total of 694 cases where a firm pair is participating in the same RJV, and we randomly select a control group of equal size from the remaining 98,096 pairs[11]. This leads to a balanced sample of 1,388 observations. The definitions of the variables used in the estimation reported below, as well as some simple summary statistics, are given in Table 1a.

INSERT TABLE 1a ABOUT HERE

The variable P_{ij} *(i≠j)* is a binary variable indicating whether the matched pair is participating in the same joint venture. It is equal to one if they are in the same RJV, equal to zero otherwise.

DASSET is the variable that measures the relative difference in firm size. We need to differentiate whether the two firms are forming an RJV. We define *DASSET* as follows,

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

$$DASSET_{ij} = \frac{\left| \overline{ASSET_i} - \overline{ASSET_j} \right|}{max\left\{ \overline{ASSET}_i, \overline{ASSET}_j \right\} \cdot 0.5} \quad when \; P_{ij} = 0$$

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 under consideration. In words, whenever the two firms participate in the same RJV (at time *t=1*) we define *DASSET* as the absolute value of the firm difference in total assets as a proportion of the larger firms assets one year prior to the RJV formation. Whenever the firms are not engaged in an RJV, we define *DASSET* as 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: 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. In order for this effect to be monotonic we set *ln(#RJV)=0.5* when the two firms are not in an RJV.

[11] The actual number of pairs available is 37,993 due to missing values and the fact that some firms are in several RJVs which leads to firms being matched with themselves.

In order to assess possible cost-sharing and free-rider effects, we construct a measure of how an RJV influences firm-level R&D spending. We define *r&d* as the change (due to the RJV) in average firm-level R&D intensities. Consequently, the variable *r&d* can only be constructed for those firms that *actually* participate in an RJV as,

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

where $r\&d_i$ is the R&D investment at the firm-level, tr_i is total revenue at the firm-level, and t is the year of the RJV formation. In other words, *r&d* measures whether the two firms spend relatively less on average after they form an RJV. It is interesting to note on average that firm-level R&D expenditures as percentage of firm-level revenues are lower prior to forming an RJV compared to after an RJV is formed. This seems to suggest that the free-rider effect dominates the cost-sharing effect. Analogously, we define an equivalent variable at the industry-level denoted by *R&D* as,

$$R\&D_{ij} = \frac{1}{2}\left(\frac{R\&D_{i,t-1}}{TR_{i,t-1}} - \frac{R\&D_{i,t}}{TR_{i,t}} + \frac{R\&D_{j,t-1}}{TR_{j,t-1}} - \frac{R\&D_{j,t}}{TR_{j,t}} \right) * 100$$

where $R\&D_i$ is the total R&D in the industry of firm *i* and TR_i is the total revenue in the industry of firm *i*.

Finally, *MEMBERS* is the logarithm of the average number of participants in the RJV if the firm-pair is engaged in the same RJV. In the case that the firm-pair under consideration is not in the same RJV, the variable *MEMBERS* is constructed by taking the logarithm of the sum of the average number of RJV participants taken place in the corresponding industry of each firm. The logarithm is incorporated in order to capture a nonlinear relationship between the change in r&d expenses and the size of the RJV.

We use a set of dummy variables to control for intra- and inter-industry effects. Accordingly, we define industry dummies (denoted *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 that the 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 7 intra-industry dummies and 21 complementarity dummies (inter-industry dummies).[12]

INSERT TABLE 1b ABOUT HERE

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 Empirical Implementation and Results

We now investigate the determinants of RJV participation given our four hypotheses (i)-(iv) mentioned above. In order to test hypotheses (iii) and (iv), we specify a logit-equation[13] which explains the probability that two firms form an RJV,

[12] One industry dummy and some complementary dummies had to be dropped due to missing observations.

[13] The decision process by which firms choose their RJV partners may be more complicated than a simple logit 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 logit 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 logit specification. On the other hand, the fact that RJVs are composed of many firms allows for more sophisticated modeling, where the decision to participate in an RJV depends on which and how many other firms are willing to join.

$$P_{ij} = \alpha_1 DASSET_{ij} + \alpha_2 r\&d^*_{ij} + \sum_{k=1}^{7} \alpha_3^k SIC_{ij}^k + \sum_{l=1}^{21} \alpha_4^l COMP_{ij}^l + e_{ij} \qquad (7)$$

where *i,j* represents the firm pair (*i≠j*), *k* the industry dummy and *l* the inter-industry dummy. Under hypothesis (iv) we would 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. If complementarities across several different industries are important factors in RJV formation one would expect the coefficients for the corresponding *COMPs* to be larger than that of the *SICs*. As discussed above, both the cost-sharing and the free rider effects have an impact on R&D spending. In order to test this impact we include the variable $r\&d^*$ which measures the *expected* change in R&D expenditures if the two firms were to form an RJV.

As defined in Section 3.2 we only observe the effect on firm-level R&D intensities whenever firms *actually* form an RJV, i.e. the variable $r\&d^*$ is not observable for firm-pairs which do not form an RJV. Consequently, we can not estimate equation (7) unless we have a measure for $r\&d^*$ when the two firms *do not* form an RJV. In order to obtain this measure we quantify the impact of RJV formation on firm-level R&D investment by following Irwin and Klenow (1996) and specify an R&D equation as,

$$r\&d_{ij} = \beta_1 R\&D_{ij} + \beta_2 MEMBERS_{ij} + \sum_{k=1}^{7} \beta_3^k SIC_{ij}^k + \sum_{l=1}^{21} \beta_4^l COMP_{ij}^l + \upsilon_{ij} \qquad (8)$$

which is estimated only for firm-pairs which are engaged in an RJV. Analogously to Irwin and Klenow our specification (8) controls for revenue and industry R&D effects. Moreover, it appears reasonable that both the cost-sharing and the free-rider effects depend on the number of participants in an RJV. We therefore include the variable *MEMBERS* in (8). In addition, we include dummy variables to control for industry-pair fixed-effects. Assuming that industry-level R&D and the number of participating members is exogenous, as well as the usual assumptions on υ_{ij}, we can estimate equation (8) by ordinary least squares. The results are presented in Table 2.

INSERT TABLE 2 ABOUT HERE

As can be seen in the table, we find the expected positive relationship between industry- and firm-level R&D intensities. The number of participating members is highly significant, indicating that a larger number of participants leads to more firm-level R&D spending. One explanation is that R&D spending in an RJV with a large number of participants are considered by firms as complementary investment activities, whereas in smaller RJVs they are considered as substitutable investments. Another potential reason for this empirical finding is that if there are significant spillovers contributing to a free-rider problem, internalization of the free-rider problem would be better accomplished by including many of the firms in an industry. In other words, large RJVs leave fewer firms outside, reducing the free-rider problem, resulting in higher R&D investments.

Among the industry dummies we find a considerable amount of heterogeneity.[14] Comparing the relative magnitude of the intra-industry dummies reveals that cost-sharing is relatively large if both firms are in the "Electronic and other Electric Equipment" (*SIC36*) or the "Communications Industry" (*SIC48*). On the other hand, "Oil and Gas Extraction" (*SIC13*), and "Industrial Machinery and Equipment" (*SIC35*), R&D savings are relatively small, indicating that free-rider problems are more significant. Turning to complementary industry effects, we find that firm-pairs from the "Chemicals and Allied Products" and "Communications" (*COMP2848)* as well as firm-pairs from the "Electronic and other Electric Equipment" and "Communications" industries (*COMP3648)* are subject to significant cost sharing. By contrast, cost sharing-effect for firm-pairs from "Oil and Gas Extraction" and "Petroleum and Coal Industry" (*COMP1329*) is relatively small.

To test whether cost-sharing or the free-rider effect dominates we need to combine the *MEMBERS* variable with the industry dummies. Given the definition of the *r&d* variable, cost-sharing dominates for firm-pairs in industry k when $NE = \hat{\beta}_2 MEMBERS + \hat{\beta}_3^k > 0$. Analogously, cost-sharing dominates for firm-pairs from different industries denoted by l when $NE = \hat{\beta}_2 MEMBERS + \hat{\beta}_4^l > 0$. We compute these effects by dividing our sample into two categories: small and large RJVs. We classify RJVs with less than or equal to 7 members[15] as

[14] Aggregating the industry dummies to *SIC* and *COMP* (i.e. only two dummies) yields no statistically significant difference between them.
[15] The highest frequency of members per RJV between 5 and 10 participants is 7 (see Section 3.1).

small RJVs, otherwise they are classified as large RJVs. Table 3 reports the net effects (*NE*) for the various industries, whereby the lower triangle reports the total effect for small RJVs and the upper triangle for large RJVs.

INSERT TABLE 3 ABOUT HERE

As expected from the coefficient on *MEMBERS*, the free-rider effect dominates in large RJVs, whereas cost-sharing dominates in small RJVs. In terms of the large RJVs the free-rider effect statistically dominates only in the "Petroleum and Coal Industry" (*SIC29*). In addition, when firms come from different industries, free-riding dominates significantly only for the "Petroleum and Coal Industry" (*SIC29*) and "Oil and Gas Extraction" (*SIC13*) Industry. Turning to the small RJVs the total effects are generally more significant. Cost-sharing significantly dominates in the "Oil and Gas Extraction" (*SIC13*), "Electronic and other Electric Equipment" (*SIC36*), and "Communications" (*SIC48*) industry. Moreover, there are a number of inter-industry relationships that achieve significant firm-level r&d reductions. The largest cost-sharing effects appear to exist between firm-pairs from the "Communications" (*SIC48*) and "Electronic and other Electric Equipment" (*SIC36*) industries as well as the "Instruments and Related Products" (*SIC38*) and "Industrial Machinery and Equipment" (*SIC35*) industries. There are no industries where the free-rider effect significantly dominates cost-sharing for small RJVs.

Overall, the results in Table 3 indicate that cost-sharing is often more important in terms of firm-level R&D. This is especially true in the "Electronic and other Electric Equipment" (*SIC36*) and "Communications" (*SIC48*) industry. 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. However, we also find evidence that free-rider behavior is more effectively internalized in large RJVs which indicates that the R&D spending in SEMATECH is positively influenced by its large size. In sum, our results suggest 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.

We now turn to the estimation and interpretation of our equation (7) which explains the incentives to RJV. Using the estimates in Table 2, we are able to construct a measure of the expected effect of an RJV on firm-level R&D intensities for any given firm-pair (even for those who do not actually form an RJV) as follows,

$$r\&d_{ij}^{*} = \hat{\beta}_1 R\&D_{ij} + \hat{\beta}_2 MEMBERS_{ij} + \sum_{k} \hat{\beta}_3^{k} SIC_{ij}^{k} + \sum_{l} \hat{\beta}_4^{l} COMP_{ij}^{l} \qquad (9)$$

Substituting (9) we can then estimate equation (7) by logit. The results are reported in Table 4.[16]

INSERT TABLE 4 ABOUT HERE

The difference in total assets (*DASSET*) has a negative and significant impact on the probability of forming an RJV, with a point estimate of -0.708. Using the definition of the variable DASSET above, this estimate implies that a firm is 15.37% less likely to form an RJV with another firm half its size, assuming that there are a total of 10 firms in the RJV[17]. Analogously, the estimated probability of RJV formation is reduced by some 23.06% 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 with another firm half its size is some 22.0% 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 32.99% higher than two firms that differ in size by a factor of four. In sum, size difference is a significant explanatory variable for RJV participation which implies that RJVs tend to be formed among firms of similar size. This, in turn, is consistent with the theoretical model developed above where it is the relative firm size that determines RJV formation, and larger firms do not want to participate in RJVs with smaller firms.[18]

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[16] Results from a probit-estimation are very similar to the results reported in Table 5. A Likelihood-Ratio Test rejects a model where the industry and the inter-industry dummies are aggregated at a 5 percent level.

[17] To compute this let $ASSET_i = k \cdot ASSET_j$, i.e. firm *i* is k times larger than firm *j*. Then, $\frac{\partial P_{ij}}{\partial DASSET_{ij}} = \alpha_1 \frac{k-1}{k} \Big/ ln(\# RJV)$, where α_1 is the point estimate given in Table 5.

[18] Note that the theory would also predict RJV formation amongst smaller (and of equal size) firms, since our theory has nothing to say about absolute firm differences. Adding a variable measuring absolute firm size in an RJV to equation (7) yields a negative and significant coefficient: there are actually more RJVs among smaller firms. This, however, does not contradict that larger firms would not participate with smaller firms.

The expected change in firm-level R&D intensities (*r&d)* has a positive and statistically significant effect on the probability of forming an RJV. The point estimate of *r&d* is 0.069, which implies that a one percent increase in r&d savings increases the likelihood of forming an RJV by some 0.07%. In other words, one of the motives 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. Since we observe the net impact of cost-sharing and free-riding on the R&D intensities, the above result suggests that the cost-sharing effect is more dominant in terms of incentives to RJV and it is a possible explanation for the small magnitude of the effect. In most companies in our sample the R&D investment in the RJV is a small portion of the firm's R&D portfolio. This also explains the small magnitude of the effect but makes it remarkable that statistically significant effects for RJV formation are obtained for this variable.

In order to test the complementarity hypothesis (iii) we now compare the intra-industry dummies (*SICs)* to the coefficients for the inter-industry dummies (*COMPs)*. As can be seen in Table 4, the point estimate for the "Petroleum and Coal Products" industry (*SIC29*) is 0.843, which is the largest significant estimate for an industry, followed by *SIC28* and *SIC13*. 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 0.005 (for *COMP2948)* to 0.795 (for *COMP3648)*. 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 the industries in our sample are simply too different in their technologies and/or products in order to engage in an RJV. In addition, as mentioned above, our data do not account for any other (asset or organizational) complementarities which may offset product market complementarities. Therefore, it is hardly surprising that we do not find product market complementarities between *all* industries.

However, we do find large statistically significant complementarities between some industry groups. In particular, the "Industrial Machinery and Equipment" (SIC35) displays relatively strong complementarities with "Electronic and other Electric Equipment" (SIC36) and "Communications" (SIC48). Complementarities are strongest between "Electronic and other

Electric Equipment" (SIC36) and "Communications" (SIC48): the likelihood of RJV formation between two firms coming from these two industries is 36% higher than for two firms coming both from "Communications" (SIC48). It is interesting to note that the highest complementarity effect exists between "Electronic and other Electric Equipment" (SIC36) and "Communications" (SIC48). These two industries appear to be subject to a number of vertical relationships, as electronic equipment is used extensively in telecommunications. Furthermore, communications protocols play a large role in the operations of electronic equipment. 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 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 which 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, 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 RJV is consistent with the theoretical model developed in the paper.

Our results are primarily positive rather than normative. However, the results of this paper suggest that there are conditions where there might be anti-trust concerns for RJVs. As we have shown (both empirically and theoretically) RJVs tend not to be formed when firms are of different size and produce similar products. In this case the larger firm does not participate with its rival. The welfare implications of this 'exclusion' outcome are however not obvious. A mean-preserving firm heterogeneity might increase welfare, as industry profits may increase by more than a possible reduction in consumer welfare. Internalization of spillovers and the associated free-rider problem imply social benefits of RJVs. Cost-sharing, however, may also have welfare reducing implications whereas RJVs between firms with complementary products are clearly welfare enhancing. Consequently, policies towards RJVs and the enforcement of those policies should take into consideration why firms are forming a particular RJV.

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 an RJV between firm *i* and firm *j*.	1388	0.500	0	1
DASSET	Measure of difference (between firms) in assets prior to forming an RJV (see the text for precise definition).	1388	0.847	0	1.999
r&d	The change (due to the RJV) in average firm-level R&D intensities (see the text for precise definition).	722	-0.370	-19.050	8.936
R&D	Averaged difference between two firms (one year before RJV formation minus the year of the RJV formation) in industry-level R&D intensities for the sum of the OECD (see the text for precise definition).	1388	-0.004	-0.545	0.746
MEMBERS	Logarithm of average number of participants in the RJV (see the text for precise definition).	1388	3.367	0.693	4.927

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	48 Communications
13 Oil and Gas Extraction	**6.20**								
28 Chemicals and Allied Products	3.60	**1.73**							
29 Petroleum and Coal Products	8.93	1.80	**1.01**						
32 Stone, Clay, and Glass Products	0.29	0.58	0	**0**					
35 Industrial Machinery and Equipment	9.87	0	6.05	0.65	**14.91**				
36 Electronic and other Electric Equipment	0	0	0	0	9.44	**2.67**			
37 Transportation Equipment	1.80	0	0	0.14	1.80	0	**0**		
38 Instruments and Related Products	0	0	0	0.14	3.67	0.43	0.22	**0.29**	
48 Communications	0	1.37	2.31	0	11.96	4.90	0	1.08	**2.16**

Table 2: R&D Intensities

Estimates of Equation (8) - Dependent Variable: *r&d*

Variables	Estimates	Standard Errors
R&D	0.988	0.584
MEMBERS	-0.614	0.179
SIC13	1.665	0.579
SIC28	2.024	0.893
SIC29	-0.326	1.166
SIC35	1.466	0.701
SIC36	2.952	0.936
SIC38	1.482	3.085
SIC48	2.396	0.954
COMP1328	1.919	1.841
COMP1329	1.386	0.555
COMP1332	2.009	3.112
COMP1335	2.469	1.057
COMP1337	2.367	1.707
COMP2829	2.773	1.707
COMP2832	1.596	1.605
COMP2848	3.355	1.969
COMP2935	1.811	1.269
COMP2948	3.094	3.179
COMP3235	2.479	1.850
COMP3237	1.034	3.076
COMP3238	1.999	3.105
COMP3536	1.684	0.801
COMP3537	2.072	1.622
COMP3538	2.426	0.866
COMP3548	1.781	0.755
COMP3638	2.614	1.838
COMP3648	2.687	0.887
COMP3738	2.293	3.099
COMP3848	2.153	1.592

NOBS=722; F-Value: 1.797; R-square: 0.0723.

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

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	48 Communications
13 Oil and Gas Extraction	**0.71*** **(0.55)** | **-0.64** **(0.72)**	-0.39 (1.87)	-0.92* (0.70)	-0.30 (3.12)	0.17 (1.05)		0.06 (1.69)		
28 Chemicals and Allied Products	0.97 (1.82)	**1.07** **(0.85)** | **-0.28** **(0.94)**	0.47 (1.69)	-0.71 (1.64)					1.05 (1.93)
29 Petroleum and Coal Products	0.43 (0.52)	1.82 (1.67)	**-1.28** **(1.15)** | **-2.63**** **(1.23)**		-0.49 (1.27)				0.79 (3.16)
32 Stone, Clay, and Glass Products	1.06 (3.10)	0.64 (1.59)			0.18 (1.87)		-1.27 (3.11)	-0.30 (3.12)	
35 Industrial Machinery and Equipment	1.52* (1.00)		0.86 (1.23)	1.53 (1.83)	**0.51** **(0.62)** | **-0.84** **(0.71)**	-0.62 (0.77)	-0.23 (1.65)	0.12 (0.88)	-0.52 (0.74)
36 Electronic and other Electric Equipment					0.73 (0.72)	**2.00**** **(0.86)** | **0.65** **(0.89)**		0.31 (1.87)	0.38 (0.84)
37 Transportation Equipment	1.42 (1.67)			0.08 (3.07)	1.12 (1.60)			-0.01 (3.12)	
38 Instruments and Related Products				1.04 (3.09)	1.47** (0.81)	1.66 (1.82)	1.34 (3.09)	**0.53** **(3.08)** | **-0.82** **(3.11)**	-0.15 (1.64)
48 Communications		2.40 (1.93)	2.14 (3.15)		0.83 (0.67)	1.74** (0.80)		1.20 (1.58)	**1.44*** **(0.89)** | **0.09** **(0.94)**

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

Table 4: Sources and Complementarities in RJV Formation

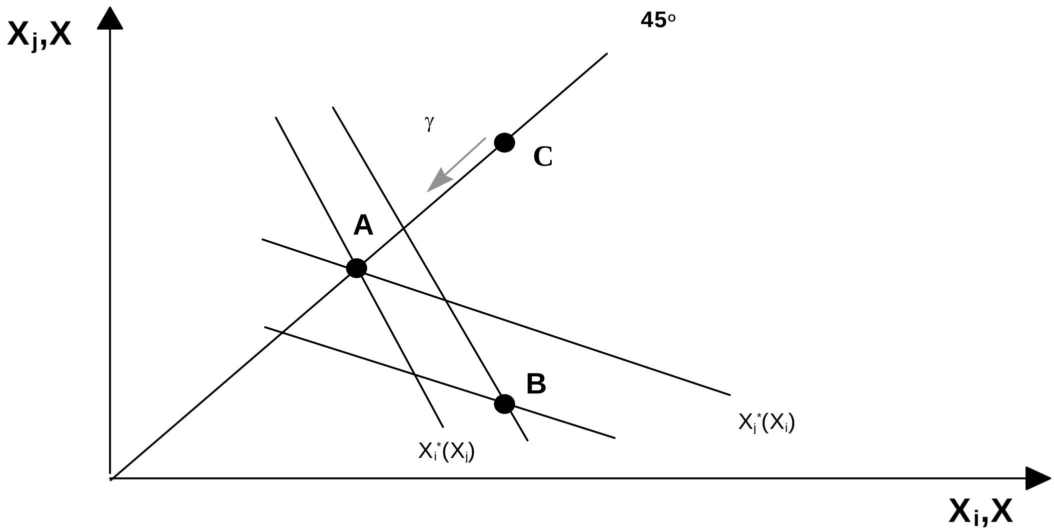
Logit Estimates of Equation (7): Dependent Variable: P_{ij}

Variables	Estimates	Standard Errors
DASSET	-0.708	0.068
r&d	0.069	0.029
SIC13	0.531	0.063
SIC28	0.704	0.385
SIC29	0.843	0.416
SIC35	0.488	0.051
SIC36	0.749	0.522
SIC38	0.708	0.999
SIC48	0.437	0.098
COMP1328	0.038	0.057
COMP1329	0.377	0.039
COMP1332	0.179	0.122
COMP1335	0.117	0.033
COMP1337	0.336	0.093
COMP2829	0.234	0.064
COMP2832	0.318	0.086
COMP2848	0.100	0.076
COMP2935	0.425	0.114
COMP2948	0.005	0.091
COMP3235	0.233	0.090
COMP3237	0.622	0.452
COMP3238	0.658	1.033
COMP3536	0.545	0.070
COMP3537	0.180	0.074
COMP3538	0.369	0.059
COMP3548	0.523	0.058
COMP3638	0.330	0.122
COMP3648	0.795	0.383
COMP3738	0.557	0.685
COMP3848	0.369	0.085

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 $\alpha_1 f(\overline{X}\alpha)$, where $\overline{X}$ is the sample mean of the exogenous. NOBS=1388; Score Test: 1074.149 (p=0.0001); the score statistics measures the influence of a combination of exogenous variables on the endogenous variable. Accordingly, our model is significant at a 0.0001 level; Log-likelihood: 809.167 (p=0.0001). Concordant=99.1%, Discordant=0.8%.

Figure 1

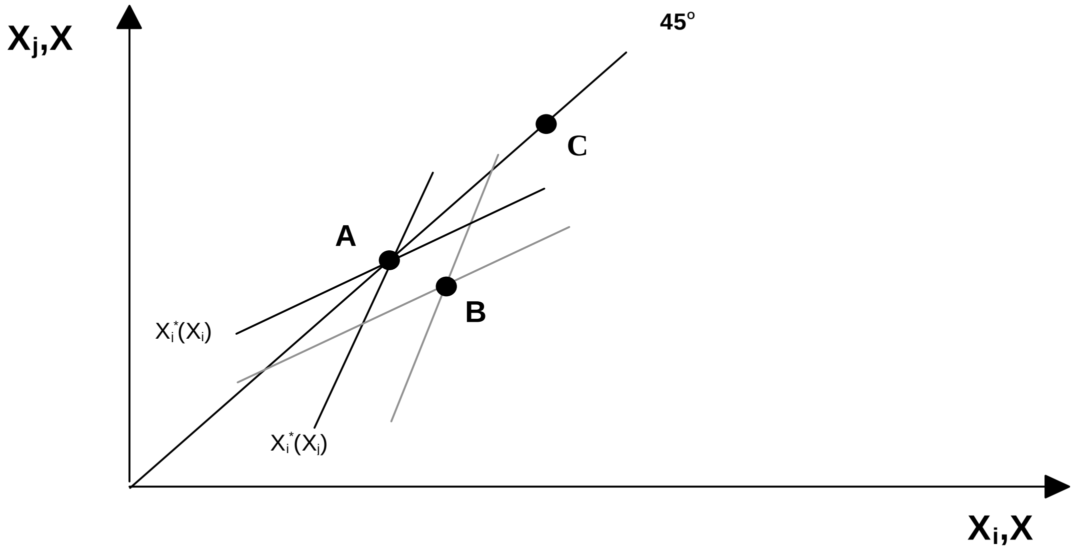
Effective R&D Investments: Substitutable Product Markets



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

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