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HOW DO CONSORTIA ORGANIZE
COLLABORATIVE R&D?:
EVIDENCE FROM THE NATIONAL
COOPERATIVE RESEARCH ACT

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How Do Consortia Organize Collaborative R&D?
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Abstract

This paper uses contract-level data to presents stylized facts about how firms organize collaborative R&D agreements. It finds several dominant modes of collaboration, including outsourcing R&D, specialization and separation of R&D activities, and more integrated "learning" approaches. It also finds that when consortia participants are direct competitors in existing product markets, they are more likely to outsource their "collaborative" R&D. The results suggest that many consortia organize to avoid spillovers, and therefore do not achieve the cross-pollination of know-how the National Cooperative Research Act was designed to achieve.

Keywords: Collaborative R&D, Research Joint Ventures, Contracts

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I. Introduction

Collaborative R&D agreements have often been considered an important policy tool to stimulate innovation. They may reduce costs by eliminating duplicative R&D efforts, by achieving economies of scale, or by enabling synergies. At the heart of the debate over the impact of a pro-collaborative R&D industrial policy is the role of spillovers and the question of whether they stimulate or discourage research spending (Spence, 1984; Katz, 1986; D'Aspremont and Jacquemin, 1988; Kamien, Muller, Zang, 1992). On the one hand, eliminating duplicative spending lowers the costs of innovation and frees up resources to spend elsewhere. On the other hand, enabling spillovers invites not only shirking but also deliberate efforts by collaborative R&D participants to appropriate their partners' technology. How firms structure R&D agreements to avoid unintended spillovers and free-riding while achieving the benefits of collaborative R&D is an open question.

The fear that know-how generated by one partner in an alliance could be misappropriated by other partners is a central concern of joint venture and alliance participants. For example, participants of the Japanese VLSI consortium (often cited as the paramount example of a successful consortia) were reluctant to send engineers to a joint R&D facility (Ouchi, 1984). In another case, members of the MCC consortium (one of the most well known U.S. consortia and a precursor to Sematech) expressed concern and hesitation that a mechanism of opting-in to particular R&D projects through employee rotation and financial contributions would enable spillovers to firms in other MCC projects (Gibson and Rogers, 1994). At least initially in both of these cases, some firms preferred consortia mechanisms whereby members strictly contributed R&D from in-house facilities, and employee rotation was severely limited.

Whether R&D collaborators typically structure their mechanisms with co-located R&D or arms-length transactions is an issue that has not been explored in the industrial organization literature. Models examining the welfare consequences of R&D consortia either assume that firms choose how much R&D to conduct knowing the precise extent of the spillover externality, or assume that the participants precisely choose the level of inter-firm spillovers when they design the agreements. These models permit no scope for unobservable spillovers or spillovers that occur beyond the bounds of the defined project. In addition, because these models focus strictly on competition between (all) joint venture collaborators in a pre-defined product market, they ignore dynamic competition and the prospect of "learning" among current-day differentiated firms that would impact the development of future technologies. Consequently, the models make assumptions about the nature of spillovers and the nature of participants that do not necessarily reflect how these deals are actually structured. The data suggest that the welfare analyses altogether miss modal collaborative R&D mechanisms.

This paper empirically explores how firms organize collaborative R&D agreements. Empirical exploration of the detailed mechanisms employed in collaborative R&D agreements has been rare due to difficulties in accessing contract-level data. While recent scholarship has explored the structure of bi-lateral firm agreements in competitive industries (Ryall and Sampson, 2004; Lerner and Merges, 1998; Elfenbein and Lerner, 2003; Lerner and Malmendier, 2003), contract-based information on multilateral consortia agreements has not been previously available. Consequently, analyses of the question most explored in the theoretical literature on consortia – the effect of product market competition between R&D collaborators on R&D contributions – has been limited to surveys of participation motives (Sakakibara, 1997a, 1997b) or examinations of outputs, such as R&D spending and patents (Sakakibara, 2001; Branstetter and Sakakibara, 1998), rather than an exploration of collaborative R&D mechanisms.

This paper makes a first attempt to fill the gap between theory and evidence regarding how firms organize collaborative R&D, particularly in multi-firm environments. I first characterize key contractual provisions of the collaborative R&D agreements of alliances and consortia that have registered under the National Cooperative Research Act. I then relate the findings to the theoretical treatment of collaborative

R&D. I use cluster analysis to find several canonical 'types' of mechanisms. I then examine the effect of both spillover potential (technological appropriability) and product-market rivalry on the choice of mechanisms. I find evidence that when collaborative agreements involve firms that compete in downstream markets, they tend to outsource their collaborative R&D to a third party. By outsourcing, firms benefit from shared costs and a reduction in duplicative efforts and, I argue, avoid spillover and opportunism problems. I also find that many consortia are organized with separation of different phases of research at different firms' facilities and little activity one would typically think of as "collaboration." The implications are that many consortia R&D agreements involve extreme measures to avoid spillovers and therefore involve little prospect for synergy. The types of R&D consortia mechanisms I observe tend to be outside the canonical mechanisms considered in industrial organization theory.

The paper proceeds as follows: Section II discusses the theory. Section III details the National Cooperative Research Act and the rise of independent research organizations. Section IV describes the data employed. Section V contains analyses, and Section VI concludes.

II. Background Literature Pertaining to the Design of Collaborative R&D Governance Mechanisms

Much of the focus of industrial organization models examining collaborative R&D has centered on the significance of product market competition and how product market competition alters the incentives of collaborative R&D partners (who are product market rivals) to contribute R&D. These models examine cost-reducing R&D and associated spillovers that reduce partners' costs. Collaborations among product market competitors may cause firms to reduce their R&D expenditures because each firm's research contributions lower its partner's (rival's) costs, and therefore may lower equilibrium prices (Katz, 1986).

While several of the papers acknowledge the potential for product differentiation, the models typically assume that innovations reduce costs symmetrically among the participants. As a result, the models make most intuitive sense when firms are direct product market competitors, and product differentiation is minimal. For example, in the model of Kamien, Muller, and Zang (1992), the symmetry in cost reduction leaves no room for differential absorption of technology either by systematic effort to absorb new information (Doz and Hamel, 1998; Hamel, Doz, and Prahalad, 1989) or by differential abilities to absorb new skills (Cohen and Levinthal, 1989; Mowery, Oxley, and Silverman, 1996).

Some scholars have made a greater attempt to acknowledge differential rates of benefits from R&D spillover externalities, or vertical relationships in product markets among collaborative R&D participants. Katz (1986) allows for the effect of a cost-reducing innovation to impact partners differently, but interprets the impact on costs as an indicator of the degree to which firms are product market competitors. Choi (1992) models the rate of innovation when two firms are vertically related both in R&D and product space. In his model, partners contract over collaborative R&D taking into account post-innovation bargaining over licensing. He finds that when contractible and non-contractible assets become more complementary, cooperative R&D becomes more sustainable.

The degree to which firms are "horizontally" related in R&D contributions or R&D capabilities has not been explored much in practice. Clearly, vertically differentiated firms with different research proficiencies should co-specialize when collaborating on R&D. However, even firms that have comparable R&D capabilities may wish to specialize in different aspects of the collaborative R&D design in order to avoid the spillover externality. At the extreme, Katz (1986) notes that if spillovers are perfect and equal (implying that firms are direct product market competitors) then firms may simply choose to contract out the R&D to a third party, and split the costs evenly. The outsourced R&D mechanism works best when product market rivalry is high because it short circuits the outcome where firms all shirk in equilibrium.

The tension between specialization and more collaborative organizational mechanisms between cooperative R&D participants has gotten relatively little attention in the industrial organization literature. The management literature, in contrast, has noted the benefits and risks of specialization. While specialization among complementary input providers has obvious benefits, co-specialized firms can experience difficulty in valuing each others' contributions ex ante, in monitoring each others' performance, and in using the alliance as an opportunity to learn complementary skills from their partners (Doz and Hamel, 1998). On the other hand, even if alliances are intentionally designed to facilitate know-how transfer, knowledge exchange can be difficult to achieve because important know-how may be sticky (von Hippel, 1994) or tacit (Polanyi, 1962; Winter, 1987). Consequently many factors influence the decision whether specialization or greater R&D integration is the preferred mode for a given collaborative R&D agreement.

In practice, mechanisms that implicate know-how transfer range from locating scientists in joint facilities, to enabling employees to revolve across facilities, and to licensing technology developed prior to the venture ("background IP"). In contrast firms can design collaborative R&D mechanisms to distance themselves and limit know-how exchange, for example, by maintaining R&D labs in separate facilities and engaging in ex ante cross-licensing of venture R&D, or by outsourcing their R&D to third parties. While these choices may be broadly consistent with theoretical models that assume that firms design their consortia to achieve a particular level of spillovers, factors beyond product market rivalry are relevant. For example, the ability of firms to engage in ex post hold-up (Williamson, 1985) should implicate whether firms choose a more open mechanism for knowledge exchange. Another central concern is whether firms can opportunistically misappropriate the technology of their partners and use it outside of the construct of the joint venture.

The ease of appropriation or misappropriation of know-how involved in collaborative R&D depends upon the characteristics of the underlying technology. For example, firms in cumulative technology industries such as semiconductors, where innovations rest upon prior innovations and products infringe numerous patents (Grindley and Teece, 1997), may refrain from misappropriating their partner's technologies because they will be disciplined when they negotiate later deals with the same partner. This argument suggests that firms in cumulative technology industries might be less likely to worry about IP spillovers through intentional misappropriation and more likely to engage in co-located R&D.

On the other hand, several papers have suggested that intellectual property rights are difficult to enforce in certain industries, notably electronics, due to ambiguity in the patent claims constructions (Merges and Nelson, 1990). Consequently, firms in industries noted for weak property rights, such as electronics, tend to favor trade secret to patents as a way of protecting their intellectual assets, whereas firms in strong property rights industries, such as chemicals, tend to use relatively more patent protection and relatively less trade secrecy (Levin, Klevorick, Nelson, and Winter, 1987). This argument would suggest that firms in electronics might be less likely to engage in co-located collaborative R&D than firms in the chemicals industry because it is more difficult to protect their intellectual property.

In this paper, I examine the types of mechanism firms use to establish some benchmark stylized facts, and relate this to the literature. I also explore how rivalry and appropriability influence the types of mechanisms consortia participants use. This study of consortia mechanisms is not definitive due to data selection issues. First, I have no way of knowing whether consortia filed under the National Cooperative Research Act are representative of all consortia in the world. Indeed, the number of consortia that file under NCRA are significantly less than the number of joint ventures found by Hagedoorn (2002) in the internationally-focused CATI data.[1] NCRA participants benefit from reduced damages should they be found guilty of violating U.S. antitrust laws. Consequently, there is no benefit to filing for NCRA protection if the joint venture participants are engaged solely in commerce outside the United States. Second, as described further in the Data section, only a subset of NCRA participating consortia have provided contractual documents to the Department of Justice and the Federal Trade Commission as part of their filing. For both of these reasons, my description of how

[1] Both the time distribution and industry distribution of NCRA ventures submitting contracts are roughly comparable to the time and industry distributions of international research joint ventures in the MERIT/CATI data collected by John Hagedoorn (2002).

firms organize collaborative R&D is not the final word. It is, however, one of the only systematic attempts to document how firms organize consortia R&D (see also Majewski and Williamson, 2004). Moreover, even without a universe of contract types, the data suggest much more nuanced issues in the formation of collaborative R&D agreements than has been acknowledged in the theory.

III. The History of Consortia in the United States

The National Cooperative Research Act

Unlike Europe and Japan where government initiatives have both created and fully funded large multi-firm research consortia as part of industrial policy (such as VLSI in Japan and ESPRIT in Europe), the U.S. government has taken a less central role. There are two primary programs that promote collaborative R&D in the U.S. First, the U.S. government partially funds collaborative research and development by extending limited federal matching funds and grants through agencies such as the National Institute of Standards' Advanced Technology Program and the National Institutes of Health. In these cases, the government does not propose initiatives, rather, firms appeal to the agencies for partial federal funding. Second, the U.S. offers reduced antitrust liability to qualifying joint ventures pursuant to the National Cooperative Research Act and the National Cooperative Research and Production Act.

The National Cooperative Research Act (NCRA) was passed by Congress in 1984 in response to concerns that U.S. firms were loosing their industrial competitiveness in global markets because they avoided cost-saving collaborative measures due to fears of domestic antitrust enforcement. Justifications for extending reduced antitrust liability to firms in collaborative R&D ranged from cost savings through reduced duplication of research, to economies of scale in R&D, and cost-sharing.[2]

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2 *"Joint research and development, as our foreign competitors have learned, can be procompetitive. It can reduce duplication, promote the efficient use of scarce technical personnel, and help*

The NCRA limits antitrust liability to participating joint venture firms, and clarifies that antitrust analysis of research joint ventures is limited to the rule of reason rather than the *per se* illegality rule. In compliance with the Act, joint ventures that provide the antitrust agencies (Department of Justice and the Federal Trade Commission) a roster of their membership and statements of purpose and that pass an initial screening qualify for reduced antitrust damages should they subsequently be convicted of violating the antitrust laws.[3] The Act was amended in 1993 to include firms involved in production joint ventures as well, and was renamed the National Cooperative Research and Production Act (NCRPA) of 1993. From the Act's inception in 1984 to date, 942 joint ventures have registered their activity with the Agencies.

The Development of Independent Research Organizations

Few consortia existed in the United States prior to the passage of the National Cooperative Research Act because antitrust enforcement was often perceived as hostile to joint ventures (Gibson and Rogers, 1994). Those consortia formed prior to 1984 tended

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to achieve desirable economies of scale." Statements of Congressman F. James Sensenbrenner, Jr., House of Representatives Report 98-656.

"I think it fair to say that even among those who believe that our antitrust laws do not—or at least under reasonable application should not—inhibit cooperation in R&D, there is general agreement that many business executives perceive such laws as significant barriers to joint research. They thus shy away from such activities—and, over the long haul, our country is the loser." Testimony of Mr. Steven Olson, Associate General Counsel of the Control Data Corporation, as summarized in Senate Report No. 98-427, P.L. 98-462.

"[T]he U.S. is suffering from a wasteful duplication of research and development efforts… This is especially valid in light of our critical shortage of competent scientific and engineering talent." Testimony of Mr. William C. Norris, Chairman of the Control Data Corporation, as summarized in Senate Report No. 98-427, P.L. 98-462.

"[T]oo much of the industrial research performed focuses only on shorter-term applied research driven by industry's need for immediate return on investment. By pooling resources, companies can afford longer-term research—the fruits of which will be employed to assure our industrial competitiveness worldwide." Testimony of Mr. Peter F. McClosky, President of the Electronics Industries Association, as summarized in Senate Report No. 98-427, P.L. 98-462.

3 Limited liability extends not only to Federal antitrust cases but to private antitrust cases as well. See Addamax Corporation v. Open Software Foundation, Inc., Civ. A. No. 91-11152-JLT., May 19, 1995.

to be in regulated industries, such as in natural gas (GRI, the Gas Research Institute) and electricity (EPRI, the Electrical Power Research Institute), where regulation of prices should have reduced the concern of anticompetitive behavior. After the National Cooperative Research Act was passed by Congress, a trend toward establishing independent research houses seems to have taken place. I refer to the organizations as "independent research organizations" because they often run many different projects funded by different firms, and often are not directly founded by the firms themselves.

Table 1 lists a number of organizations dedicated to conducting or coordinating multiple simultaneous R&D projects for members who opt-in to specific R&D programs. The majority of these organizations were formed after the passage of, and seemingly in response to, the NCRA. These independent research houses tend to be organized as not-for-profit entities that either conduct R&D at their own dedicated facilities, or coordinate R&D conducted by member firms at the firms' home facilities. Whether an R&D project involves research conducted by members or at the members' facilities, and whether R&D personnel revolve between the firms and the consortium facility generally varies from project to project. In many cases within the data, the same independent research house will run multiple projects using different mechanisms. This empirical analysis of consortia contracting mechanisms examines specific R&D projects on a case-by-case basis. I examine any R&D project that filed for protection under the NCRA, engaged in research, and included contractual documents in their filing.

Table 1 is meant to be suggestive of the types of organizations alliance partners may use to outsource their R&D projects. It is not exhaustive, however. For example, the data indicate numerous occasions where alliance partners effectively outsource their R&D project to a for-profit company. The purpose of Table 1 is to indicate that the NCRA appears to have sparked a trend toward the creation of independent research organizations, and that these independent research organizations sometimes conduct all the "collaborative" R&D of a given outsourced research project.

IV. Data

The question this paper poses is "how do consortia organize collaborative R&D?" To tackle this question, it examines the detailed contractual provisions of the 142 R&D joint ventures and consortia that submitted their contracts as part of the application process when they registered with the Department of Justice under the NCRA and the NCRPA. Only 15% of joint ventures registered under the NCRA[4] submitted their contract documents to the Agencies during the review process. The data includes all cases where firms submitted their contracts in the filing. The fact that this sample of joint ventures submitted their contracts to the agencies may indicate that their lawyers were overly cautious and overly inclusive. It may also indicate that the Agencies' staff requested the information. Interviews with numerous government officials indicate there is no *a priori* reason to believe that NCRA files containing contracts were systematically different from NCRA files that did not include contracts. The relative distributions of all NCRA joint ventures and NCRA joint ventures that supplied their contracts are roughly comparable over time (see Figure 1).

While U.S. consortia are not created by and funded entirely through the government, as is the case in Japan (Sakaibara, 2001), roughly 37% of NCRA consortia in the sample had some relation with a government agency. These ranged from consortia that received government funds through the National Institutes of Standards Advanced Technology Program (ATP), to consortia filing for NCRA status prior to bidding on a Department of Defense (DOD) contract, to consortia that included some research conducted at a national laboratory (usually under contract with the Department of Energy). Government contact with a consortium could, in theory, influence its organizational structure. For example, the ATP program is designed to bring together complementary technology holders to do relatively more basic research. ATP contracts

[4] Throughout the remainder of the paper I refer to filings under both NCRA and NCRPA collectively as "NCRA."

should be unlikely to be outsourced, and more likely to involve firms that are not product market rivals.

Nearly one-third of the consortia in the sample had a university (21%) or national laboratory (7%) as a member. University and national lab participation suggests that these consortia involved stages of research that were relatively more 'basic' and pre-development stage. Firms involved in more basic research should have less concern that product market rivalry would lead to shirking (see Table II).

Although the modal consortium in the sample concentrated on development of software, NCRA consortia involve R&D in both "high tech" and "low tech" industries. Additionally, environmental remediation or compliance initiatives were strongly represented in the sample in the form of consortia in automotive emissions, petroleum refining, and bioremediation. Table III breaks down consortia observations by technology.

Data on contract mechanisms and parties involved were coded by the authors in prior work (Majewski and Williamson, 2004) by reading the text of contracts. The rivalry measure is the sum of squared shares of the primary industries (based on SIC codes) of consortium participants, and is the inverse of the diversity measure used by Montgomery (1982) and Sakakibara (2001, 1997a). To construct this variable I collected the 4-digit primary SIC code of each venture participant in the year of the contract agreement using Compustat. Where data was unavailable in Compustat, current-year primary SIC codes were found by searching Nexis-Lexis sources, primarily the Directory of Corporate Affiliations and the OneSource(R) CorpTech(R) Company Database, matching both company name and address information. I was unable to collect SIC codes for every alliance partner in some cases, as a result the sample size dropped to 127 alliances for analyses using the rivalry variable. Table IV summarizes the data collected on contract mechanisms, number of participants, and rivalry.

V. Analyses and Results

A. Collaborative R&D Organizational Mechanisms

I employ cluster analyses to find representative "types" of consortia agreements. The advantage of cluster analysis is that by using mathematical algorithms for matching observations, the analysis chooses groups according to an objective criterion. The disadvantage of cluster analysis is that the objectivity of algorithms can lead to nonsensical clusters, or to generally sensible groupings of data containing incorrectly placed observations. In addition, cluster analysis requires substantial discretion on the part of the researcher regarding inclusion of variables to avoid the algorithm stratifying observations in illogical ways (Everitt, Landau, and Leese, 2001). Most notably, researchers are advised not to over-include variables, which may result in "masking" variables confounding results. Consequently, I present the cluster analysis as a starting point toward understanding the types of mechanisms firms employ.

To tackle the obstacle of "masking variables" I choose a reduced set of variables that target contract terms contemplated by the industrial organization theory, theories suggesting knowledge-exchange or "learning," and theories regarding spillover control and shirking. To examine more horizontal modes of collaboration, I include whether firms split costs evenly, and whether they engage in profit sharing. Regarding the learning theory, I look at whether scientists rotate across firms, and whether firms license their background IP to each other. I also look at issues regarding IP spillover control and shirking. These variables are whether the ventures outsource their R&D to a third party, and whether firms retain hold-up power on the ability of their partners to license venture-related IP. Lastly, I examine whether the collaboration is structured as an equity joint venture because equity participation is thought to align incentives and reduce the threat of opportunism in the transactions cost economics literature (Williamson, 1985; Oxley, 1997).

I employ a k-means analysis. K-means algorithms recursively add and subtract members to groups until within group distances are minimized (and between group distances are maximized) by minimizing the sum of squared errors by variable and by group. I use the sum of the first five principal components as starting values for the K-means algorithm. F-tests based on the sum of squared residuals between each observation and its group centroid suggest that five groups are appropriate. Table V details the contractual terms for each of these five clusters.

The dominant feature of Group One is that the majority of its observations involve R&D outsourcing, and so I title this group “Outsourced R&D.” A high proportion of ventures in the sample outsource the majority of their R&D to a third party, 56 of 128 (43%). The dominant mechanism for outsourced R&D agreements is for firms to split costs equally (98%), and for firms to share profits resulting from the innovations (54%). The fact that many ventures outsource R&D and split costs, but do not share profits appears to be primarily attributable to ventures involving process innovations, such as in the petrochemicals industries, where the venture participants may not intend to market their innovations because the only likely buyers would be competitors. The results also indicate some more nuanced modes of organization. Five of the 56 outsourcing ventures (9%) also allow personnel to revolve between firms, and 4 of 56 (9%) involve licensing of background intellectual property to either member firms or the outsourced researcher. This suggests that in some cases, consortia members outsource a portion of their R&D, but continue to work internally on other aspects or parallel aspects of R&D.

Group Two is largely composed of firms that do research for the venture (do not outsource) and license background intellectual property rights to their partners for the purpose of research (not commercialization). One interpretation of this cluster is that the background IP licensing facilitates idea exchange and learning. Consistent with the learning hypothesis, four of the 24 collaborations (17%) in this group also allow researchers to rotate between firm facilities. But note that the algorithm placed the majority of collaborations with employee exchange into a separate group (group 4).[5] An

[5] The stratification of four observations with both employee and background IP exchange into group 2, while seven observations with these same features were placed into group 4 highlights the weakness of cluster analysis. The alternative is for the researcher to reassign observations to groups after

alternative hypothesis is that firms might simply license each other rights to background IP to facilitate "rights of way," credibly committing not to sue each other for patent infringement. So while Group Two consists of firms that license each other rights to background IP, the motive for the mechanism is not clear.

All of the consortia in Group Three have a provision in their contracts that no firm may license venture-related IP without the approval of all other member firms. Ventures in this group primarily involve firm R&D rather than outsourcing (94%), and also entail background IP licensing between member firms (74%), and an equal sharing of costs (59%). These observations follow the traditional concept of joint venture, where firms establish a separate entity (the joint venture), license it rights to background IP, conduct related R&D, contribute R&D resources, and share equally in the joint venture's costs. But unlike the traditional notion of joint venture, profit sharing and equity participation are not dominant features in this cohort.

Group Three is interesting in that the mechanism these consortia employ, veto power over third party licensing, could *enable* opportunism or hold-up. One explanation is that this organizational mechanism attempts to control spillovers by mandating that no licensing of venture technology can occur without unanimous approval by members. Firms may wish to limit the ability of third parties to gain access to venture IP generated by their partners that may be built upon their own technology, including background IP, as a way of containing spillovers. I label this group "Spillover Control."[6]

All the observations in Group Four entail employee visitation across firm-members. As a result, I label this group "Learning via Personnel Exchange." In addition, seven of eight (88%) involve background IP licensing, and seven of eight involve

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using cluster analysis to suggest groupings. I chose not to do this because I feel the cluster analysis results are sufficiently suggestive of canonical modes of organization to draw broad inferences.

[6] An alternative explanation is that this organizational form exhibits cartel behavior by coordinating on licensing. However, since the coordination only pertains to foreground intellectual property, there would seem to be no antitrust concern unless the firms' foreground intellectual property would have been developed absent the venture and would have competed against each other absent the venture. Even then, the arrangement may not reduce welfare to the extent that duplicative research is avoided.

restrictions that members cannot license foreground IP without approval of other members. This mode is consistent with a learning explanation and is also consistent with attempts to limit spillovers within the group of partners. Interestingly, the relative proportion of consortia that fall into this group that clearly enables know-how exchange is small, only 6% of the sample. However, some consortia that did enable employee visitation across firms were placed by the algorithm into other groups. I discuss this issue in more detail below.

Lastly, I label Group Five “Specialization.” The general pattern of these ventures is that firms conduct R&D, retain rights to their own IP, do not share profits or costs, do not engage in exchange of personnel or IP, and do not restrict the licensing of each others’ foreground IP. This organizational mode is one where firms engage in ex ante nonexclusive licenses of separate components of an innovative product or process. One reason why firms may wish to maintain separation and independence is to avoid opportunism, hold-up, and spillovers.

There are a number of interesting inferences to draw from the cluster analysis. First, the largest proportion of consortia in the sample conforms to mechanisms suggested by models of horizontally-related competitors in product markets. However, these consortia conform to the extreme case of rivalry (spillovers are perfect or no product differentiation exists; Katz, 1986) where all outsource a significant portion of their R&D to a third party. Outsourcing enables them to split costs evenly without fear of shirking or opportunism. This suggests, however, that the R&D conducted by this group of firms does not require technological complementarities and does not result in synergistic gains. Rather, the benefit of collaborative R&D for this group of firms is strictly one of cost sharing and reduced duplication of effort.

Second, mechanisms that do support learning and technology exchange are present in the data, but their relative significance is unclear. Only 19 of 128 consortia in the sample (15%) allowed scientists or engineers to revolve across firm facilities. Fifty-three of 128 consortia (41%) either involve background IP licensing or employee exchange. If one supports the argument that background IP licensing is a precursor for learning, then the learning theory is significantly represented in the sample. Levin, Klevorick, Nelson and Winter (1987) found, for example that licensing was a primary avenue for learning about new process and products. An alternative explanation, however, is that background IP licenses are not used for learning, but rather simply facilitate "rights of way" to conduct R&D without fear of infringement litigation by partners. Licensing to facilitate rights of way, rather than learning, has been particularly noted in cumulative technology industries such as semiconductors, where firms engage in mass cross-licensing covering entire "fields" of research (Grindley and Teece, 1997).

Third, a significant mode of organization is one of specialization. Nineteen of 128 observations (15%) involve member R&D (do not outsource) without background IP licensing or restrictions on the licensing of foreground IP. Firms in these consortia license each other venture-related innovations *ex ante* on a nonexclusive basis and retain rights to license their own venture-related innovations to third parties. That firms specialize is consistent with the "Resource Based" theories in the management literature that all firms are unique collections of assets (Connor and Prahalad, 1996), but not with a view that firms use these consortia as opportunities for synergy or learning. Moreover, to the extent that the firms in these consortia are not competitors in research or production, then these ventures may not facilitate a welfare improving reduction in duplicative R&D.

B. The Effects of Appropriability and Rivalry on Organization

Using the results of the cluster analysis as a guide, I next examine the effect of both appropriability and rivalry on the choice of organizational mechanisms. The ability of firms to appropriate the returns from their technology, including the ability to guard IP from unintended spillovers is not uniform across technologies (Levin, Klevorick, Nelson, and Winter, 1989; Cohen, Nelson, and Walsh, 2001). A growing body of literature has shown that firms are better able to capture returns from intellectual property in certain industries (such as chemicals and pharmaceuticals) than others (such as electronics), and so I test whether industry effects may influence how collaborative R&D is achieved.

I also examine whether consortia composed of more product-market rivals are more likely to choose certain organizational mechanisms, particularly whether they are more likely to outsource their R&D (Katz, 1986). Consortia among firms that are product market competitors may decrease the incentives for participants to contribute R&D because cost reducing R&D will translate to lower equilibrium market prices, particularly if all market participants join the consortium. As a result, collaborations of competitors may reduce overall spending on R&D, and all firms shirk in equilibrium. Consequently, one might expect that consortia of rivals would be more likely to outsource their collaborative R&D than do it in-house in order to achieve innovations without inducing the shirking problem.

I examine whether consortia in weaker appropriability environments or consortia with more rivalrous members are more likely to choose outsourcing as their mode of organization. I examine whether appropriability and rivalry affect the choice to pursue modes of governance that facilitate learning or scientific exchange. I also examine whether these factors influence the choice to organize R&D via specialization and separation of assets. To do this, I regress whether firms outsource their R&D, whether they allow scientists and engineers to revolve across firms, whether they exchange licenses on background intellectual property, and whether firms engage in vertical separation of R&D on SIC code proxies for appropriability in the technology of the collaborative R&D, and the rivalry index. I control for the stage of research by including dummy variables for university or national lab participation, which are associated with more "basic" research. I also control for whether the subject of research related to federal regulations toward pollution abatement, which as stated earlier, are often outsourced. Results are provided in Tables VI and VII.

The results in table VI confirm the hypothesis that collaborations between present-day product market competitors are more likely to be outsourced. Of the variables I explore, rivalry is the greatest factor in outsourcing. At the mean of the data, a one standard deviation increase in the horizontalness of collaborators (.24) increases the probability of outsourcing from 47% to nearly 72%. The number of consortia members also factors prominently in the decision to outsource R&D, with increased membership causing an increase in outsourcing, but the affect of an increase in membership is comparable to the affect of the technology researched.

The hypothesis that appropriability of technologies influences the outsourcing decision does not seem to hold well. The coefficient on SIC 28 (chemicals and pharmaceuticals; a proxy for a strong property rights regime) is not significant, and the coefficient on SIC 36 (electronics; a proxy for weak property rights regimes) looses significance as more terms are entered. In contrast, the other industry codes relatively more prominent in the sample, SIC 35 (engines) and SIC 73 (software) have a statistically significant effect. Firms in consortia pertaining to engines are more likely to outsource R&D (although some of this effect pertains to designing emissions-reducing engines), and firms in consortia that entail software development are less likely to outsource R&D.

Lastly, the above effects hold, even controlling for consortia involvement with the two federal agencies most commonly associated with consortia in the data. Firms in collaborations arranged through the National Institutes of Standards Advanced Technology Program are less likely to outsource R&D, which makes sense given that the ATP program is designed to encourage cooperative R&D. Firms bidding on Defense Department contracts or otherwise funded in part by DOD are also less likely to outsource their R&D.

Table VII shows the affects of rivalry and appropriability on learning modes, and on R&D specialization. I define R&D specialization as cases where full IP rights and title go to the research entity, there are no restrictions on that research entity with respect to later-stage licensing of that IP, and the research entity is a member of the consortia rather than a contractor. Table VII shows that rivalry is an important driver, causing firms to disallow scientists and engineers from revolving across campuses. However, it is neither an important factor in the decision to license background IP, nor in the choice to organize R&D via complete separation and specialization. In addition, the proxies for appropriability in Table VII are not significant factors in any of these choices.

Taken together, the results suggest that collaborations of rivals prefer to outsource their R&D, and/or to avoid exchange of scientific personnel, but they do sometimes exchange licenses to background intellectual property. This suggests that background IP exchange may be more attributable to firms' desire to promote research by removing the threat that their partners will sue them for patent infringement, and less attributable to learning. In addition, the strength or weakness of property rights does not seem to influence either the decision to outsource, the decision to allow revolving scientific personnel, or the decision to organize collaboration as a complete separation of research across firms. Rather than appropriability, rivalry seems to be the dominant factor in firms' choice of collaborative R&D mechanisms.

VI. Conclusion

This paper attempts to characterize the mechanisms firms use to organize multi-firm collaborative R&D. It shows that the traditional model of collaboration, where firms split costs evenly and share profits, holds for a significant subset of the data (31%), but not the majority of it. Interestingly, when collaborators are horizontal competitors in product markets they are more likely to outsource their R&D to a third party contractor. This mechanism enables firms to share costs and avoid duplicative R&D, but has no synergistic benefits.

Another subset of consortia in the sample appears to organize collaboration by distributing research among specialized firms. In these arrangements, partners produce their own components of research separately and maintain full title and control to their own resulting IP. These specialized R&D arrangements exist even when firms are product market rivals. In the specialized case, the consortia very nearly resemble arms-length markets rather than the collaborative R&D hierarchies that many authors assume. The question of whether specialized R&D consortia achieve welfare benefits, and particularly the hypothesized welfare benefits of reduced duplication of research, economies of scale in R&D, or synergy, remains an open question.

There is one mechanism that clearly seems to be consistent with a management theory that firms engage in collaborative R&D to learn from each other. That mechanism enables scientists and engineers to revolve across firm facilities. While the data do support a learning hypothesis, the visitation mechanism is seldom used in the sample. Moreover, firms in large consortia and consortia composed of rivals are far less likely to allow scientific or engineering personnel exchange.

I interpret many of the alternative organizational designs as attempts to prevent unintended spillovers. For example, a cohort of consortia employs a veto mechanism in the choice of third party licensees, I argue, to prevent the ability of members to profit from deliberate misappropriation of IP. However, the theory that differences in technologies drive differences in firms' abilities to appropriate returns from those technologies, and consequently influence organizational choice, is not supported by the data. The standard proxies for appropriability, SIC codes for chemicals and electronics, do not seem to influence the decision to outsource, the decision to permit employee exchange across firms, the decision to engage in background IP licensing, or the decision to separate R&D projects across collaborative partners.

Together, these results suggest a substantial diversity in organizational attributes associated with collaborative R&D. If one were to infer population attributes from patterns in the sample, one might be tempted to conclude that the welfare effects of the National Cooperative Research Act may not be as great as its crafters had hoped. At least one-third of the consortia in the sample avoid duplicative research by outsourcing their R&D, and to the extent that firms are specialized in research, one must question whether they would have conducted each other's stage of R&D absent collaboration. Indeed, the fact that a significant subset of observations organizes their collaboration as a nexus of arms-length contracts raises the question of what "collaborative R&D" means, and why firms chose ex ante arms-length agreements rather than ex post markets? Lastly, real synergistic gains as might be facilitated through scientific employee exchange seem infrequent. This research opens up the door for a more nuanced debate about the effects of pro-collaborative R&D industrial policies.

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TABLE I

SOME EXAMPLES OF INDEPENDENT RESEARCH ORGANIZATIONS
AND CONSORTIA EMPLOYING INDEPENDENCE ACROSS RESEARCH PROJECTS

Consortia	Year Founded	Description
Gas Research Institute (GRI) / Gas Technology Institute (GTI)	1941	Independent, non-profit technology organization related to natural gas use and environmental aspects of natural gas use.
Southwest Research Institute (SWRI)	1947	Independent, non-profit applied R&D organization specializing in the creation and transfer of technology in engineering and the physical sciences.
Michigan Molecular Institute	1971	Independent, non-profit research and educational organization, conducting both basic and applied research in polymer science and technology.
Electric Power Research Institute (EPRI)	1973	Non-profit energy research consortium.
Bellcore	1984	Formerly Bell Labs. Bellcore was divested from AT&T in 1984 due to antitrust litigation. It was the collaborative research lab of the Bell Companies (RBOCs) until it was spun off by the RBOCs in 1997.
Software Productivity Consortium	1985	Non-profit partnership of industry, government, and academia in systems and software process improvement. Founded by a group of companies in the aerospace, defense, electronics, and systems integration industries.
National Center for Manufacturing Sciences (NCMS)	1986	Non-profit consortium devoted exclusively to manufacturing technologies, processes, and practices.
Petroleum Environmental Research Forum (PERF)	1986	Non-profit forum created for the collection, exchange, and analysis, of information relating to the development of technology for health, environment & safety, waste reduction and system security in the petroleum industry
Sematech	1986	Global consortium of leading semiconductor manufacturers that engages in cooperative precompetitive efforts to improve semiconductor manufacturing technology.

TABLE I (continued)

SOME EXAMPLES OF INDEPENDENT RESEARCH ORGANIZATIONS
AND CONSORTIA EMPLOYING INDEPENDENCE ACROSS RESEARCH PROJECTS (continued)

Edison Materials Technology Center	1987	Consortium to facilitate the development, deployment, and commercialization of materials and processing technology.
Silicon Integration Initiative (Si2)	1988	Organization of leading companies in the semiconductor, electronic systems, and EDA tool industries focused on improving productivity and reducing cost in creating and producing integrated silicon systems.
ATM Forum	1991	Non-profit organization formed with the objective of accelerating the use of Asynchronous Transfer Mode products and services through rapid convergence of interoperability specifications.
Ohio Aerospace Institute	1992	Private non-profit corporation joining businesses, universities, and government agencies to conduct aerospace-related R&D, provide a forum for know-how exchange, and promote commercialization of technologies.
Financial Services Technology Consortium (FSTC)	1993	Consortium of leading North American-based financial institutions, technology vendors, independent research organizations, and government agencies. It sponsors collaborative R&D on interoperable, open-standard technologies.
Petrotechnical Open Standards Consortium (POSC)	1994	International not-for-profit corporation designed to facilitate E&P information sharing and business process integration.
The Open Group	1995	International technology-neutral consortium to lower the time, cost and risk associated with integrating new technology across enterprises.
IFX Forum, Inc.	1997	Interactive financial exchange forum formed to create a messaging standard for financial services under network-based computing models.
Liberty Alliance Project	2001	Consortium to establish an open standard for federated network identity, and to create specifications that will interoperate and promote secure federated identity management.
Smart Active Labels Consortium (SAL)	2002	Non-profit international interest group intended to develop the use of smart active label technologies in an number of industries.

Source: Federal Register Filings, Google searches for "National Cooperative Research Act" and "Consortium"

Figure 1: Distribution of All NCRA Joint Ventures, and NCRA Joint Ventures with Filed Contracts

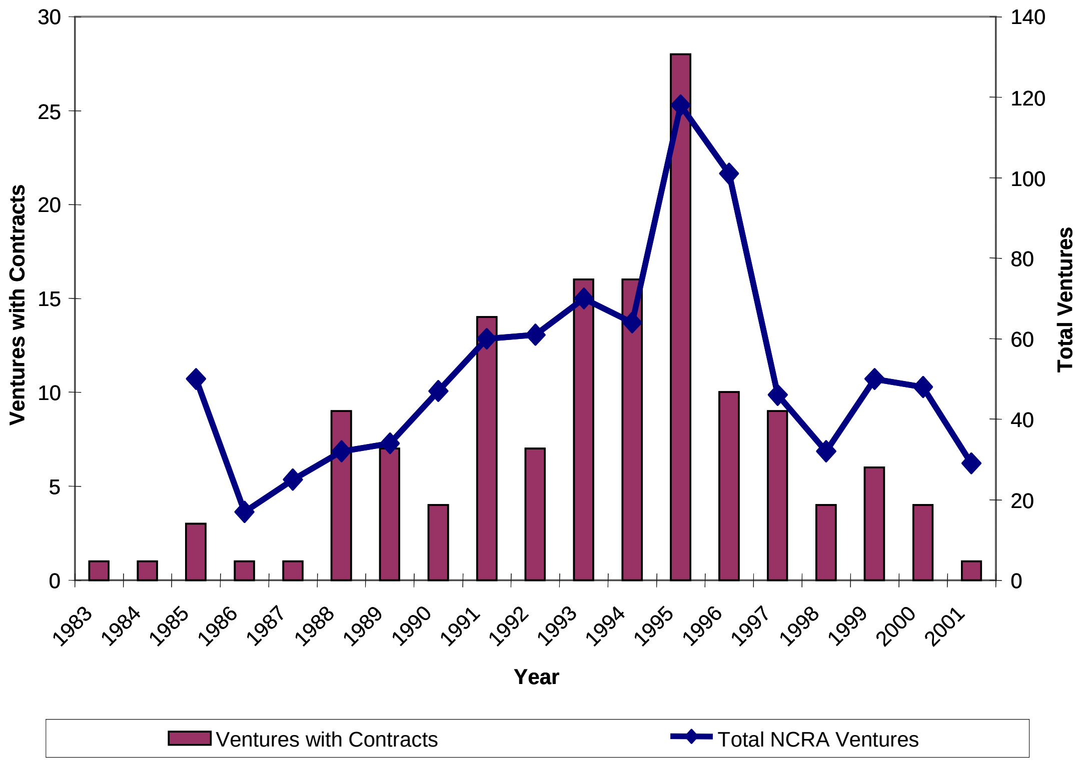

TABLE II

CHARACTERISTICS OF NCRA CONSORTIA

	Number of Observations	Frequency
Total Number of Consortia with Filed Contracts	142	
Contracts Among Firms Only	73	51.4%
Contracts Involving At Least One University	31	21.8%
Contracts Involving At Least One Government Agency	38	26.8%
Department of Defense (DOD)	21	14.8%
National Institutes of Standards and Technology (NIST)	21	14.8%
Department of Energy (DOE)	6	4.2%
National Aeronautics and Space Administration (NASA)	4	2.8%
Environmental Protection Agency (EPA)	3	2.1%
Federal Aviation Administration (FAA)	2	1.4%
Food and Drug Administration (FDA)	2	1.4%
National Science Foundation (NSF)	2	1.4%
Department of Agriculture (USDA)	2	1.4%
Department of Transportation (DOT)	1	0.7%
Contracts Involving At Least One National Laboratory	10	7.0%

TABLE III

TECHNOLOGIES RESEARCHED BY NCRA CONSORTIA

	Number of Observations	Frequency
Software	19	13%
Petroleum Exploration	13	9%
Automotive	12	8%
Automotive Emissions	9	6%
Petroleum Refining	8	6%
Bioremediation	7	5%
Chemicals	7	5%
Lasers / Laser Optics	7	5%
Metals/ Materials	7	5%
Semiconductor	7	5%
Computing	6	4%
Electronics	6	4%
Pollution Remediation	6	4%
Chemicals - Remediation	5	4%
Biotechnology	3	2%
Instruments	3	2%
Steel Foundary Processes	3	2%
Aerospace	2	1%
Broadcasting	2	1%
Imaging	2	1%
Liquid Crystals	2	1%
Ordnance	2	1%
Cigarettes	1	1%
Drugs	1	1%
Machinery	1	1%
Machining	1	1%

TABLE IV A

SUMMARY STATISTICS

	Number of Observations	Mean	Std. Dev.	Minimum	Maximum
Number of For-Profit Members	132	6.894	6.808	2	50
University Participant	142	0.218	0.415	0	1
National Lab Participant	142	0.070	0.257	0	1
National Institutes of Standards (NIST)	142	0.148	0.356	0	1
Defense Department (DOD)	142	0.148	0.356	0	1
Is R&D Outsourced ?	142	0.479	0.501	0	1
Do Firms Split Costs 1/n ?	137	0.613	0.489	0	1
Is IP Title Reassigned from Researcher to Another Entity ?	141	0.142	0.350	0	1
Do Firms Have Veto Power Over Foreground IP Licensing By Partners ?	133	0.338	0.475	0	1
Do All Rights to Foreground IP Go To Patent Title Holder ?	118	0.746	0.437	0	1
Do Firms Share Profits ?	137	0.394	0.490	0	1
Do Firms License Each Other Rights to Background IP ?	140	0.357	0.481	0	1
Employee Visitation Across Firms ?	140	0.136	0.344	0	1
Is Venture Concerned with Pollution Abatement or Emissions Reduction ?	141	0.298	0.459	0	1
Equity Joint Venture	142	0.021	0.144	0	1
Rivalry Index	130	0.468	0.248	0.080	1

TABLE IV B

CORRELATION MATRIX

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 No. Members	1														
2 University	0.101	1													
3 National Lab	-0.041	0.111	1												
4 NIST	-0.181	-0.053	-0.093	1											
5 DOD	0.127	0.151	0.169	-0.164	1										
6 R&D Outsourced	0.211	0.073	-0.131	-0.319	-0.219	1									
7 Cost Split 1/n	0.116	0.016	-0.017	-0.523	-0.362	0.640	1								
8 Reassigned IP Title	-0.027	-0.116	0.053	0.035	0.112	-0.047	0.025	1							
9 Veto on Partner FIP Licenses	-0.148	-0.058	0.121	-0.166	0.003	-0.013	0.108	0.049	1						
10 FIP Rights to Patent Holder	-0.080	-0.046	-0.075	0.166	-0.024	-0.191	-0.203	-0.063	-0.652	1					
11 Profit Sharing	0.050	-0.194	-0.018	-0.226	-0.186	0.289	0.275	0.238	0.269	-0.338	1				
12 BIP License Exchange	-0.197	-0.153	0.098	0.240	0.269	-0.521	-0.405	0.145	0.158	-0.054	-0.027	1			
13 Employee Visitation	-0.167	-0.104	0.014	-0.024	-0.037	-0.172	-0.159	-0.175	-0.001	0.089	-0.134	0.183	1		
14 Pollution Abatement	-0.004	0.085	-0.062	-0.273	-0.222	0.452	0.477	-0.059	-0.092	0.004	0.289	-0.377	-0.320	1	
15 Equity Joint Venture	-0.090	-0.075	-0.034	-0.058	-0.060	-0.140	-0.041	-0.055	0.197	0.087	0.165	0.031	0.123	-0.101	1
16 Rivalry Index	-0.118	0.099	-0.056	-0.133	-0.342	0.062	0.291	-0.004	-0.099	0.131	0.025	-0.174	-0.049	0.379	0.026

TABLE V

CLUSTER ANALYSIS GROUPS
(n=128)

Label Attributed To Group	Outsourced R&D	Learning via Background IP Licensing	Spillover Control	Learning via Personnel Exchange	Vertical Specialization	
Group Number	1	2	3	4	5	Total
Profit Sharing Mechanism	30	4	7	6	5	52
	58%	8%	13%	12%	10%	100%
Cost Split 1/n	55	3	10	3	7	78
	71%	4%	13%	4%	9%	100%
Employee Cross-Firm Visitation	5	4	0	8	2	19
	26%	21%	0%	42%	11%	100%
BIP Licensing for R&D	4	24	13	7	0	48
	8%	50%	27%	15%	0%	100%
Equity Joint Venture	0	0	1	1	1	3
	0%	0%	33%	33%	33%	100%
Veto Power Over 3rd Party Licensing	18	0	17	7	2	44
	41%	0%	39%	16%	5%	100%
Outsourced R&D	56	1	1	0	2	60
	93%	2%	2%	0%	3%	100%
N	56	24	17	8	23	

Notes: First row in each cell refers to the count of joint ventures with given contract feature. Second row refers to the percentage of joint ventures using given contract feature allocated to that cluster analysis group.

TABLE VI

PROBIT REGRESSION
DEPENDENT VARIABLE: OUTSOURCED R&D

	(1)		(2)		(3)	
No. Members	0.353	***	0.389	***	0.408	***
	0.067		0.074		0.082	
Members ^ 2	-0.015	***	-0.016	***	-0.016	***
	0.003		0.003		0.004	
Rivalry Index (4-digit SIC)	1.039	**	1.132	**	1.016	**
	0.417		0.446		0.468	
Members * Rivalry	-0.140	**	-0.172	**	-0.207	***
	0.062		0.068		0.072	
SIC 28			0.027		-0.059	
			0.135		0.139	
SIC 35			0.355	**	0.304	*
			0.151		0.182	
SIC 36			-0.279	*	-0.237	
			0.116		0.145	
SIC 73			-0.318	**	-0.273	**
			0.093		0.108	
University			0.212	*	0.258	*
			0.127		0.144	
National Lab			-0.147		-0.077	
			0.161		0.185	
NIST					-0.315	**
					0.102	
DOD					-0.340	**
					0.097	
Pollution Abatement					0.237	*
N	127		127		126	
Log Likelihood	-66.48907		-55.88605		-47.78034	
R-squared	0.2439		0.3644		0.4525	

Notes: Table shows marginal effects rather than coefficients from probit regressions. *** indicates significant at 1%, ** indicates significant at 5%, * indicates significant at 10%. Two outlier observations were dropped because their unusually high membership caused the residual estimates to become unusually large.

TABLE VII

PROBIT REGRESSION

Dependent Variable	(1) Scientist and Engineer Exchange Across Firms		(2) Background IP Licensing		(3) R&D Specialization	
No. Members	-0.093	***	-0.082		-0.031	
	0.027		0.074		0.039	
Members ^ 2	0.001	**	0.003		0.000	
	0.001		0.004		0.001	
Rivalry Index (4-digit SIC)	-0.635	**	-0.057		0.019	
	0.252		0.444		0.338	
Members * Rivalry	0.088	**	-0.001		0.022	
	0.037		0.070		0.051	
SIC 28	-0.069		0.120		-0.039	
	0.041		0.140		0.098	
SIC 35			-0.210		-0.170	
			0.120		0.086	
SIC 36	-0.034		0.150		0.034	
	0.055		0.158		0.122	
SIC 73	-0.008		0.340	**	-0.108	
	0.070		0.147		0.093	
University	-0.060		-0.152		-0.038	
	0.046		0.112		0.096	
National Lab	0.001		-0.001		-0.004	
	0.104		0.185		0.146	
NIST	-0.083		0.199		0.445	***
	0.035		0.159		0.148	
DOD	-0.075		0.354	**	0.114	
	0.042		0.141		0.145	
Pollution Abatement			-0.164		-0.059	
			0.124		0.098	
N	125		124		120	
Log Likelihood	-42.1560		-60.0301		-54.3892	
R-squared	0.182		0.275		0.180	

Notes: Table shows marginal effects rather than coefficients from probit regressions. *** indicates significant at 1%, ** indicates significant at 5%, * indicates significant at 10%.

R&D Specialization is defined to be cases where: 1) foreground IP rights go to the patent title holder, 2) the patent title goes to the research entity (and is not reassigned to a third party such as the joint venture itself), 3) there are no restrictions on the ability of firms to license their own IP (no veto power by other members), and 4) the research entity is not a contractor.

Two observations were dropped to facilitate comparing results with results on outsourcing. In addition, 2-7 observations for each regression were dropped due to missing data. The regression for engineer visitation across firms dropped SIC 35 and the pollution abatment dummy because there was no variation within these groups with respect to the dependent variable.