

# VIRTUAL DIVERSIFICATION IN RESEARCH JOINT VENTURES\*

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Abstract: Firms can diversify by expanding internally, expanding by acquisition, or expanding "virtually" by cooperation. This paper studies the patterns of virtual diversification of firms which have joined a large number of US-based research joint ventures during 1985-1995. The patterns of diversification between participant firms and nonparticipants are found to be considerably different. Both are different from the patterns of virtual diversification in RJVs. Vertical integration has been the dominant type of cooperation and this paper graphs the cornucopia of linkages in the examined RJVs. The indicated linkages between suppliers and buyers have long been considered very important for successful technological innovation.

Keywords: Diversification; Cooperation; R&D; Research Joint Venture; Innovation

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## **§1. Introduction**

The causes and effects of business diversification form the basis of many interesting policy questions with respect to technological change. For example, Why and how do firms expand into new product markets? To what extent are the decisions for diversification in the private sector influenced by public policy? Are there any discernible patterns of business diversification? How do these patterns relate to the concerns of policy decision makers with industrial technological advance, on one hand, and the competitiveness of national/regional economies, on the other? How does diversification affect firm performance and, by extension, public welfare?

Firms can diversify by expanding internally (branching out), expanding externally by merger or acquisition, or expanding "virtually" by cooperation. This paper concentrates on the third type of expansion. We study the patterns of "virtual diversification" within a large number of research joint ventures (RJVs) formed in the United States from the mid-1980s to the mid-1990s. We examine the pattern of virtual diversification induced by the RJVs that were registered with the U.S. Attorney General during January 1, 1985 and December 31, 1995 in fulfillment of the requirements of the National Cooperative Research Act of 1984 — recently extended to the National Cooperative Research and Production Act (1993) (Vonortas, forthcoming, a). The patterns of virtual diversification are also compared to the patterns of diversification by individual firms including both those that have participated in the RJVs in question and those that have not.

We examine whether observed diversification in industry has been non-random and

whether the patterns of diversification of RJV participants have been different from the patterns of diversification of nonparticipants. We also bring together detailed information on the observed combinations of industrial activities within the RJVs in question and relate it to arguments in the available literature concerning the expected private benefits from cooperating in research and development (R&D) in order to appraise the incentives of firms to join the examined RJVs. Finally, we try to explain the most frequently observed pairs of industrial activities in RJVs through the prism of efficiency in technological innovation.

Such analysis is necessary because, with few exceptions, inter-firm cooperation in R&D has not been systematically analyzed as a form of business diversification.<sup>1</sup> This is unsatisfactory given that the literature on the rapidly expanding phenomenon of inter-firm strategic alliances has stressed the effort of partners to access complementary resources.<sup>2</sup> A reason for the omission may be the powerful impact of the traditional theoretical economic models depicting firms as "symmetric" producers of homogeneous products. Thus, research joint ventures (RJVs) — an important type of strategic alliance — have been studied in formal economic theory primarily as cost saving agreements and, secondly, as risk decreasing agreements.<sup>3</sup>

Business literature and science and technology policy literature, however, have emphasized a host of incentives for firms to participate in RJVs in addition to cost sharing and risk pooling including: accessing complementary resources such as technological knowledge, exploiting synergies in research, pooling resources to achieve a critical minimum mass, maintaining the necessary continuity for long term research, creating investment options that would be unattainable otherwise due to the high resource commitment requirements and/or

insufficient appropriability of the research outcome, and reducing research duplication. Resource complementarity and research synergy have been emphasized as probably the primary reasons why firms participate in RJVs.

In this paper, we recognize these diverse sources of incentives to join an RJV. We try to establish the patterns of virtual diversification across all industrial sectors in the United States with the help of what may well be currently the largest and most detailed database of its kind. We also try to get a handle on the very difficult question of potential systematic behavioral differences between frequent RJV participants and nonparticipants. We think the results should be of significant interest to economists, business strategists, and policy decision makers alike.

The paper is organized as follows. The second section provides a brief overview of the literature on business diversification. The third section outlines the research hypotheses. The fourth section explains our data set. The fifth section examines the evidence on diversification in view of the hypotheses laid out in section three. Finally, the sixth section concludes.

## **§2. Diversification: Incentives, Scope, Profitability**

The appraisal of industrial diversification has focused on three issues: the reasons for diversification, the direction (scope) of diversification, and the benefits (profitability) from diversification. The reasons for diversification proposed in the literature can be succinctly categorized into three groups focusing on (Montgomery, 1994):

(i) Expectations for additional profit via increased market power. Higher market power for the diversifying firm will be the outcome of cross-subsidization between markets, mutual

forbearance (less competition) due to the recognition of multi-market contact with competitors, and collusion to foreclose markets to new entrants.

(ii) Better use of resources. The resource-based view of the firm (Penrose, 1959) has stressed that the firm, characterized by its unique (difficult to imitate) collection of resources and capabilities, diversifies in order to employ more profitably its underutilized resources;<sup>4</sup>

(iii) Agent "misbehavior." Agency theory points out that the managers of a public firm (agents) may not behave in the best interest of the owners of the firm (principals) and divert from the ultimate objective of profit maximization. The agents may, instead, act self-servingly and try to govern larger, less risky conglomerates that may better suit their own skills.

Although firms have been shown to diversify in non-random ways (Teece et al., 1994), there is significant uncertainty in explaining the direction of diversification. Some apparent relationships have been established empirically. For example, there has been some evidence pointing to a relation between the resource base of firms — particularly in research and development (R&D) and marketing — and their choices of diversified expansion (Lemelin, 1982; MacDonald, 1985; Montgomery and Hariharan, 1991). This is reminiscent of the arguments founded in the resource-based view of the firm anticipating successful diversification to occur "close to home," in industries related to the core competencies of the expanding firm (Streitwieser, 1991; Leech, 1993).

While, in principle, this is a straightforward proposition, substantiating the implied causality from capabilities to patterns of diversification with more than anecdotal evidence and stylizing (modelling) the process is not. Consider, for example, Kodama (1995) who, in his study of the impact of superior technology on business expansion, takes issue with the typical

conceptualization of diversification as a spin-off process — essentially postulating that a technology is first developed for a high-end process and is subsequently extended to less technologically demanding, low-end goods. In environments where the codevelopment of product and process technologies is the norm, he argues, business diversification follows the opposite trajectory: technical knowledge is first developed and applied to low-end markets. Instead of a "trickle-down" process, the accumulated technology and production experiences in the low-end markets direct development toward high-end markets in a "trickle-up" process.

More complex explanations of the scope (direction) of firm diversification have been offered in the fields of institutional and evolutionary economics where a research priority has been to establish the boundaries of the firm. Teece et al. (1994), for example, have proposed that learning, path dependencies, technological opportunities, the selection (competitive) environment, and the complementary assets of the firm determine the firm's boundaries — i.e., they determine the incentives to expand (contract) and the direction of expansion (contraction). Though attractive because they are based on multi-directional effects, such explanations have depended until now on primarily anecdotal evidence.

Finally, our understanding of the benefits from diversification has been limited to external diversification, basically expansion by acquiring a firm or plant with an existing position in the desired product market.<sup>5</sup> On average, more diversified firms have been found less profitable, horizontal and especially conglomerate expansions have frequently resulted in loss of profitability, and many such acquisitions are later reversed (Mueller, 1985; Ravenscraft and Scherer, 1987). Although all forms of (external) diversification have experienced high failure rates, diversification into related industries has been proven the most profitable.

Overall, the resource-based view of the firm has appeared the most robust in consolidating arguments toward a more coherent explanation of the boundaries of the firm. Naturally, then, one wonders what the implications of this approach might be for "virtual" forms of diversification through inter-firm cooperative agreements (Mowery, Oxley and Silverman, forthcoming). In this paper, we concentrate on a specific form of cooperation involving collaborative R&D. An RJV will be defined as the formation of a new organization, jointly controlled by at least two parent firms, whose primary purpose is to engage in research and development activities. RJVs may involve equity investment. The examined group of RJVs is described in a subsequent section.

### **§3. Hypotheses**

If business expansion is non-random, firms will be expected to combine industrial activities methodically in order to benefit from technological economies of scope and from complementarities in R&D, production, marketing and distribution. In industries where operational flexibility is of paramount importance, however, strategic business planners worried about keeping their organizations lean may opt for less direct exposure by either internal or external growth and more indirect exposure through cooperation (asset sharing). It is expected that frequent participants to RJVs will be less preoccupied with purposively combining industrial activities internally than firms which do not use RJVs. In the least, the former firms should diversify differently than the latter. Therefore, if a measure of industrial "relatedness" can be devised to reflect the extent to which two industrial activities have already been combined:

*H1.* The "relatedness" of industrial activities as combined in individual firms will, on average, be lower for RJV participants than similar firms which do not depend on RJVs for diversification.

On the other hand, RJVs can be expected to be formed only if they provide sufficient benefits to participants to overcome the increases in administrative costs and decreases in control by any single firm they entail. RJVs will be put together only when the whole is expected to be bigger than the sum of the parts — that is, when there are significant expected complementarities to exploit (high purposive diversification). If RJVs are perceived as virtual organizations, the combinations of industrial activities achieved in RJVs must then be even more distant from a random pattern than the combinations in individual firms.

*H2.* The "relatedness" of industrial activities will, on average, be higher in virtual organizations like RJVs than in either the firms participating in these RJVs or non-participating firms.

Corollary. RJV participants will try to exploit complementarities and synergies in research.

It has been argued that virtual diversification by joining RJVs simply replicates (substitutes for) similar diversification within individual firms (Scott, 1988, 1993). While this alone does not automatically invalidate RJVs as a socially beneficial institution — there may still be long-term benefits from incentives due to scope economies and complementarities in R&D strengths — evidence to that effect raises the possibility that the "market power" approach

to diversification mentioned in the previous section may be more valid for explaining virtual diversification in RJVs than it has been for explaining diversification in individual firms. In particular, if, as Scott argues, multi-industry RJVs merely substitute for multi-industry firms, there is at least the possibility of a decrease in social welfare as a direct result of lesser competition in the presence of RJVs. Mutual forbearance and market foreclosure would, for example, be much easier to enforce by firms which "meet" in many markets (Van Wegberg and Van Witteloostuijn, 1995). For all this to be likely, the necessary (but not sufficient) condition is for virtual diversification through RJVs to be similar to the diversification of individual firms.

*H3.* RJVs allow patterns of virtual diversification which, although potentially useful for pursuing the specific type of R&D, are also typically observed in stand-alone firms.

The resource-based view of the firm has stressed the importance of firm-specific technological assets in determining the pattern of diversification of the firm. Accordingly, successful diversification should tend to involve industrial activities that are related to a firm's existing products and core competencies. There is no reason a priori why this should not also apply to firms diversifying virtually by joining in RJVs. We would expect that RJV participants will tend to diversify virtually in areas related to core activities.

*H4.* Firms often participate in RJVs which are related to their principal industrial activities.

Corollary. RJVs will attract firms in the same industry as the RJV or in very related industries.

On the other hand, however, RJVs may be used by firms as a fairly inexpensive and less risky way of opening up opportunities in new product areas. This "options" approach to the formation of RJVs complements well known arguments stressing the private benefits to RJV participants from their increased ability to access complementary resources and exploit research synergies (Tucci, 1996). We expect that collaboration in RJVs provides access to complementary resources and access to markets and that such access becomes even more important when firms are trying out new product areas and exploring new technological paradigms (Dosi, 1988).

*H5.* RJVs will be established frequently in industrial activities with no well defined (i.e., changing) technological paradigms.

The complementary resources brought together in RJVs will be intended to raise the efficiency of innovation (Sinha and Cusumano, 1991). Importantly, however, resource complementarity frequently does not only involve technical assets. It may also involve "information assets," including the ability of the suppliers and the users of an innovation to communicate effectively before the innovation is first introduced in the market. The link between suppliers and buyers of technologically advanced products has been stressed repeatedly to be very important for raising the efficiency of innovation (Von Hippel, 1988; Riggs and Von Hippel, 1994; Lee, 1996). If RJVs do indeed serve as vehicles of communication for efficient innovation, vertical linkages should be observed more frequently than horizontal linkages.

*H6.* Vertical partnerships will be observed in RJVs more frequently than horizontal partnerships.

Corollary. Vertical RJVs will tend to combine suppliers and buyers of the products expected to be the outcome of the collaborative research activity.

#### **§4. The Data**

In this paper we use information from the NCRA-RJV database which records publicly available information on *all* RJVs registered with the U.S. Department of Justice and the Federal Trade Commission under the National Cooperative Research Act (NCRA) of 1984 and its extension, the National Cooperative Research and Production Act (NCRPA) of 1993. The database also records information on the identified business firms that participate in the RJVs.

Vonortas (forthcoming, a) explains in some detail the contents of the NCRA-RJV database and the prevalent characteristics of the RJVs and their business participants.<sup>6</sup> Suffice it here to say that 575 new RJVs had registered between January 1, 1985 and December 31, 1995. The number of RJV registrations had increased at a yearly average rate of 17% during the examined time period. These RJVs and their business participants are the subjects of this investigation.

RJVs were classified arbitrarily on the basis of their technological focus as indicated in the statement of purpose accompanying the announcement of each RJV. In a few cases where the technology to be pursued collectively was difficult to classify more or less unambiguously,

RJVs were categorized to the industry in which the participants would probably expect to reap the benefits from collaboration.<sup>7</sup> For the needs of this paper, each RJV is classified under a single two-digit SIC industry, called the "technological field" of the RJV (table 1).

[TABLE 1 HERE]

Manufacturing (SIC 20-39) accounts for the majority of RJVs (63%). They are especially concentrated in two groups: one group is comprised of chemicals and petroleum refining (SIC 28-29) (16%); the other group is comprised of machinery and computing equipment, electronic and electrical equipment, transportation equipment, and measuring, analyzing and controlling instruments (SIC 35-38) (38%). Communications (SIC 48), business services (basically computer software) (SIC 73) and oil and gas extraction (SIC 13) also account for significant shares (17%, 8% and 6% respectively).

Excluding participation by individuals, 9,141 new memberships to these RJVs were accounted for during the examined 11-year period. About 90% (8,106) of these memberships have been positively identified (by cross checking in a number of commercially available sources of business information). These memberships corresponded to 3,447 entities, including firms, universities, nonprofit organizations, government agencies, and joint ventures that have been members of the examined RJVs. Eighty five percent of these entities (2,913) are business firms.

About three quarters of the identified entities (2,388) have participated in only one RJV. However, almost half (47%) of all identified memberships were accounted for by only 8% of the identified entities. Publicly traded corporations have been the most active participants: 1,024 of them have been positively identified (35% of all identified business entities) and they account for

4,505 memberships (56% of all identified memberships). Private firms in the database are also numerous, albeit considerably less active: 973 (28% of all identified business entities) are privately owned and account for 1,234 memberships (15% of all identified memberships).<sup>8</sup>

The analysis in section 5 takes into account the 1,318 identified business participants in the examined RJVs for which we have an industrial breakdown by primary and secondary SICs. The classification of the 977 public firms among them was taken from Compustat (11/29/96 version). The classification of the remaining 341 private firms was taken from CorpTech (June 1996 version).

## **§5. Analysis**

We use a two-pronged approach to diversification. First, a "measure of relatedness", based on all pairs of industrial activities observed in either stand-alone firms or RJVs, is used to infer diversification behavior. Second, two detailed "technology tables" are created allowing to address the Who-collaborates-in-what and Who-collaborates-with-whom questions respectively.

### 5.1. Industry Relatedness

In this section we examine whether firms diversify randomly, whether the firms which have chosen to participate in NCRA RJVs are different in terms of strategic behavior in creating competencies internally from those that have chosen not to participate, and whether RJVs put industrial activities together similarly to individual firms.

We draw on the methodology of Teece et al. (1994) to develop a "measure of

relatedness" between the elements of all pairs of four-digit SIC industrial activities observed in individual firms and RJVs. This measure is based on the survivor principle of Stigler (1968) according to which competition eliminates in time inefficient organizational forms. In accordance with Teece et al. (1994), then, we assume that "activities which are more related will be more frequently combined within the same corporation." (p. 5). We will interpret frequent meetings between two industrial activities to imply that the activities in question are highly related. On the contrary, infrequent meetings or no meetings whatsoever between two industrial activities will be considered to imply that the activities are unrelated.

Let  $K$  be the number of diversified firms in a population; that is, firms which are active in more than one industrial activities. Let  $I$  denote the set of four-digit SIC industries in the population. Let  $C_{ik}$  equal one if firm  $k$  is active in industry  $i$  and zero otherwise. Let  $m_k = \sum_i C_{ik}$  denote the number of industries firm  $k$  participates in — i.e., the number of industries firm  $k$  is classified in. The number of firms in industry  $i$  is, then,  $n_i = \sum_k C_{ik}$ . Given that all firms in the population are diversified,  $n_i$  is also the number of individual links involving industry  $i$  — simply put, the number of industry pairs with  $i$  as one of the elements. Then, the number of firms active in both industries  $i$  and  $j$  — or, equivalently, the number of time industries  $i$  and  $j$  meet in the examined population of firms — can be written as  $J_{ij} = \sum_k C_{ik}C_{jk}$ .

One way to create a *measure of relatedness* between any two industries  $i$  and  $j$  is by comparing the number of observed linkages between two industries  $i$  and  $j$ ,  $J_{ij}$ , to the number of linkages that would have been expected if firms diversified randomly (no relatedness between  $i$  and  $j$ ) given  $n_i$ ,  $n_j$ , and  $K$ .<sup>9</sup>

Let  $x_{ij}$  be the number of firms active in both industries  $i$  and  $j$  given that  $n_i$  and  $n_j$  are randomly chosen samples (without replacement) from the population of  $K$  firms. Then:

$$(1) \quad Pr[X_{ij} = x] = \frac{\binom{n_i}{x} \binom{K - n_i}{n_j - x}}{\binom{K}{n_i}}$$

$$(2) \quad \mu_{ij} = E(X_{ij}) = \frac{n_i n_j}{K}$$

$$\sigma_{ij}^2 = \mu_{ij} \left(1 - \frac{n_i}{K}\right) \left(\frac{K}{K-1}\right)$$

with

The postulated measure of relatedness is:

$$(3) \quad t_{ij} = \frac{J_{ij} - \mu_{ij}}{\sigma_{ij}}$$

This measure of relatedness between industrial activities  $i$  and  $j$  reflects the degree to which the observed linkage between the two activities exceeds the expected linkage if the assignments of industrial activities to companies were random.

We use four different populations of business entities in our calculations. Population A comprises the universe of diversified firms in our dataset (18,945 firms). It is composed of all publicly traded and diversified firms in the United States from the "active firm" file of

Compustat and a large number of public and private, high technology, diversified firms in the United States from CorpTech. Population N contains all firms in A which never participated in any NCRA RJV (17,992 firms). Population P contains all firms in A which participated in at least one RJV (953 firms). Population R contains 406 entities; these are the RJVs with at least two business firm participants with different four-digit SIC primary industries. RJVs are essentially treated here as (virtual) entities comprising only the primary industries of their members. In R, an industrial activity is counted only once if more than one firms in an RJV have declared it as their primary activity. This is so because we are interested in observing how industries are linked across RJVs.

Table 2 presents basic characteristics of the four populations, aggregate results concerning the relatedness measure, and the correlation coefficients for  $J_{ij}$  and  $t_{ij}$  between these populations.

[TABLE 2 HERE]

It should be stressed at the outset that the statistics for  $t_{ij}$  and  $J_{ij}$  are not strictly comparable across populations since both are sensitive to  $n_i$ ,  $n_j$  and  $K$ .<sup>10</sup> Nonetheless, Table 2 reveals a number of particularly interesting observations:

- (i) Business entities diversify nonrandomly, irrespective of population. The average  $t$  in all cases were significantly different than 0. A simple statistical test supported overwhelmingly that the difference is statistically significant at the 95% confidence level;<sup>11</sup>
- (ii) Firms in the aggregate population A are found to have, on average, similar diversification characteristics to firms which have not participated in NCRA RJVs (N population). This should be expected given that N firms make up 95% of the A firms;

(iii) Firms which have participated in NCRA RJVs (P) seem to follow on average different diversification patterns than nonparticipants (N). Relatively speaking, the former seem less purposively diversified than the latter as indicated by lower average  $t$ , much smaller spread of  $t$ , and lower standard deviation of  $t$ ;

(iv) Perceived as stand-alone entities, RJVs (population R) appear less purposively diversified than entities in any other group;<sup>12</sup>

(v) The correlation coefficients also underline the close association in terms of both relatedness of pairs of industries ( $t_{ij}$ ) and frequency of pairs of industries ( $J_{ij}$ ) between populations A and N. Significantly less association is indicated between populations N and P, especially in terms of frequency of observed pairs of industrial activities. The combination of industries in populations N and R is quite different.<sup>13</sup>

In order to check the validity of the above observations further, we also examined: (i) the most and least "related" pairs of industries in the four populations; and, (ii) the most frequently observed pairs of industries in each of the four populations. We found that A and N firms share 19 out of the 25 most related pairs of industries and 23 out of the 25 least related pairs of industries. On the other hand, P firms share no common pairs among the 25 most related pairs of industries with either A or N firms. P firms share 3 of the 25 least related pairs of industries with A and N firms. With only one exception between R and P, entities in R share no common pairs with either the most or least related pairs of industries with A, N or P firms. Moreover, A and N firms were found to share 23 out of the top 25 most frequent pairs of industries. N and P firms share only 5 and P firms and R entities share only 2 of the 25 most frequent pairs.

All evidence, thus, conspired in support of the argument that the diversification patterns

of firms that have participated in NCRA RJVs and those that haven't differ. Patterns of virtual diversification in RJVs are also different from the average diversification of both types of firms.

## 5.2 Patterns of Collaboration - Virtual Diversification

The objective of this section is to understand, at an aggregate level, Who collaborates with whom on what in NCRA RJVs. This is done with the help of two detailed "technology maps" based on the core (primary) industrial activities of RJV business participants. The first map, shown in Table 3 and Figure 1, interlocks the technological fields of RJVs and the core industrial activities of the RJV participants at the two-digit SIC level. The clustering by technological field addresses the Who-collaborates-on-what part of the question. The second map, shown in Table 4 and Figure 2, interlocks the core industrial activities of participants in all RJVs at the two-digit SIC level.<sup>14</sup> The information is then presented across industries. This clustering addresses the Who-collaborates-with-whom part of the question.<sup>15</sup>

[TABLE 3 & FIGURE 1 HERE]

One way of looking at Table 3 is as a kind of technology input-output table where the rows — corresponding to the core industrial activities of RJV participants — are the inputs and the columns — corresponding to the technological fields of RJVs — are the outputs. The number in a cell represents the number of memberships by firms whose primary industry is indicated at the beginning of the row to all RJVs classified in the industry indicated at the top of the column. The numbers in the final column to the right represent the sum of memberships across all RJVs by firms whose primary industry is indicated at the very left hand side of each

row. The numbers in the second row from bottom represent the sum of memberships by firms in all RJVs classified in the technological field indicated at the top of the column. The diagonal (shaded) cells indicate the number of memberships by firms whose core industrial activity coincides with the technological field of the RJVs these firms participate in.<sup>16</sup>

The most densely populated technological fields for NCRA RJVs have been business services (basically computer software) (SIC 73), communications (SIC 48) and electronic and electrical equipment and components (SIC 36). These were followed in some distance by chemicals (SIC 28), petroleum refining (SIC 29) and oil and gas mining (SIC 13). A third group is made of electrical machinery and computers (SIC 35), engineering services (SIC 87), and health services (SIC 80).

Firms in communications (SIC 48), machinery and computer equipment (SIC 35), and electronic and electrical equipment (SIC 36) have been the most active participants in NCRA RJVs. Firms in transportation equipment (primarily automobiles) (SIC 37), software (SIC 73), petroleum refining (SIC 29), chemicals (SIC 28), and scientific instruments (SIC 38) have also been very active.

The clearly distinguishable spike in Figure 1 corresponds to communications firms (SIC 48) participating in RJVs in the same field (843 memberships).<sup>17</sup> Machinery and computer equipment (SIC 35) and electronic and electrical equipment (SIC 36) producers have also been significantly active in communications RJVs. The most diverse and significant participation, however, has been in RJVs focusing on software (SIC 73). Firms with core activities in the SIC 73, 35, 36, 48, 37 and 38 industries have been particularly active in the latter RJVs.

The pattern of collaboration in R&D differs from industry to industry. Firms in

chemicals (SIC 28), petroleum refining (SIC 29) and software (SIC 73) have been very own-sector oriented in terms of the technological field of the RJVs they chose to participate in. On the contrary, firms in machinery and computer equipment (SIC 35) and electronic and electrical equipment (SIC 36) spread out their collaborative R&D effort to many fields. Firms in transportation equipment (SIC 37), instruments (SIC 38) and communications (SIC 48) have tended to be fairly narrowly focused to a few other fields beyond their own core industrial activity.

A tentative conclusion at this point would be that information technology has, by and large, led the activity for cooperative R&D in NCRA RJVs. This is an important conclusion given that information technology permeates the industrial structure of developed economies. It implies that cooperation in R&D is part and parcel of the more general trend in rapidly rising levels of inter-firm strategic alliances of all kinds driven by the rapidly rising costs, increasing complexity, and widespread awareness of the importance of information technologies in contemporary industry (Hagedoorn and Schakenraad, 1992; Vonortas and Safioleas, 1995).

We now turn to the who-collaborates-with-whom question. A number of observations concerning the construction of Table 4 and Figure 2 must be made before proceeding. First, all industrial links are weighed equally. For example, if an RJV lists firms A, B, and C as members, we count all three possible linkages in this RJV (AB, AC, BC) and give them equal weights (assume that all three firms cooperate equally extensively).<sup>18</sup> Second, the diagonal cells correspond to horizontal cooperation and the off-diagonal cells correspond to vertical cooperation. Third, linkages between two industrial activities are counted as many times as they have occurred in an RJV. If, for example, firms A and B in the RJV have the same primary

industry, both the AC and BC linkages are counted even though they are the same. This procedure is followed because we are interested in observing how many times two industrial activities have met in RJVs.<sup>19</sup> Fourth, the Table (but not the Figure) intentionally double counts entries. Because the rows and the columns are defined identically, either the upper or the lower half of the Table (always including the diagonal) contains all the information. It can be observed that the two halves are identical: taking any diagonal cell, the remaining row entries to its right (left) are identical to the remaining column entries below (above) it. Put differently, the information in the cells of a row is identical to the information in the cells of the column corresponding to the same industry. This is done for expositional reasons.<sup>20</sup>

[TABLE 4 AND FIGURE 2 HERE]

Firms in machinery and computer equipment (SIC 35), electronic and electrical equipment (SIC 36), communications (SIC 48), and software (SIC 73) have registered most cooperative R&D activity. The same industries have the highest rates of horizontal cooperation. Significant activity (more than 1,000 linkages) has also been registered by firms in chemicals (SIC 28), petroleum refining (SIC 29), transportation equipment (SIC 37), and instruments (SIC 38).

The closest cooperative relationship has been that between software (SIC 73) and machinery and computer equipment (SIC 35). Other strong cooperative relationships include machinery and computer equipment (SIC 35) and electronic and electrical equipment (SIC 36), electronic equipment (SIC 36) and software (SIC 73), communications (SIC 48) and computer equipment (SIC 35), communications (SIC 48) and software (SIC 73), electrical machinery and computer equipment (SIC 35) and scientific instruments (SIC 38), and so forth. If intra-sectoral

cooperation is added to inter-sectoral cooperation, one easily confirms the earlier conclusion that the production and application of information technologies have lead cooperation in NCRA RJVs.

It is interesting to note that manufacturing firms have tended to cooperate with other manufacturing firms at the same rate at which they have also cooperated with service firms. Horizontal cooperation among manufacturing firms has been slightly higher than horizontal cooperation among service firms. Finally, although horizontal cooperation has not been negligible by any means, it is vertical cooperation that has dominated industrial linkages in NCRA RJVs.

### 5.3 Interpretation of the evidence

The industrial relatedness evidence presented above largely supports the first hypothesis in section 3. There are significant differences between the diversification patterns of participant and nonparticipant firms. Although no causation has been proven, the  $t$  measures of relatedness signified that RJV participants are, on average, less preoccupied with purposively combining industrial activities internally than firms which have never joined an NCRA RJV. Moreover, the pairs of industrial activities with the highest and lowest degrees of relatedness as well as the most frequently observed pairs of activities were found quite different between the two kinds of firms.

The evidence does not support hypothesis 2. The relatedness between the primary industries of the RJV participants is lower on average than the relatedness of activities combined

in stand-alone firms, particularly nonparticipants. In terms of a measure of relatedness based on the "survivor principle", whereby the more often two industrial activities are combined the more related they are, one cannot claim that NCRA RJVs methodically combine the core activities (strengths) of individual members in ways that increase the relatedness between those activities.

The evidence does not support hypothesis 3 either. The results in section 5.1 show that the patterns of diversification in RJVs are not typically observed in stand-alone firms. There is little correlation between the measures of relatedness calculated for populations R and P and, even less, between populations R and N. At least in terms of the pairs of industrial activities at the highest and lowest levels of relatedness and in terms of the most frequently observed pairs, the firms that had never participated in any of the examined RJVs (N) taken as a whole were diversified very differently than either the firms that had participated in at least one RJV (P) or the RJV entities themselves (R). The evidence, thus, seems to contradict arguments that RJVs are just replicating what the individual firms would have done on their own anyway.

Hypothesis 4 is confirmed to a large extent by the information on Table 3 (and Figure 1). Firms in chemicals (SIC 28), petroleum refining (SIC 29) and software (SIC 73) were particularly inclined to participate in RJVs concentrating in their core activities. Firms in transportation equipment (SIC 37), instruments (SIC 38), and communications (SIC 48) also tended to be fairly narrowly focused to a few other activities beyond their core; those activities tended to be either directly related to the core activity or provide crucial inputs to the core activity of the participant.

For example, firms in transportation equipment (SIC 37) frequently joined RJVs focusing on software (SIC 73), electronic components (SIC 36), machinery (SIC 35) and chemicals (SIC

28) beyond those in their core industrial activity. Software and machinery provide necessary inputs in automating production, and electronic components and chemicals (under which new materials are mainly classified) relate to subcomponents for automotive vehicles and aircraft.

Firms in scientific instruments (SIC 38) often joined RJVs focusing on software (SIC 73), electronic components (SIC 36), and chemicals (SIC 28) beyond those in their own industry. Their strategy should not be a surprise: advanced computer software, electronics, and new materials are very important components of sophisticated instruments.

Firms in communications (SIC 48) often joined RJVs focusing on software (SIC 73) and electronic components (SIC 36) beyond those in their own industry. The importance of both computer software and electronic components for the creation of advanced communications systems cannot be overemphasized.

Finally, the observation that producers of machinery and computer equipment (SIC 35) and electronic and electrical equipment (SIC 36) spread out their collaborative R&D effort to many technological fields reflects the fact that computer hardware and electronic components have increasingly permeated manufacturing and service industries. Still, firms in these two industries most often joined RJVs focusing on software (SIC 73), electronic and electrical equipment (SIC 36) and communications (SIC 48) beyond RJVs in their own industry. The linkages are obvious.

Hypothesis 5 is largely confirmed by the finding that information technology and, to a lesser extent, biotechnology and advanced materials (featured in the group of chemicals) have been the dominant technological areas during the first eleven years of NCRA RJVs. Information technology, biotechnology, and advanced materials offered the highest technological

opportunities during this time period. In addition, these technological areas share two important characteristics that make them good candidates for the formation of RJVs.

First, all three areas have lacked well defined technological trajectories (routes of technological advance (Dosi, 1988)), save for narrow product ranges. This is most visible in information technology which can be defined as hardware and software with the capacity to identify, retrieve, store, process, and communicate words, numbers and images and to control and connect equipment and processes. As technologies converge, previously distinct boundaries between telecommunications, computing and mass media have become increasingly blurred, propelling the industrialized world into an age of high-capacity network computing, multimedia communications, and "information infrastructures." In a digital world, the networks used to transmit voice, data, and video can be unified in the same transmission systems and be connected to computing equipment. As a result, an ever expanding range of technologies and products fall under the term information technology including "... telephones, facsimile machines, computers, switches, compact discs, video and audio tape, coaxial cable, wire, satellites, optical fiber transmission lines, microwave networks, televisions, scanners, cameras, and printers as well as advances in computing, information, and networking not yet envisioned. .... [Beyond hardware and software, information technology] is also a system of applications, activities, and relationships. There is the information itself, whatever its purpose or form, e.g., video programming, scientific or business databases, images, sound recordings, library activities, or other media. There are also standards, interfaces, and transmission codes that facilitate interoperability between networks and ensure the privacy and security of the information carried over them, as well as the security and reliability of the networks themselves." (Department of

Commerce, 1995). One could argue that the areas of biotechnology and advanced materials have also been undergoing equally important redefinitions of their technological trajectories with the newly acquired capabilities for DNA/RNA sequencing and gene manipulation, on the one hand, and capabilities for building novel materials atom by atom to exact specifications, on the other.

Second, all three technological areas have "infrastructural" characteristics. That is to say, the underlying technologies in each area affect a wide array of industries ranging from agriculture, to mining, to manufacture, and services. Information technologies are the most "infrastructural" of the three, but the other two follow not very far behind.

The combination of very high technological opportunities, lack of well defined technological trajectories, and infrastructural characteristics makes information technology, biotechnology and advanced materials primary candidates for inter-firm cooperation in R&D. The evidence presented in this paper clearly indicates that firms are willing to join RJVs to "hedge their bets" against the very high technological and market risks involved. In fact, the implied effort of firms to create "technological options" by joining RJVs agrees with the finding reported above in relation to hypothesis 2 that the relatedness of industrial activities in RJVs is lower on average than the relatedness of activities combined in stand-alone firms. One is led to the conclusion that firms use RJVs as a less costly (and less risky) way of pursuing longer term, strategic R&D that will create the technological options of the future. It is in this "experimental" sense that one should perceive the anecdotal evidence pointing that firms try to exploit complementarities and synergies in research by joining RJVs, rather than the stable environment underlying the argument that led us to hypothesis 2.

It should be kept in mind that our measure of relatedness,  $t$ , is a survivor-based measure

judging the degree of relatedness between two industrial activities according to the number of times these activities have actually been put together by economic agents. Such a measure should be used with caution, to say the least, in cases of paradigmatic change when economic agents are more interested in how to be creative in making new combinations of activities and in opening up new technological pathways and market niches, and less interested in becoming more efficient in performing well established tasks. Although neither of these two strategies can ever be pursued totally independent of the other, the fact is that experimentation has been the dominant approach to innovation in information technology, biotechnology, and new materials during the examined time period. It is clearly reflected in the formation of NCRA RJVs.

Finally, the information in Table 4 (and Figure 2) goes a long way toward confirming hypothesis 6. Vertical integration is indeed the dominant type of cooperation in the examined RJVs indicating linkages among suppliers and buyers of products in the technological fields of the RJVs. In addition to any technical assets, the complementary resources brought together in RJVs often also include information assets such as those exchanged frequently between the suppliers and the users of an innovation. Users may participate in RJVs in order to influence the outcome of the research performed therein so that the final products/services fit their specific needs. Suppliers may use the RJVs as a vehicle for getting important customers on board early in the R&D process. The RJVs in question could therefore provide an additional venue for fostering close supplier-customer linkages. Such linkages have long been considered very important for successful technological innovation.

## **§6. Conclusion**

This paper presented evidence indicating that the diversification behavior of firms that have participated in NCRA RJVs is different from the behavior of firms that have not. Patterns of virtual diversification in RJVs are also different from both of these. All in all, this evidence contradicts the argument that NCRA RJVs may be detrimental to social welfare because they tend to replicate the combinations of industrial activities of stand-alone firms.

Information technology primarily, as well as biotechnology and advanced materials, have been the predominant technological areas underlying the formation of NCRA RJVs. The combination of very high technological opportunities, lack of well defined technological trajectories, and infrastructural characteristics makes these three technological areas primary candidates for inter-firm cooperation. Firms join RJVs to "hedge their bets" against the very high technological and market risks involved in these areas. They also join because they find RJVs to be a less costly (and less risky) way of pursuing longer term, strategic R&D to create the technological options of the future.

Vertical cooperation has been the dominant type of cooperation in the examined RJVs indicating linkages among suppliers and buyers of products and services in the technological fields of the RJVs. Like other forms of strategic alliances, then, RJVs seem to provide a venue for fostering close supplier-customer linkages which have long been known among business practitioners to be extremely important for successful innovation.

Vertical cooperation points out at least two additional sources of potential social benefit from NCRA RJVs. First, by facilitating supplier-customer linkages — thus making the innovation process more efficient — in the areas of information technology, biotechnology, and

advanced materials, RJVs may be creating significant social benefits given the pervasiveness of these technologies in contemporary industry. Second, vertical RJVs may help maintain markets that would disappear as a result of mergers and acquisitions to access information and control markets. Given the more permissive antitrust regime in the US since the early 1980s (Mueller, 1993), one could argue that a lot of this concentration would have gone unchallenged.

Both previous points need to be subjected to further scrutiny. For example, it would be extremely interesting to delve in greater detail into the red, yellow and blue sections of Table 4 to examine the patterns of manufacturing-manufacturing, manufacturing-services, and services-services R&D collaboration. The question of whether RJVs induce or inhibit competition, thereby affecting innovation, remains a most interesting issue in industrial economics and science and technology policy, particularly in light of significant evidence of multimarket contact through NCRA RJVs (Vonortas, forthcoming, b).

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## Notes

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<sup>1</sup> Needless to say, the business literature is rife with case studies of joint efforts to diversify. As is well known, however, generalizing from case studies is a treacherous procedure if not accompanied by systematic empirical analysis using formal data sets with large populations of joint ventures. The exceptions in the text refer to such analysis. They include Mowery, Oxley and Silverman (forthcoming) and Scott (1993). Kogut (1991) included all types of joint ventures in his analysis.

<sup>2</sup> See, for example, Harrigan (1986), Contractor and Lorange (1988), Mowery (1988), Link and Bauer (1989), Hagedoorn and Schakenraad (1990), Vonortas (1991), Coombs et al. (1996).

<sup>3</sup> See, for example, Joshi and Vonortas (forthcoming), Kamien, Mueller and Zang (1992), Katz (1986), Vonortas (1994).

<sup>4</sup> Stickiness and difficulty of imitation imply the market failure which Teece (1982) proposed must exist in transferring the economies a firm has managed to create through time.

<sup>5</sup> The reason for this focus has been the difficulty to obtain reliable information on internal diversification across large numbers of firms. This situation is not very satisfactory given that close to half of all entries in industry are accounted for by internal growth (Leech, 1992).

<sup>6</sup> Slight differences between the numbers presented in this section and Vonortas (forthcoming, a) are due to more complete identification of RJV members reported herein. The NCRA-RJV database is annotated regularly. Further information can be obtained from Nicholas Vonortas.

<sup>7</sup> Scott (1993) used this principle to categorize an earlier, much smaller sample of these RJVs.

<sup>8</sup> Another 877 business entities (30% of all identified business entities) accounting for 1,158 memberships (14% of all identified memberships) have been positively identified but we have no indication of their type. We expect the vast majority of them to be small, privately owned firms and, possibly, a few non-profit organizations. Finally, we have been unable to identify 896 entities with 1,035 corresponding memberships. The vast majority of them are also expected to be small private firms (and, possibly, a few non-profits).

<sup>9</sup> The conditional probability that a firm is active in industry  $j$  given that it is active in industry  $i$  is not a good measure of relatedness in this case because  $P(i/j) = P(j/i)$  a priori.

<sup>10</sup> It can be easily checked that  $n_i \uparrow \rightarrow J_{ij} \uparrow, t_{ij} \uparrow$ ;  $n_j \uparrow \rightarrow J_{ij} \uparrow, t_{ij} \uparrow$ ;  $K \uparrow \rightarrow J_{ij} \uparrow, t_{ij} \uparrow \downarrow$ .

<sup>11</sup> The test is  $T = \sum t_{ij} / \text{SQRT}(I(I-1)/2)$  which, under the assumption of independently distributed  $t_{ij}$ , is expected to be distributed normally. ( $I$  is the set of industries  $i$  and  $j$ .)

<sup>12</sup> The calculations on the R sample were also run by including the secondary industrial

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activities of participants. The results for the modified population R/S were similar to those reported for R in Table 2. With secondary industries included, we had 554 virtual entities in R with the following statistics: average  $t_{ij}=3.7385$ , max  $t_{ij}=23.4947$ , min  $t_{ij}=-8.1060$ , st.dev.  $t_{ij}=3.5774$ , var.  $t_{ij}=12.7979$ .

<sup>13</sup> When the R population was modified into R/S (footnote 12), the correlation coefficients between R/S and A, N, and P increased by approximately 53% for  $t_{ij}$  and 64% for  $J_{ij}$ . As can be deferred from Table 2, however, even such increases left the pairs of industries between R/S and A, N, and P very different.

<sup>14</sup> The appropriateness of classifying diversified firms on the basis of primary industry alone can be questioned to the extent that larger companies may combine very different lines of business even at the two-digit SIC level of aggregation used here. The primary industry classification was maintained on two considerations. First, the numbers in the cells of Tables 2 and 3 become very large and unwieldy when secondary industries are included. Second, these numbers are of dubious interpretation anyway in the absence of industry weights for individual firms. The large number of entries was expected to help average out misrepresentations.

<sup>15</sup> In constructing both Tables 3 and 4 (and, thus, Figures 1 and 2), all joint ventures participating in the examined RJVs have been broken up to their respective members.

<sup>16</sup> Note that different memberships of the same firm may be included in different cells.

<sup>17</sup> This number reflects the very extensive participation of Bellcore in the examined RJVs. As in the case of all joint ventures in this section, Bellcore was broken up into its constituent members (seven local Bell companies).

<sup>18</sup> Clearly, this is an oversimplification. The RJV type, RJV size, the type of the participants, the status of the participants within an RJV, and the technological field of an RJV may have a significant impact on the individual industrial linkages. In addition, our focus on the primary industrial activities of the participating firms is also not entirely satisfactory; see footnote 14.

<sup>19</sup> This procedure is different from that followed in constructing the R population of entities in Section 5.1. The question of interest then (what activities are brought together in RJVs) was different from the current question.

<sup>20</sup> Suppose for a moment that only the lower left area of Table 4 was presented. Suppose one is interested in figuring out the total number of linkages of a certain industrial activity A with self and all other industrial activities — meaning the linkages of firms that have industry A as their core activity with others whose core activity is A or anything else. Then, one would need to add the cells of the row (corresponding to industry A) and the cells in the column (also corresponding to industry A). Duplication (filling up the other half of the table) allows one to read across any row or column for the total number of linkages of RJV participants that have the same core industrial activity.