Federal laboratories as research partners

By: Dennis Patrick Leyden, Albert N. Link

Leyden, Dennis P and Link, Albert N. "Federal Laboratories as Research Partners," *International Journal of Industrial Organization*, 1999, 17(4):575-92.

Abstract:
Since the passage of the National Cooperative Research Act (NCRA) in 1984, nearly 600 formal research joint ventures (RJVs) have been filed with the U.S. Attorney General and the Federal Trade Commission. Researchers have documented this trend and have examined, both theoretically and empirically, various aspects of collaborative research behavior. However, the composition of the membership of RJVs has yet to be explored. In this paper we present a theoretical explanation consistent with the empirical observation that Federal laboratories are most prevalent as research partners when the membership of the RJV is large.
Keywords: Research joint venture; Collaborative research; Federal laboratory
JEL classification: 031; 038; 032

Article:

1. Introduction

In response to declining productivity growth throughout the manufacturing sector during the late 1970s and early 1980s and the related decline in global competitiveness, and in light of Japan's innovative success through collaborative research joint ventures (RJVs), Congress passed the National Cooperative Research Act (NCRA) of 1984 (PL 98-462) to encourage collaborative research activities among industrial firms.[1] The two primary objectives of the NCRA were to establish a rule of reason for evaluating the antitrust implications of each RJV on an individual case basis, and to limit potential liability to actual damages rather than treble damages as is more common under antitrust law. In 1993, the NCRA was amended by the National Cooperative Research and Production Act (NCRPA) (PL 103-42) so as to include cooperation in production activities as well as research activities.

Though these laws have generated increased collaborative research and production activities, surprisingly little is known about the composition of these collaborative ventures. As a result, the National Science Foundation in 1994 established the Collaborative Research (CORE) database in an effort to better understand the fundamental characteristics of RJVs.[2] The CORE database defines the RJV to be the relevant unit of observation; it contains summary information about each RJV as determined from Federal Register filings, supplementary data, and interviews with key research participants.[3]

One interesting pattern that emerges from an analysis of the CORE database is that RJV's often include public sector research partners, particularly Federal laboratories. Through calendar year 1995 there have been 561 separate RJV's reported in the Federal Register.[4] As shown in Table 1, Federal laboratories are or have been involved in nearly 9 percent of all RJVs.[5] A second interesting pattern is that Federal laboratories are more common as members of large RJVs. Specifically, the average number of members in an RJV with a Federal laboratory as a research partner is over three times that of other RJVs.

Surprisingly, previous research has not addressed issues related to the composition of RJVs. To be sure, previous researchers have considered a number of important issues related to collaborative research relationships. Industrial organization and legal scholars examined early on the antitrust implications of research

collaboration, finding conditions under which collaboration in research acts as a stimulus to innovation (Ordover and Willig, 1985; Brodley, 1990; Jorde and Teece, 1990; Shapiro and Willig, 1990).

Table 1
Federal laboratories as members of RJVs, by year

Year	No. filings	% with Fed. lab.
1985	50	8.0%
1986	17	0%
1987	26	0%
1988	31	9.7%
1989	27	11.1%
1990	46	2.2%
1991	62	4.8%
1992	59	1.7%
1993	72	5.6%
1994	63	7.9%
1995	108	23.1%
Overall	561	8.7%

Others have investigated the theoretical conditions associated with the private profitability and social desirability of cooperative R and D (Katz, 1986; d'Aspremont and Jacquemin, 1988; Henriques, 1990; Kamien et al., 1992; Suzumura, 1992; Combs, 1993; Simpson and Vonortas, 1994; Vonortas, 1994; Yi, 1996).[6] And some researchers have undertaken empirical or case-based investigations related to economic factors associated with joining an RJV and to the economic benefits from participating in such an arrangement (Mowery, 1988, 1989; Scott, 1988, 1996; Link and Bauer, 1989; Link et al., 1996). However, there is a conspicuous absence of information about the characteristics of members of RJVs. Such knowledge is fundamental to a more complete understanding of innovation strategy and how market structures might change as a result of internal sharing of resulting technology. And, such information is timely given the strategic importance of collaboration in internationally competitive environments (Council on Competitiveness, 1996; Mowery and Teece, 1996).

Moreover, beyond adding to a fuller understanding of both RJVs and the research role of Federal laboratories, this knowledge is especially relevant in today's political climate. The Government Performance and Results Act (GPRA) of 1993 (PL 103-62) explicitly calls for a more complete understanding of the role of Federal laboratories in support of private sector research by mandating that laboratories put in place evaluation mechanisms that emphasize quantifying the results of their activities on the private sector. One prerequisite to such evaluations is a more complete documentation of the role of Federal laboratories in the private sector innovation process.[7]

This paper offers a theoretical explanation as to why Federal laboratories are invited to participate in RJVs more frequently when the number of participants in the RJV is large. The paper concludes with an econometric analysis of the association between RJV size and Federal laboratory participation that is consistent with the model's predictions.

2. Toward a theory of federal laboratories as research partners

One intuitive explanation for the positive relationship between the number of RJV participants and the presence of a Federal laboratory as a research partner is that while larger RJVs are likely to generate economies of technological scope that come from the larger number of participants, larger size also results in a greater cost of monitoring the RJV and a reduced ability of member firms to individually appropriate the research output of the RJV. Federal laboratory participation, while reducing still further the ability of members to appropriate research results, may also, as we explain below, reduce the cost of monitoring the RJV. For smaller RJVs, the loss in appropriability associated with Federal laboratory participation is too great and the savings in monitoring costs too low to justify inviting the laboratory to participate. However, for a large RJV, the additional loss in appropriability may be sufficiently small and the savings in monitoring costs sufficiently high that a Federal laboratory's participation becomes desirable.[8]

More formally, consider a private-sector RJV comprised of *N* members, and assume that each member seeks to maximize the net returns H associated with the use of the research results of the RJV in private sector activity. The revenues associated with using such output will depend on both the amount of RJV output as well as the degree to which each firm can appropriate that knowledge. Let *R* represent the maximum revenue that could be earned by a member firm were it not subject to competition from any other firm with access to the output of the RJV, and assume that *R* is an increasing, concave function of the number of member firms:

$$R = R(N) \ni \frac{\partial R}{\partial N} > 0, \frac{\partial^2 R}{\partial N^2} < 0. \qquad (1)$$

R is an increasing function of *N* because of the economies of technological scope that come from having a larger number of firms participate in an RJV. *R* is a concave function of *N* because the firms in an RJV typically face downward sloping demand curves thus resulting in revenues rising at a diminishing rate as the number of firms in the RJV, and hence the output of the RJV, increases.

Of course, the actual revenue that a member firm can earn is typically less than the maximum amount *R*. While a number of factors affect the ability of the firm to earn such revenues, an increase in the number of RJV participants will in general reduce the ability of an individual firm to earn *R* both because it increases the probability that among the firm's competitors will be a fellow member of the RJV and because it reduces the time before a competitor firm that is not a member of the RJV acquires the knowledge produced by the RJV as the knowledge developed by the RJV spreads through other industries. [9] Thus, letting *A* be the proportion of *R* which the firm can actually appropriate, we find:

$$A = A(N) \ni 0 < A < 1, \frac{\partial A}{\partial N} < 0, \frac{\partial^2 A}{\partial N^2} > 0. \qquad (2)$$

Finally, there are the costs, *C*, associated with participating in the RJV. These costs include the direct costs borne by the firm as a result of participating in the RJV as well as the firm's share of the common set of costs associated with managing the RJV. Among the common costs of the RJV include normal R and D operating costs, the cost of administering and monitoring the participation of the various members of the RJV, and outside costs such as lobbying incurred by the RJV. We assume that such costs to the firm increase at an increasing rate with the size of the RJV for two reasons. First, with the increased number of participant we would expect to see in general an increase in the scale of R and D activity. While there may be some scale economies at first, ultimately, diminishing returns are likely to be present. Second, with increased size comes an increasing chance that some member firms may free ride. With a small number of firms, the likelihood that free riding is a rational choice for members is low, and the cost of detecting it is also low. However, as the size of the RJV increases, it becomes both more likely that some members will try to free ride, and more difficult to detect the free riding and to take action to stop it. Thus, the cost of monitoring the RJV will increase with size. In addition, the larger the collaboration, the greater the problem of a subset of members manipulating the activities of the whole for their own private benefit. If the organization is small, the ability to do this and not be detected is small. However, as the size of the organization increases, it becomes increasingly more costly to monitor individual member activities to protect against such activities. Thus:

$$C = C(N) \ni \frac{\partial C}{\partial N} > 0, \frac{\partial^2 C}{\partial N^2} > 0. \qquad (3)$$

The per-firm net returns to RJV participation will therefore be the difference between the revenues associated with the appropriable amount of the RJV's output and the firm's share of the cost of managing the RJV:

$$\Pi_0 = A(N) \cdot R(N) - C(N). \qquad (4)$$

Fig. 1 illustrates this determination of a member firm's net returns over alternative sized RJVs.

The decision to invite a Federal laboratory to join the private RJV is conceptualized as depending on whether the Federal laboratory would increase or decrease the per-firm net returns to RJV participation. A Federal laboratory affects those per-firm net returns in three ways.

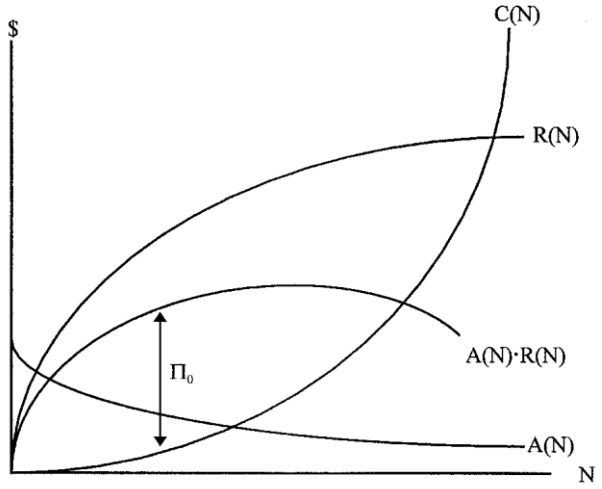

Fig. 1. Determination of a member firm's net returns over alternative sized RJVs.

First, participation by the Federal laboratory creates what may be called economies of technological scope. At a minimum, Federal laboratories may be thought of as simply another RJV member. Thus, Federal laboratory participation in the RJV, much like the participation of any new member, creates the possibility of more interactions and more access to research capital. This in turn gives the RJV the opportunity to increase its revenue stream. But of course, Federal laboratories are not like other members. Federal laboratories embody unique human and technical capital that is rarely available in the private sector.[10] Federal laboratory participation makes available such unique capital to all the members of the RJV thereby increasing research synergy that comes from being able to explore more facets of research and from being able to consider a broader scope of research questions in a fundamental way. As a result, ceteris paribus, Federal laboratory presence affords a greater ability to member firms to increase revenues.

Second, participation by the Federal laboratory reduces the ability of the RJV's members to appropriate the output of the RJV. Because the Federal laboratory is a public agency intended to provide general benefits to society, it tends to focus on more basic research than do private sector firms, and the commercial value of basic research is by its nature more difficult to appropriate. In addition, the reward structure of many Federal laboratory scientists is based on publications (Link, 1996a; Stephan, 1996), thus reducing further the ability to appropriate the commercial value of research generated with Federal laboratory contributions.

Finally, participation by the Federal laboratory will affect each member's cost of participating in the RJV, though the direction of change is not clear. On the one hand, Federal laboratory participation might be expected to reduce each firm's costs both because the Federal laboratory may not require full compensation for the R and D production costs it incurs as a member of the RJV owing to the infrastructural nature of laboratory research, and because Federal laboratories, in their role as an "honest broker," can reduce various monitoring and transaction costs incurred by the private sector firms. Tripsas et al. (1995), for example, argue in their study of the Italian Societi di Ricerca program that government can play a role in discouraging opportunistic behavior on the part of RJV participants through improved monitoring (perhaps by formal auditing of the activities of the private sector members), through an ability to threaten reprisal (either explicitly if the RJV gives the Federal laboratory the legal power to discipline non-compliant firms, or implicitly if the Federal laboratory is willing to exclude noncompliant firms from future collaborative activities), or through facilitating longer term relationships (by lending a sense of continuity and stability to cooperative arrangements, by giving firms the chance to demonstrate a willingness to cooperate, and by establishing forums for long-term networks). Such activities are a natural part of a Federal laboratory's participation because the laboratory, as a public agent, adheres to certain standards of reporting and research interactions.[11] This results in a fuller participation on the part of the RJV's private sector members and a reduced chance of the RJV's activities being manipulated to the benefit of a subset of those members. On the other hand, each firm's cost may rise as a result of Federal laboratory participation because of additional costs associated with Federal laboratory requirements or with the

added lobbying and reporting costs for the RJV associated with participating in the political process. Thus, the net result on the cost to each firm is not clear.

Given the above changes associated with Federal laboratory participation, per-firm net returns to RJV participation assuming Federal laboratory participation can be represented by:

$$\Pi_L = \alpha A(N) \cdot \sigma R(N) - \gamma C(N) \ni 0 < \alpha < 1, \sigma > 1, \gamma > 0, \qquad (5)$$

where α represents the effect of Federal laboratory participation on the firm's ability to appropriate the output of the RJV, σ represents the effect of the increased economies of technological scope on revenue, and γ represents the change in costs. Note in particular that γ may be greater or less than 1.

The question of whether to invite the Federal laboratory to participate, therefore, hinges on whether per-firm net revenues without the Federal laboratory, Π_0, are greater or less than the per-firm net revenues with the Federal laboratory, Π_L. Using Eqs. (4) and (5), we find:

$$\Pi_L \gtrless \Pi_0 \text{ if } A(N) \cdot R(N)(\alpha\sigma - 1) \gtrless C(N)(\gamma - 1). \qquad (6)$$

The implications of Eq. (6) for inviting or not inviting a Federal laboratory to participate in an RJV will depend on the relative values of α, σ, and γ. Consider the following three cases.[12]

Case 1. *Economies of technological scope outweigh the loss in appropriability*. If the increase in the economies of technological scope σ is sufficiently great to outweigh the loss in appropriability α, then $\alpha\sigma > 1$ and Eq. (6) can be rewritten:

$$\Pi_L \gtrless \Pi_0 \text{ if } \frac{A(N) \cdot R(N)}{C(N)} \gtrless \frac{\gamma - 1}{\alpha\sigma - 1}. \qquad (6')$$

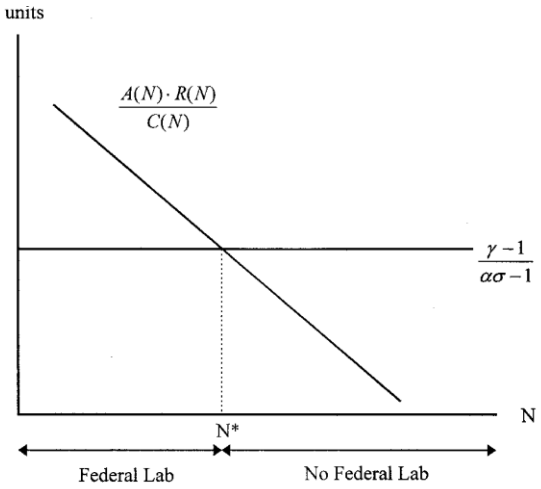

Fig. 2. Federal laboratory participation when economies of technological scope outweigh the loss in appropriability.

The revenue–cost ratio is clearly positive. Hence, whether it pays to invite a Federal laboratory to join the RJV depends on the value of the ratio (γ - 1 /$\alpha\sigma$ - 1). If the Federal laboratory increases each firm's cost of participating in the RJV, that is, if $\gamma > 1$, then the ratio (γ - 1 /$\alpha\sigma$ - 1) will be positive and the RJV will only invite the Federal laboratory to participate if the original revenue–cost ratio is sufficiently large. But given the convexity assumptions of our model, the revenue– cost ratio for each member firm will fall with the size of the RJV. As a result, for sufficiently small RJVs, the revenue–cost ratio is likely to lie above the ratio (γ - 1 /$\alpha\sigma$ - 1), thus resulting in a decision to invite the Federal laboratory to participate. However, beyond a critical size N^*, the revenue–cost ratio for firms in the RJV will be less than (γ - 1 /$\alpha\sigma$ - 1). Hence, for RJVs with more than N^* members, there will be no Federal laboratory participation. See Fig. 2. Of course, it is also possible that the Federal laboratory will either not change each firm's cost of participating in the RJV or reduce it, that is, $\gamma \leq 1$.

In this situation, the ratio $(\gamma - 1/\alpha\sigma - 1)$ will be non-positive, and it will always pay to invite the Federal laboratory to participate. Intuitively, this makes sense. If, regardless of the size of the RJV, revenues always rise and costs never rise when a Federal laboratory joins, then the RJV will always invite the Federal laboratory to participate.

Case 2. *Economies of technological scope offset the loss in appropriability*. If the increase in the economies of technological scope s is sufficiently great to exactly offset the loss in appropriability α, then $\alpha\sigma = 1$ and Eq. (6) can be rewritten:

$$\Pi_L \gtrless \Pi_0 \text{ if } C(N) \gtrless \gamma C(N). \qquad (6'')$$

In this case, because revenues do not change if a Federal laboratory joins the RJV, the decision whether to invite a Federal laboratory to join the RJV depends on whether the cost to the RJV's member firms rises or falls. If the Federal laboratory increases each firm's cost of participating in the RJV, that is, if $\gamma > 1$, then the RJV, regardless of size, will not invite the Federal laboratory to participate. If Federal laboratory participation reduces the cost of participating in the RJV, that is, $\gamma < 1$, then the RJV, regardless of size, will invite the Federal laboratory to participate. If by chance, the cost of participating in the RJV is not affected by the Federal laboratory, the RJV will be indifferent to it joining.

Case 3. *The loss in appropriability outweighs the economies of technological scope*. If the loss in appropriability α is sufficiently great the outweigh the increase in the economies of technological scope σ, then $\alpha\sigma < 1$ and Eq. (6) can be rewritten:

$$\Pi_L \gtrless \Pi_0 \text{ if } \frac{A(N) \cdot R(N)}{C(N)} \lessgtr \frac{\gamma - 1}{\alpha\sigma - 1}. \qquad (6''')$$

Once again, the revenue–cost ratio is clearly positive. Hence, whether it pays to invite a Federal laboratory to join the RJV depends on the value of the ratio $(\gamma - 1/\alpha\sigma - 1)$. If the Federal laboratory does not reduce each firm's cost of participating in the RJV, that is, if $\gamma \geq 1$, then the ratio $(\gamma - 1/\alpha\sigma - 1)$ will be non-positive and the RJV will never invite the Federal laboratory to participate. Intuitively, if Federal laboratory participation reduces revenues and costs do not fall, it never pays to invite the Federal laboratory to participate. However, if Federal laboratory participation does reduce the cost to the RJV's member firms, that is, if $\gamma < 1$, then the ratio $(\gamma - 1/\alpha\sigma - 1)$ will be positive and the decision whether to invite a Federal laboratory to participate will depend on the relative size of the original revenue–cost ratio. For sufficiently small RJVs, the revenue– cost ratio is likely to lie above the ratio $(\gamma - 1/\alpha\sigma - 1)$, thus resulting in a decision to not invite the Federal laboratory to participate. However, beyond a critical size N^*, the revenue–cost ratio for firms in the RJV will be less than $(\gamma - 1/\alpha\sigma - 1)$.

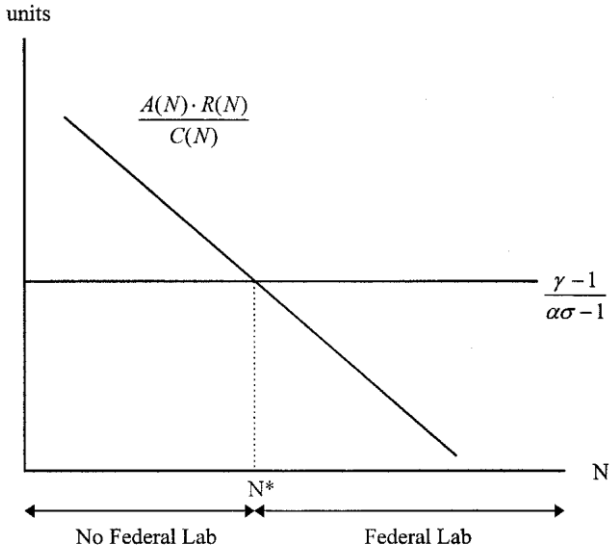

Fig. 3. Federal laboratory participation when the loss in appropriability outweighs the economies of technological scope.

Hence, for RJVs with more than N^* members, a Federal laboratory will be invited to participate. See Fig. 3.

The intuition behind Fig. 3 is relatively simple. If a Federal laboratory participates in an RJV, member firms see both costs and revenues reduced. If the RJV is small, costs were not large to begin with and so the cost reduction is relatively small. However, member firms of a small RJV also have relatively little problem appropriating the output of the RJV. Hence, a Federal laboratory would result in a significant loss of appropriability. The net result is that small cost savings and a large reduction in appropriability result in a fall in per-firm net revenues if the Federal laboratory participates. With a large RJV, the intuition works in reverse. Costs, particularly monitoring costs, become large, and the Federal laboratory by playing the role of an "honest broker" can reduce those costs significantly. Appropriability, on the other hand, is already relatively low so that the Federal laboratory's participation has relatively little effect. The result is the Federal laboratory's participation increases per-firm net revenues. Of course, for both small and large RJVs, the fact that the Federal laboratory also may increase the economies of technological scope ($\sigma > 1$) means that the size N at which it becomes profitable to invite the Federal laboratory to participate will be affected. In general, the greater the degree to which the Federal laboratory generates increased economies of technological scope, the smaller the size of the RJV required to make invitation of the Federal laboratory profitable.[13]

Table 2
Which RJVs invite Federal laboratory participation?

	Case 1 ($\alpha\sigma > 1$)	Case 2 ($\alpha\sigma = 1$)	Case 3 ($\alpha\sigma < 1$)
$\gamma > 1$	Small RJVs do Large RJVs do not	No RJV does	No RJV does
$\gamma = 1$	All RJVs do	All RJVs indifferent	No RJV does
$\gamma < 1$	All RJVs do	All RJVs do	Large RJVs do Small RJVs do not

Table 2 provides a summary of the three cases discussed above. Because γ could be greater than one, equal to one, or less than one, three possibilities presented themselves for each case, thus resulting in the nine cells of Table 2. As our empirical analysis will show below, eight of the nine cells are inconsistent with the data. Only the Case 3 cell associated with $\gamma < 1$ is consistent with the finding that larger RJVs are more likely to have Federal laboratories as partners. We interpret this consistency as evidence (1) that the loss in appropriability associated with Federal laboratory participation is greater than the economies of scope that the Federal laboratory brings, and (2) that on net, Federal laboratory participation reduces the cost of participating for the RJV's member firms.

3. Additional empirical evidence

As discussed in the Introduction, the average membership size of RJVs with a Federal laboratory as a member is more than three times that of RJVs without a Federal laboratory. More specifically, the average number of members in RJVs with a Federal laboratory is 37.0 compared to 10.8 members.[14] See Table 3.

However, RJVs differ in their research character. Of the 561 RJVs, 54 were formed for the specific purpose of developing technology infrastructure such as an industry standard or protocol (TI = 1).[15] While certainly an important form of research, and well within the scope of activities defined in the NCRA and the NCRPA, such activities are fundamentally different from research leading to a new product or process.[16] Still, even among the 507 so-called traditional research relationships (TI = 0 in Table 3) the average membership size of RJVs with Federal laboratories as a member dominates those without: 34.7 compared to 9.6 members.

This descriptive information uniformly suggests that larger (defined by size of membership) collaborative research relationships have a greater incentive to include a Federal laboratory as a member than smaller ones. Fundamental to this conclusion are the implicit assumptions that the decision to invite a Federal laboratory is made after the RJV is formed and that our size metric (number of members of the RJV) is valid. There is some evidence to support the assumption that the Federal laboratory is invited to participate only after the RJV is in operation. It is generally the case among RJVs funded under the Advanced Technology Program within the

U.S. Department of Commerce's National Institute of Standards and Technology that Federal laboratories are brought into the collaboration only after research has begun (Link, 1996a). Pisano (1990) presents similar evidence in his analysis of pharmaceutical firms expanding their R and D boundaries into biotechnological R and D.

Table 3
Average membership size of RJVs

	RJV population	TI = 0	TI = 1
With Fed. lab.	37.0 (n = 49)	34.7 (n = 46)	71.7 (n = 3)
Without Fed. lab.	10.8 (n = 512)	9.6 (n = 461)	21.3 (n = 51)
Overall	13.1	11.9	24.1

In addition, while our membership count metric for size does not distinguish between RJVs with extremely large R and D-active members, and RJVs with relatively small R and D-active members, we do not view such a distinction as critical to either the descriptive observations in Table 3 or to the theoretical model developed in the previous section. First, there is no evidence to suggest that the resources devoted to the collaborative research venture by a member firm are proportional to the size of the member firm (Link and Bauer, 1989; Link, 1996a). In fact, it is generally the case that a member firm allocates only a portion of one scientist's time to the collaborative project along with some supporting infra-structure. And second, there is no evidence that the size of the supporting corporate infrastructure is even proportional to the size of the member firm (Finan and Link, 1994; Link et al., 1996). Thus, the number of members in an RJV seems to us to be a valid measure of size, and thus a valid proxy for the economies of technological scope of the collaboration, although we investigate this point below.

To formalize our empirical observations, a more systematic, cross-sectional econometric analysis was conducted. In this analysis, the dependent variable, LAB_i, is defined to equal 1 if a Federal laboratory is present as a research partner in the ith RJV, and 0 otherwise. The size of the ith RJV, SIZEi, is measured as the number of research members as listed in its most recent Federal Register filing. Also held constant in this analysis is a binary variable that indicates whether the purpose of the RJV is to establish a standard or protocol; TI_i equals 1 if this is the case, and 0 otherwise. And finally, two-digit industry dummies are included to account for possible industry differences in the nature of collaborative research.[17]

Owing to the dichotomous nature of the dependent variable, the following probit model, and selected variations in it, were estimated:

$$P(\mathrm{LAB}_i) = F(a + b_1\mathrm{SIZE}_i + b_2\mathrm{TI}_i + \sum_{j=1}^{18} b_{j+2}\mathrm{INDUSTRY\ DUMMY}_{ij}) \qquad (7)$$

where F is the cumulative normal probability function.

As shown in Table 4, the probit coefficient on SIZE in each variation of Eq. (7) is positive and asymptotically significant, as we expected given the descriptive data above and as predicted from our model. The probit coefficients on the technology infrastructure variable are negative but at best marginally statistically significant. Perhaps, because of the more basic nature of the research conducted in Federal laboratories, the presence of such a research environment is unwarranted when industry infrastructure is a stated output. Regarding the industry dummies, the estimated coefficients on the SIC 87 and SIC 35 industry dummy variables were consistently positive and statistically significant, whereas the coefficients on the other industry dummies were not statistically different from zero.

Other variations of Eq. (7) were considered. Specifically, a non-linear SIZE variable was included as a regressor, but its estimated coefficient was never statistically different from zero. Also, in an effort to specify more completely the model in Eq. (7), average member size was also held constant. While no information on the size (e.g. sales) of the private sector member of the RJV is given in the Federal Register, information

provided by Vonortas (1998) was used as the basis for constructing such variables. When available from such sources as Compustat and CorpTech, the average of each such member's 1994 sales was calculated. Of course, data for all private sector firms were not available. When included in the model, the estimated coefficient was negative but never statistically different from zero. [18]

Table 4
Estimated probit results for Eq. (7) (asymptotic t-ratios in parentheses)

Variables	(1)	(2)	(3)
SIZE	0.0069	0.0072	0.0077
	(3.29)	(3.37)	(3.47)
TI	−0.41	–	−0.40
	(−1.25)		(−1.31)
Industry dummies	yes	–	–
Constant	−1.35	−1.48	−1.45
	(−4.25)	(−17.50)	(−16.86)
Log (L)	−139.08	−158.73	−157.78
k	20	1	2
$\chi^2_{(k)}$	54.35	15.04	16.95
Partial derivative on SIZE	0.00069	0.0011	0.0012

These results, reported in Table 4, are consistent with the hypothesis that the ability of an organization (i.e., an RJV) to assimilate useful technical knowledge from its environment (i.e., from a Federal laboratory) depends on the extent of the organization's previous research and hence technological base (Cohen and Leventhal, 1989, 1990).[19] To the extent that larger RJVs embody economies of technological scope, then the size–laboratory relationship is logical. Moreover, this finding of greater research interaction with Federal laboratories among the larger RJV organizations is consistent with the finding of Roessner and Wise (1994) that larger-sized firms are more likely to acquire technology from an external source, specifically a Federal laboratory, than smaller-sized firms.[20]

4. Concluding statement

The purpose of this paper is twofold: to set forth in the literature the empirical observation that Federal laboratories more commonly participate in large RJVs as opposed to small RJVs, and to offer a theoretical explanation for this observed behavior. It is intended that future research will also focus on the composition of RJVs, not only as a more complete specification of an equation like (7), but also as, for example, the strategic importance of the diversified (across industries) RJVs or RJVs that include universities as research partners. As researchers attempt to further public policy toward innovation, such behavioral questions become fundamental.

Notes:

[1] The legislative history of the NCRA and its earlier preliminary form, the Joint Research and Development Act of 1984 (HR 5041), is reviewed in Link and Bauer (1989) and Scott (1989). For a more complete understanding of the role of Japan's success in collaborative research arrangement on the formulation of the NCRA, see U.S. Congress (1983).

[2] The CORE database is maintained, through support from the National Science Foundation, in the Department of Economics at the University of North Carolina at Greensboro. See Link (1996b). The database, and its annual updates, are available upon request from the authors.

[3] Parties in RJVs seeking indemnification under the NCRA and the NCRPA are required to file notification of their research arrangement within 90 days with the U.S. Attorney General and the Federal Trade Commission. The purpose of this notification is to disclose the identities of the parties in the RJV as well as the research nature of the venture itself. Notifications are made public through the reproduction of filings in the *Federal Register*.

[4] RJVs must re-file if their membership changes or if the scope of their research changes. Such re-filings are not treated as a new collaborative research arrangement in the CORE database. However, the CORE database is updated from these re-filings. Thus, the number of members reported for each RJV, as discussed below, is the current number of members.

[5]For a detailed analysis in annual variations in the number of filings, see Brod and Link (1996).

[6] See also DeBondt (1995) for a review of the literature on innovation spillovers from cooperation.

[7] Federal laboratory accountability of public resources can be traced to the Competition in Contracting Act of 1984 (PL 98-369) and to the Chief Financial Officers Results Act of 1990 (PL 101-576). See Cuzzens (1995) and Link (1996a).

[8]Firms interact with Federal laboratories for a number of different reasons including research but also including direct technology transfer or assistance with commercialization of previously transferred technology (Bozeman and Crow, 1995). Accordingly, it would be misleading to characterize any industry–laboratory interaction as a homogeneous activity. However, for the purposes of this paper that is not an issue because all units of observation are RJVs thus the relationship with the laboratory is by definition one in support of a collaborative research endeavor.

[9] Anand and Khanna (1996) argue that the inability to fully appropriate the value of an innovation is due to the presence of weak property rights that arise because of an inability to specify the context and boundaries of knowledge in a manner that makes violation of those property rights verifiable. Cohen (1994) notes that this inability for the RJV to fully appropriate the value of the RJV's research may, if severe enough, lead to incentive problems in forming an inefficient RJV, that is, an RJV that conducts more research than would be generated in the absence of the RJV.

[10] For example, it is not uncommon for semiconductor manufacturers or even SEMATECH to partner with Federal laboratories in order to take advantage of specialized knowledge (such as predictive advanced technology and simulation tools fundamental to the industry as a whole) developed at Los Alamos National Laboratory.

[11] For example, the Semiconductor Research Corporation has relied on Federal laboratories to coordinate intellectual property agreements among member companies.

[12] The ensuing discussion implicitly assumes that α, γ, and σ are not functions of N and hence that the ratio $(\gamma - 1)/(\alpha\sigma - 1)$ is a constant. This assumption is made for the sake of model clarity. However, we recognize that these parameters may indeed vary to some degree with the size of the RJV. One possibility that is plausible and consistent with the conclusions of this paper is that the loss in appropriability associated with the participation of a Federal laboratory is relatively smaller for larger RJVs than for smaller RJVs (i.e., $\partial\alpha/\partial N > 0$), while the cost savings associated with Federal laboratory participation is relatively greater for smaller RJVs than for larger RJVs (i.e., $\partial\gamma/\partial N < 0$). Under such circumstances (and assuming any change in the economies of scope parameter s is relatively small), the ratio $(\gamma - 1)/(\alpha\sigma - 1)$ would be a positive function of N. Of course, the issue is an empirical one and deserving of future work.

[13] Similar comparative static analyses also reveal that the size at which it becomes profitable to invite a Federal laboratory to participate will depend on the degree to which the Federal laboratory's participation reduces the ability of the RJV's member firms to appropriate the research output of the RJV and on the degree to which the Federal laboratory's participation reduces the costs of monitoring the RJV. In general, the greater the reduction in the ability to appropriate that is associated with Federal laboratory participation, that is, the smaller is α, the larger the RJV must be before Federal laboratory participation becomes profitable. Likewise, the larger the monitoring cost savings associated with Federal laboratory participation, that is, the smaller is γ, the smaller the RJV must be before Federal laboratory participation becomes profitable.

[14] Alternatively dividing the sample of 561 RJVs into large- and small-sized RJVs—where a large RJV (n = 100) is defined for purposes of this illustration to be one with more than the overall mean (n=561) number of members of 13.1, and a small RJV is defined to be one with less than 13.1 members (n=461)—the percentage of large RJVs with a Federal laboratory as a member is 14.0 and the percentage of small RJVs with a Federal laboratory as a member is 7.6.

[15]Tassey (1992), (1995) discusses this research under the heading of infratechnology.

[16] And in addition, the size of RJVs engaged in technology infrastructure-related research is systematically larger than the size of RJVs engaged in product/process research. This is to be expected if the purpose of such an RJV is to reach an industry consensus. See Leyden and Link (1992) and Tassey (1992).

[17] Each RJV was assigned to a specific two-digit industry on the basis of the dominant industry represented by the industrial participants. In a few cases, a dominant industry could not be determined. These filings are

subsumed in the constant term as are those observations for which the dominant SIC is represented two or fewer times.

[18]This result was consistent across various coverages. That is, a coverage ratio was calculated for each RJV as the number of private sector firms for which sales data are available divided by the number of private sector firms in the RJV. Three estimations were conducted: 25 percent or greater coverage (n = 402), 50 percent or greater coverage (n = 3 35), and 75 percent or greater coverage (n = 174). In no case was the estimated Probit coefficient on average member size statistically significant. These results are available upon request from the authors.

[19] See also Colombo and Garrone (1996) for empirical evidence.

[20] However, one could alternatively argue that this empirical finding is paradoxical; it is the absence of economies of technological scope in an RJV that make a Federal laboratory an attractive research partner owing to its endowment of research equipment and expertise (Bozeman and Papadakis, 1995; Bozeman et al., 1995). Thus, one should have expected to observe smaller RJVs seeking laboratory collaboration.

References

Anand, B.N., Khanna, T., 1996. Intellectual Property Rights and Contract Structure. Working Paper #3, Working Paper Series H, Yale School of Management, July.

Bozeman, B., Crow, M., 1995. Federal Laboratories in the National Innovation System: Policy Implications of the National Comparative Research and Development Project. Georgia Institute of Technology mimeo.

Bozeman, B., Papadakis, M., 1995. Companies Interactions with Federal Laboratories: What They Do and Why They Do It. Journal of Technology Transfer 20, 64–74.

Bozeman, B., Papadakis, M., Coker. K., 1995. Industry Perspectives on Commercial Interactions with Federal Laboratories. Final Report to the National Science Foundation.

Brod, A., Link, A.N., 1996. Trends in Collaborative Research Activity: An Interpretation of the Evidence. Mimeographed.

Brodley, J.F., 1990. Antitrust Law and Innovation Cooperation. Journal of Economic Perspectives 4, 91–112.

Cohen, L., 1994. When Can Government Subsidize Research Joint Ventures? Politics, Economics, and Limits to Technology Policy. American Economic Review 84, 159–163.

Cohen, W.M., Leventhal, D.A., 1990. In: Smith, V.K., Link, A.N. (Eds.), The Implications of Spillovers for R and D Investment and Welfare: A New Perspective in Advances in Applied Micro-Economics. JAI Press, Greenwich, CO.

Cohen, W.M., Leventhal, D.A., 1989. Innovation and Learning: The Two Faces of R and D. The Economic Journal 99, 569–596.

Colombo, M.G., Garrone, P., 1996. Technological Cooperative Agreements and Firm's R and D Intensity: A Note on Causality Relations. Research Policy 25, 923–932.

Combs, K.L., 1993. The Role of Information Sharing in Cooperative Research and Development. International Journal of Industrial Organization 11, 535–551.

Council on Competitiveness, 1996. Endless Frontier, Limited Resources: U.S. R and D Policy for Competitiveness. Council on Competitiveness, Washington D.C.

Cuzzens, S.E., 1995. Assessment of Fundamental Science Programs in the Context of the Government Performance and Results Act GPRA. Critical Technologies Institute, Rand.

d'Aspremont, C., Jacquemin, A., 1988. Cooperative and Noncooperative R and D in Duopoly with Spillovers. American Economic Review 78, 1133–1137.

DeBondt, R., 1995. Spillovers and Innovative Activities, Presidential Address. Meetings of the European Association for Research in Industrial Economics, September.

Finan, W.F., Link, A.N., 1994. Evaluation of the Value of the Semiconductor Research Corporation to Its Members. SRC Technical Report T94–177.

Henriques, I., 1990. Cooperative and Noncooperative R and D in Duopoly with Spillovers: Comment. American Economic Review 80, 638–640.

Jorde, T.M., Teece, D.J., 1990. Innovation and Cooperation: Implications for Competition and Antitrust. Journal of Economic Perspectives 4, 75–96.

Kamien, M., Muller, E., Zang, I., 1992. Research Joint Ventures and R and D Cartels. American Economic Review 82, 1293–1306.
Katz, M., 1986. An Analysis of Cooperative Research and Development,. Rand Journal of Economics 17, 527–543.
Leyden, D.P., Link, A.N., 1992. Government's Role in Innovation. Kluwer Academic Publishers, Boston.
Link, A.N., 1996a. Evaluating Public Sector Research and Development. Praeger Publishers, Westport, CO.
Link, A.N., 1996. Research Joint Ventures: Patterns from Federal Register Filings. Review of Industrial Organization 11, 617–628.
Link, A.N., Bauer, L.B., 1989. Cooperative Research in U.S. Manufacturing. D.C. Heath, Lexington, MA.
Link, A.N., Teece, D.J., Finan, W.F., 1996. Estimating the Benefits from Collaboration: The Case of SEMATECH. Review of Industrial Organization 11, 737–751.
Mowery, D.C. (Ed.), 1988. International Collaborative Ventures in U.S. Manufacturing. Ballinger, Cambridge.
Mowery, D.C., 1989. Collaborative Research in High-Temperature Superconductivity. In: Link, A.N., Tassey, G. (Eds.), Cooperative Research and Development: The Industry–University–Government Relationship. Boston, Kluwer Academic Publishers.
Mowery, D.C., Teece, D.J., 1996. Strategic Alliances and Industrial Research. In: Rosenbloom, R.S., Spencer, W.J. (Eds.), Engines of Innovation: U.S. Industrial Research and the End of an Era. Boston, Harvard University Press.
Ordover, J., Willig, R.D., 1985. Antitrust for High Technology Industries: Assessing Research Joint Ventures and Mergers. Journal of Law and Economics 28, 311–333.
Pisano, G.P., 1990. The R and D Boundaries of the Firm: An Empirical Analysis. Administrative Science Quarterly 35, 153–176.
Roessner, D.J., Wise, A., 1994. Public Policy and Emerging Sources of Technology and Technical Information Available to Industry. Policy Studies Journal 22, 349–358.
Scott, J.T., 1988. Diversification versus Co-Operation in R and D Investments. Managerial and Decision Economics 9, 173–186.
Scott, J.T., 1989. Historical and Economic Perspectives of the National Cooperative Research Act. In: Link, A.N., Tassey, G. (Eds.), Cooperative Research and Development: The Industry–University– Government Relationship. Boston, Kluwer Academic Publishers.
Scott, J.T., 1996. Environmental Research Joint Ventures Among Manufacturers. Review of Industrial Organization 11, 655–679.
Shapiro, C., Willig, R.D., 1990. On the Antitrust Treatment of Production Joint Ventures. Journal of Economic Perspectives 4, 113–130.
Simpson, R.D., Vonortas, N., 1994. Cournot Equilibrium with Imperfectly Appropriable R and D. Journal of Industrial Economics 42, 79–92.
Stephan, P., 1996. The Economics of Science. Journal of Economic Literature 34, 1199–1262. Suzumura, K., 1992. Cooperative and Noncooperative R and D in an Oligopoly with Spillovers. American Economic Review 82, 1307–1320.
Tassey, G., 1992. Technology Infrastructure and Competitive Position. Boston, Kluwer Academic Publishers.
Tassey, G., 1995. Technology and Economic Growth: Implications for Federal Policy. National Institute of Standards and Technology (NIST) Planning Report 95-3.
Tripsas, M., Schrader, S., Sobrero, M., 1995. Discouraging Opportunistic Behavior in Collaborative R and D: A New Role for Government. Research Policy 24, 367–389.
U.S. Congress, House Science and Technology Committee, 1983. Japanese Technological Advances and Possible U.S. Responses Using Research Joint Ventures. Hearings Before the Subcommittee on Investigation and Oversight and the Subcommittee on Science, Research, and Technology. Washington, DC, June 29–30.
Vonortas, N., 1994. Inter-firm Cooperation with Imperfectly Appropriable Research. International Journal of Industrial Organization 12, 413–435.
Vonortas, N., 1998. Research Joint Ventures in the United States. Research Policy, forthcoming.
Yi, S.-S., 1996. The Welfare Effects of Cooperative R and D in Oligopoly with Spillovers. Review of Industrial Organization 11, 681–698.