Technical roles and success of US federal laboratory-industry partnerships

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Drawing from questionnaire-based data of 229 US federal laboratory–industry joint R&D projects, this research examines the composition of the technical interaction by character of the R&D performed to determine the impacts on effectiveness of the technical roles played by research partners. In addition to the particular technical roles, their number and diversity are examined, giving particular attention to the subset of projects in which the company played no technical role. Our findings show that increased technical range on the part of industry is associated with increased product development and net economic benefit. Relatively few companies are technically passive with respect to their partnerships with federal laboratories. Nevertheless, a passive role can have positive results in terms of product development and improvement.

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PUBLIC POLICY MAKERS and politicians arguing against a role for US federal laboratories in commercialization of technology use highly charged terms such as 'industrial policy' and 'interference in the market place.' Proponents use very different language referring to federal laboratories as 'engines of innovation.' However, the companies actually involved in federal laboratory–industry partnerships concern themselves very little with the political rhetoric of technology partnerships and a great deal with the realities of business strategy. The political tempest surrounding these technical partnerships can obscure the fact that they are, fundamentally, strategies for producing and appropriating technical knowledge.

Federal laboratory–industry partnerships can be evaluated in much the same terms as other technical information acquisition strategies. Unfortunately, little evidence is available about the effectiveness of particular strategies implied by various technical roles. While there is a growing literature on such strategically-relevant technical acquisition approaches as "induce vs. purchase" (Link *et al*, 1983, Link 1978; 1983) and companies' participation in joint ventures and various technical alliances (Niosi and Bergeron, 1992), there are still only a few studies (such as Hill and Roessner, 1998; Geisler and Clements, 1995; Berman, 1994) of the effectiveness of federal laboratory partnerships. There are even fewer that focus on the business strategies driving the partnerships.

Using data developed in a national study (Bozeman *et al*, 1995; Crow and Bozeman, 1998) of federal laboratory–industry technical partnerships, our

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study research seeks to determine the impact of companies' and federal laboratories' respective technical roles on the success of the partnerships. Drawing from questionnaire-based data of 229 federal laboratory–industry joint R&D projects, this research examines the composition of the technical interaction by character of the R&D performed — basic research, precommercial applied research, commercial applied research, development, and testing. The central question is "What are the impacts on effectiveness of the technical roles played by research partners?".

In addition to the particular technical roles, we examine the number and diversity of those roles. Do projects with a greater number of technical roles ('technical range') have different outcomes than those that involve fewer technical roles? We give particular attention to the sub-set of projects in which the company played no technical role. Are projects in which the company is passive (at least in its R&D contributions) as effective as those in which companies contribute R&D?

Results of previous research from the present database (Crow and Bozeman, 1998; Bozeman *et al*, 1995; Bozeman and Papadakis, 1995; Bozeman, 1996) agree strongly on one point: no single indicator captures the effectiveness of technology transfer and commercialization efforts. In this study, we employ two quite distinct measures of effectiveness: companies' commercialization of products resulting from the projects; and companies' reported net benefit resulting from the projects.[1] Commercialization is measured as a dummy variable — did the project result directly in a new, marketed technology or service? Net benefit is an estimate provided by the company's project director. The measures are discussed more fully in a subsequent section of this paper.

A strategic perspective

Despite pressures on federal laboratories to market their wares to industry, companies initiate most federal laboratory–industry partnerships. Bozeman and Papadakis (1995) found that 87% of projects were initiated by either companies' top management or their research managers. In many instances, then, the company is initiating the partnership, pursuing the federal laboratory as a source of technical knowledge. In almost every case, the company's objective is to acquire scientific or technical knowledge. More specifically, some seek to develop new products or processes (42%), whereas others seek to develop their scientific and technical employees by providing additional skills and training (27.5%).

A strategic perspective on partnerships assumes that companies generally make self-conscious and well thought out decisions to engage in partnerships, and typically companies understand the costs involved, including opportunity costs (Kingsley *et al*, 1996). A strategic perspective considers not just whether to engage in a partnership but also the allocation of technical tasks among partners.

Thus, for example, companies might plan to exploit the partnership through joint research or by appropriating laboratory research while performing little or none of their own. Similarly, companies may plan to have the federal laboratory proceed along a more fundamental research line but then to do their own development or testing work. Alternatively, some companies come to laboratories specifically because they have equipment that permits tests the company could not perform alone.

Naturally, decisions about the allocation of technical activity are not the only strategic decisions. Companies in federal laboratory partnerships also consider intellectual property agreements (Chiang, 1995), financing of R&D (Tither, 1990), and the relationship of marketing to the resultant technical knowledge (Link and Zmud, 1986). There are many strategic approaches and issues. The focus of our study, however, is the allocation of technical activity and roles.

There is a good deal of research on companies' approaches to seeking technical information (Daghfous and White, 1994; Allen, 1966). While our specific focus is on the allocation of technical roles rather than patterns of technical information search, the two issues are not entirely separable. Thus, in this section, we present a brief summary of the

Downsizing/elimination of corporate research labs is a factor in companies' choice of technology strategies: one route is to acquire new technical knowledge from other organizations, another is to enter cooperative R&D agreements

It has been argued that the 'treasure chest' model (that federal labs have technology on-the-shelf ready for direct application to industry) is an inaccurate characterization of laboratory–industry relationships. According to Ham and Mowery (1995, page 72), "[e]xtended collaboration between labs and private firms will be needed to modify and apply most laboratory-developed technologies."

Another survey (Roessner, 1993) examined the types of interaction between private firms and federal labs. By far, the dominant reason for interaction was "access to unique technical resources." Downsizing and elimination of corporate research labs is one factor in companies' choice of technology strategies. One issue, then, is how to acquire new technical knowledge from other organizations (Rubenstein, 1994).

Entering into cooperative research and development agreements is another strategy firms use to acquire technical information. Miyata (1996) concluded that diversification might not be a strong reason for cooperative R&D. On the other hand, Miyata found that industries facing costly R&D and industries searching for basic research are more interested in cooperative R&D agreements. The behavior and style of business managers has been examined as it relates to adopting new technologies. in adopting new technologies for the firm, managers behave more like entrepreneurs than administrators (Gagnon and Toulouse, 1996).

Researchers have given a good deal of attention to the effects of various technical roles on innovation and commercialization of technology (Aram *et al*, 1992; Gates, 1988; Roessner, 1984). Indeed, companies' technical activity and the composition of their R&D says much about business strategy. For example, companies competing on the basis of innovation usually are more concerned with basic research and fundamental knowledge.

Industrial research has recently moved away from fundamental research (which was never dominant) to an even greater focus on highly focused research, and product and process development. At the same time, firms have been increasing their reliance on outside sources for technical information through alliances and industry–university collaborations (Rosenbloom and Spencer, 1996). A recent study of the National Science Foundation's (NSF) Engineering Research Centers (ERCs) concluded that "what firms appear to value in the ERCs is the availability of a flexible, multifaceted R&D supplier that permits them to buy into a capability to solve future problems" (Feller and Roessner, 1995, page 83).

In sum, business firms adopt various strategies and roles in generating and acquiring technical information and new technologies. In the next section, we provide some hypotheses about the relation of the strategies to success in industry–federal laboratory partnerships.

We examine two factors that may determine the effectiveness of federal laboratory–industry partnerships: technical role; and technical range. The first question is: "Are some combinations of technical roles (such as basic research, applied) and performer (for instance, federal laboratory, company, both) more effective than others?" The second is: "Regardless of the particular technical roles, does the number of technical roles relate to effectiveness?".

Technical range

Research and development theory supports the notion that companies with a broad technical approach, with skills along the R&D spectrum from basic to applied research to development, are more likely to appropriate scientific and technical information (Nelson, 1959; Link and Long, 1981). However, a more focused and specialized approach to R&D can also be effective (Archibugi and Pianta, 1992). The chief question here is whether partnerships involving a broad spectrum of technical activity are more effective than those involving a narrower set of activities. Does a project that involves, say, only applied research fare better (or worse) than one that involves applied and basic research, development and testing?

We address this question by examining three variables: the range of technical activity brought to the project (by both the company and the lab), the range of technical activity on the part of the company and the range of technical activity on the part of the federal laboratory. These three variables, labeled 'project technical range,' 'company technical range' and 'lab technical range,' are described in more detail in the Methods section of this paper.

> Hypothesis 1: A high level of technical range tends to be associated with partnership success, specifically high levels of net economic benefit for the companies and high rates of product development.

While the hypothesis does not specify any differences between company and lab range, we might expect that company range would be particularly important to success measures. Ultimately, the company has responsibility for incorporating a wide array of knowledge into a marketable product. A company that is engaged in a wide range of research and development will have the expertise and experience to make efficient use of resources and have an understanding of what is needed to be successful in the marketplace.

Technically passive role

In most federal laboratory–industry partnerships, the company is an active technical partner. It does not always collaborate directly with federal laboratory personnel but often performs in-house R&D directly related to the project. However, there are cases when the company is passive, at least with respect to the R&D performed as part of the project. In such circumstances, the lab has something the company wants (such as a nearly finished product or service, technical knowledge or know-how) and the company's concern is how best to capture the resource provided by the federal lab.

Technically passive companies may be quite active in other respects. They may be highly active in performing legal tasks necessary to appropriate the lab's resource, marketing the resource, paying for the resource, either by financing laboratory work, or providing in-kind services for the lab (such as serving as a beta test site). The question of interest here is the effectiveness of partnerships in which the company is passive with respect to R&D.

> Hypothesis 2: Partnerships in which the company is technically passive will tend to be associated with low levels of effectiveness in net economic benefit but high levels of effectiveness of product development.

Cohen and Levinthal (1990a; 1990b) have made a strong case that companies' benefit from R&D is related to their being an active performer of R&D. While agreeing with the general notion that companies' R&D capability and 'absorptive' capacity are important determinants of ability to innovate, a technically passive role may be appropriate to some purposes. In the particular instance of federal laboratory–industry partnerships, a passive role may relate (perhaps not causally) to product development effectiveness because the passiveness of the company implies that there is an existing resource (of the federal laboratory) to be appropriated.

In cases in which the company is technically passive, the net benefit will tend to be less for much the same reason — a product is about all that can be gained by the company when its technical role is entirely passive. If the company, say, simply licenses a federal laboratory technology, there is little opportunity for improving human capital, process technology or know-how.

Technical roles

With respect to any particular type of technical activity (such as basic research, applied research) there are four ways to allocate responsibilities for role performance: the lab can perform the role; the company can perform the role; both can perform the role; or neither. We examine projects that include five types of technical activity: basic research; precommercial applied research; commercially focused applied research; development; and testing. Within the confines of this conceptualization, there are some 20 ways in which technical roles can be allocated (five technical activities by four allocation schemes).

Using this framework we can consider a strategic question of considerable importance. Are there particularly effective approaches to allocating technical tasks in R&D partnerships? Several questions flow from this overarching one. Are there comparative advantages such that, for example, companies should invest their energies in development activity and leave basic research to the federal labs? Or is the road to project success complementary and collaborative R&D, with both company and federal lab performing the same type of technical activity? Are there some activities that are best performed by federal labs, some best performed by companies and some best performed collaboratively?

> Hypothesis 3: Projects in which the federal laboratory performs basic research will tend to be more effective in terms of high level of net economic benefit for the company. Projects in which companies perform development and testing will tend to have greater effectiveness in terms of product development and net benefit.

The hypothesis tests the conventional wisdom that public goods-oriented federal labs will be more effective in research where the results have less divisible economic character (Betz *et al*, 1980). Do companies succeed when their technical activity is nearer the end stages of technical development? According to Roessner (1993), the dominant reason for companies to interact with the federal labs is to have access to unique technical resources. There also has been a shift of corporate R&D strategies toward more applied research (Feller and Roessner, 1995). Our hypothesis suggests that project success will increase with specialization, with federal laboratories doing what they do best — basic research — and business firms doing what they do best — product development and commercialization.

Methods and measures

This study is based on data from questionnaires sent to industrial organizations that have interacted with federal laboratories during the past five years. The data include 229 federal laboratory–industry

This study is based on data from questionnaires sent to industrial organizations that have interacted with federal laboratories during the past five years: 229 federal laboratory–industry interactions on projects are included

projects are from 27 federal government laboratories, including most of the leaders in federal laboratory–industry commercial activity. While most of the projects involve collaborative R&D and formal cooperative research and development agreements (CRADAs), some entail personnel exchange, resource sharing and use of specialized equipment, licensing of technology, and technical assistance.[3]

Even though the project (not the laboratory) was the unit of analysis, decisions had to be made about which of the more than 300 federal laboratories were to be used to develop the project sample. The choice of federal laboratories was not random. Since strategic and managerial questions were paramount in the study, the focus was on commercially active federal laboratories, ones meeting any of a variety of commercialization criteria (see Bozeman *et al*, 1995). Among the labs included in the study are all the US Department of Energy multi-program labs, and more than one from the Defense Department, the National Aeronautics and Space Administration and the National Institute for Standards and Technology. A complete list is available from the authors.

The effective sampling population was 544 industry–federal laboratory projects. A total of 229 usable surveys were returned, giving an effective response rate of 42.2%.

Measures

The technical range variables are derived from questionnaire data asking the respondent to indicate the technical roles played by, respectively, the company's participants and the federal laboratory's participants in the R&D partnership. The respondent was asked to indicate whether, as part of the specifically identified project in question,[4] the company or the federal laboratory performed basic research, precommercial applied research, applied research, development, or testing.[5] The variable 'company technical range' is simply the respondent's report of the total number (0–5) of technical roles the company played in the project. Similarly, 'federal lab technical range' is the number of roles played by the federal lab. 'Project technical range' is the sum (0–10) of 'company technical range' and 'federal lab technical range.'

The variable 'technically passive' is measured as a dummy variable, 0=no technical role for the company, 1=one or more technical roles. There was, of course, no equivalent variable for the federal laboratories since they played at least one technical role in each of the projects.

The dependent variables are also based on questionnaire data. Respondents were asked to indicate whether, as a direct result of the specifically identified project:

- a product had been developed and marketed;
- an existing product had been improved;

derway; or

- no product was developed nor was product development underway.
- The variable 'product marketed' is a dummy variable based on the response to whether a product had been developed and marketed. The variable 'product improved' is a dummy variable based on response to whether a product had been improved.[6]

It is important to note that this study does not examine the impacts of products once marketed. From one perspective this is not a particularly serious limitation. If one takes the "out-the-door" model (Bozeman and Fellows, 1988; Bozeman and Coker, 1992) as the gauge for technology transfer success, the federal lab should be held accountable for companies' adoption of laboratory technology, not for the companies' subsequent success. Arguably, the federal lab has little control over such important factors as the companies' expertise in manufacturing and marketing, or such exogenous factors as the external economic conditions (such as changes in energy prices) that often affect market success.

From another perspective, using the "market model" of technology transfer (Bozeman and Fellows, 1988; Bozeman and Coker, 1992) it is important to go beyond the fact of transfer to consider the impacts of the transfer. While the federal laboratory can never control all factors related to economic impacts of its outputs, it does have choice with respect to the partners it uses to help deliver those outputs. In any event, the fact that this study looks at the commercialization of products and processes rather than their impacts, is a notable limitation.

The variable 'benefit' is the response to the following survey question:

> "Considering all the possible **benefits** (e.g. training of personnel; developing products or manufacturing processes; receiving technical assistance) **but not the cost**, what is your estimate of the dollar value (if any) of your company's interaction with the lab on this project?"

The variable 'cost' is the response to the following question:

> "Regardless of the amount of benefit received by your company from this project, approximately how much did this project cost your company in dollar terms? (For example, your company's share of R&D expenses, license fees, salaries for researchers located at the federal lab.)"

The variable 'net benefit' is defined as the remainder from subtracting costs from benefits. Because of the difficulties involved in benefit–cost measures where there are no direct costs, projects for which there were no reported costs were excluded from the analysis.[7]

Parenthetically, one possible approach to examining the impacts of technologies commercialized (the limitation noted above) would be to consider reports of benefit in projects in which technology was commercialized. This approach was rejected because many of the respondents observed that the benefits of working with federal laboratories often corresponded little with the actual development and commercialization of products but, instead, involved capacity building and development of fundamental knowledge with expected long-term payoffs. This is empirically verified by the lack of significant correlation between commercialization and measures of benefit (Bozeman *et al*, 1995).

Findings

Ours is an exploratory study based on data that are not robust. Thus, the preliminary analysis we present here is based largely on descriptive statistics, especially contingency tables. We feel this approach is adequate for the isolation of empirically-based strategy but one must exercise great caution in drawing inferences about cause.

Technical range and effectiveness

According to Hypothesis 1, higher degrees of technical range for the company, for the lab, and for the project (that is, company and lab), are expected to be associated with higher levels of net benefit and product development. The results show that the previously stated hunch that company technical range would be more important is borne out. Whereas the companies' degree of technical range seems to make a good deal of difference, there is no relationship between labs' and projects' technical range and the effectiveness measures.

Table 1 is a contingency table relating the variable 'company technical range' to the variable 'product'.[8] The results show a clear tendency for the companies with greater technical range (in the project) to have marketed products from the project, peaking at the most extreme degree of technical contribution (five different types of technical contribution) where half the projects marketed products. The nonparametric gamma coefficient of 0.36 summarizes the relationship.

One issue deserving some attention is the possible relationship between the year the project was initiated and whether a product resulted from it. It seems plausible that projects beginning earlier would have had more time to result in products and, thus, would have a higher rate of product production. Since the time origins of the project may be systematically related to several other factors considered in this analysis, the question bears addressing at this point. Cross-tabulations between the year the interaction began and whether a product resulted showed surprisingly little relationship (in the interest of space tables are not presented here, for more detail see Bozeman *et al*, 1995).

The earliest origin for projects was 1978 and the latest 1994, but of the more than 229 projects only 13 began in 1985 or earlier. The projects are strongly skewed, with larger concentrations beginning in 1989. Comparing 39 pre-1989 projects with 112 from 1989 and later, the rate of production of a product is 0.25 for the earlier group and 0.31 for the later group.[9] If the four 1994 projects are eliminated, none of which had developed products because the projects had just begun, then the rate moves up to 0.33.

What is happening here with respect to lag (or 'non-lag') effects is less mystifying than it seems. Public policies encouraging technology transfer and development began to take hold in the latter part of the 1980s and individual actors exerted considerable influence to increase the level of technology transfer activity (see Crow and Bozeman (1998) for a

Table 1. Company technical range and product development from project[a]

Company technical range	Product-no	Product-yes
No technical role	11 (91.7%)[b]	1 (8.3%)
One technical role	58 (84.1%)	11 (15.9%)
Two technical roles	36 (81.8%)	8 (18.2%)
Three technical roles	27 (67.5%)	13 (32.5%)
Four technical roles	15 (75%)	5 (25%)
Five technical roles	8 (50%)	8 (50%)
Column total	155	46
Gamma=0.36		

Notes: [a] Number of technical roles is a raw count and does not take into consideration the type or combination of roles
[b] Percentages are row%

Table 2. Company technical range and net benefit

Company technical range	Median net benefit (US$)	Mean net benefit (US$)
No technical role	−22,500	895,495
One technical role	−20,000	337,561
Two technical roles	0	−43,773
Three technical roles	25,000	4,635,261
Four technical roles	75,000	24,054
Five technical roles	250,000	78,798

Table 3. Patterns of R&D for net benefit of projects of US$1,000,000 plus

Rank net benefit	Basic company	Basic federal laboratory	Precommercial company	Precommercial federal laboratory	Applied company	Applied federal laboratory	Development company	Development federal laboratory	Test company	Test federal laboratory
1		X	X				X	X	X	
2							X	X	X	X
3	X		X	X	X	X	X	X	X	
4	X		X		X	X	X	X	X	
5		X	X		X		X			
6			X				X			
7	X	X	X		X					
8	X	X	X		X		X			X

public policy history). For present purposes, there seems little need to break down the analysis according to the time of project origin, especially given the strong concentration of projects within just a few years, 1989–1992 (71% of total projects).

The relationship between 'company technical range' and measures of net benefit are provided in Table 2. The results of the median net benefit measure indicate a strong, monotonic relationship between companies' technical range and net benefit from the projects. The results for the mean are highly skewed by two projects that reported enormous benefits and substantial costs. These extreme outliers were not eliminated because follow-up analysis showed that the projects did, in fact, yield prodigious benefit, but, from the standpoint of statistically testing generalizable hypotheses (as opposed to historical and case analysis), the use of the median seems a more reasonable approach.

Moreover, the results for the median net benefit are stark. The more technical roles performed by the company, the higher the net benefit. Performance of three technical roles seems to be the 'break even point.' It is also noteworthy that these findings are quite strong even without any consideration of particular combinations of technical activity.

A further indication that it is the number of technical activities that is important rather than some magic combination of particular activities is presented in Table 3; this focuses only on the eight (of 229) projects that reported net benefits of greater than US$1,000,000. With one exception, each of the projects included four or more project technical activities (that is, performed by either the federal lab or the company). There is no clear-cut 'winning' strategy, but there are some regularities. Seven of eight of these highly successful projects involved company-performed precommercial R&D and seven involved company-performed technology development. Largely absent from the profiles of these successful projects is federal lab-performed precommercial R&D (only one project), federal lab-performed applied research (only two projects) and federal lab testing (only two projects).

Table 4. Technical roles and product rates

Strategy	Number of companies	Percentage product marketed (%) (22.5%, n=207)	Percentage product improved (%) (26.3%, n=205)
Basic company	23	39.1	26.1
Precommercial company	47	31.9	22.9
Applied company	49	42.9	38
Development company	62	37.1	35.5
Testing company	44	43.2	34.1
Company passive	22	40.9	36.4
Basic federal lab	57	29.8	20
Precommercial federal lab	20	45	38.1
Applied federal lab	–[a]	–	–
Development federal lab	–	–	–
Testing federal lab	13	30	30.8
Basic both	60	11.7	23.3
Precommercial both	62	17.3	23.4
Applied both	20	25	30
Development both	42	21.4	25.6
Testing both	31	24.1	38.7

Note: [a] If $n \leq 10$, not reported

Impacts of particular roles

Aside from the number or combination of roles, it is possible that some particular roles tend to have higher pay-off than others. Thus, for example, federal laboratories might prove excellent basic research partners but less able development partners. Likewise, in their contribution to technical partnerships, companies may be more adept at some roles than others. Table 4 provides an account for each particular technical role, in terms of the percentage in which a product was marketed from the project, or a product was improved. Table 5 examines technical role with respect to net benefit.

Table 5. Technical roles, costs and benefits

Strategy	Number of companies	Benefit (US$) (US$925,975, n=154)	Cost (US$) (US$419,355, n=155)	Net benefit (US$) (US$487,588, n=142)
Basic company	23	354,244	221,200	133,044
Precommercial company	47	2,084,844	308,951	1,755,981
Applied company	50	432,361	290,988	137,736
Development company	59	340,437	353,971	(–18,840)
Testing company	43	456,696	281,763	167,295
Company passive	21	705,000	495,875	148,538
Basic federal lab	60	1,837,315	430,599	1,390,466
Precommercial federal lab	21	372,285	255,134	33,175
Applied federal lab	–[a]	–	–	–
Development federal lab	–	–	–	–
Testing federal lab	13	326,416	261,095	90,450
Basic both	59	430,024	453,745	(–79,310)
Precommercial both	62	381,847	665,111	(–296,840)
Applied both	19	615,466	824,421	(–172,333)
Development both	43	2,936,333	343,596	2,632,991
Testing both	31	2,560,891	520,870	2,041,239

Note: [a] If $n \leq 10$, not reported

There is a considerable range of effectiveness of particular technical role/performer combinations with respect to product development and improvement. For companies, testing, applied research and, surprisingly, basic research all have high rates of product development and improvement. For federal laboratories, the most effective role seems to be precommercial R&D. Interestingly, the effectiveness indicators tend to be considerably lower for technical roles when both the company and federal laboratory are performing the same technical role.

The results for net benefit differ somewhat. The most effective single company role is precommercial R&D, whereas the most effective single federal laboratory role is, as anticipated, basic research. With respect to jointly performed technical roles, development and testing seem to yield considerable net benefit, whereas jointly performed research (basic, precommercial, applied) actually produces net negative. This, taken with the relatively poor results of jointly performed R&D for product development provides a strong indication that when federal laboratories and companies perform the same technical roles there is more inefficiency than synergy.

Interestingly, technically passive companies are actually more likely to develop or improve products: this is probably less a testament to the value of passivity than to the single-mindedness of those companies pursuing such a strategy

Technically passive strategy

One strategy that companies can pursue is to contribute no technical activity to company–federal laboratory interactions and simply appropriate the results. This does not, of course, mean that the company is necessarily passive in all its technical information strategies. It is possible, for example, that technically active companies might wish to use most of their R&D resources for internal R&D. Similarly, a company might be technically passive on one project but not another. Thus, our question is what does technical passivity mean within the context of particular industry–federal lab projects (not more generally).

Technically passive companies are relatively rare among the projects examined here. Only 22 compa nies do not themselves play a technical role (other than user of technical information) in their partnerships with federal laboratories. From the standpoint of developing products from interactions, the passive strategy is not necessarily a bad one. As can be seen from Table 4, such companies are actually more likely to develop products (41% of 'passive' companies as compared to 21% of others) or improve products (36.4% compared to 26.3%). This finding is probably less a testament to the value of passivity than to the single-mindedness of those companies pursuing such a strategy. Whereas 40% of all projects had as their objective developing a new product, 80% of the passive companies' projects had product development as an objective.

The results for net benefit (Table 5) are considerably different. The 'inert' companies tend to report benefits somewhat below the average and costs somewhat above. Whereas the average net benefit is US$487,588, the average for the technically passive companies is only US$148,538. Incidentally, it is worth observing that there is, in general, relatively little correlation between rates of product development and reported benefits and costs (Bozeman *et al*, 1995). Many respondents indicated that employee training and development objectives were an extremely important benefit of federal lab–company interactions, even when the project yielded no commercial product.

Conclusions

Generally, assessments of the effectiveness of government laboratory–industry technical partnerships fail to consider the wide variety of technical roles played by the respective partners. We have shown that there is, indeed, an array of technical roles and that some seem to be more successful than others. Conceptualizing government laboratory–industry technical partnerships as, essentially, business strategy seems to have much to recommend it. Clearly, companies' objectives for these partnerships vary considerably (Bozeman and Papadakis, 1995; Bozeman *et al*, 1995) and there is no reason to assume that the various technical strategies used in the pursuit of those objectives will be equally effective.

We found that increased technical range on the part of industry was associated with increased product development and net economic benefit. At a time when many companies are reducing and restricting their in-house R&D, such results may suggest that companies should consider maintaining a broad range of research and technical activity, even if (or especially if?) the R&D staff is not particularly large.

We found that relatively few companies are technically passive with respect to their partnerships with federal labs. Yet even such a passive role can have positive results in terms of product development and improvement (although the economic benefit for the technically passive companies is somewhat lower than more active companies). Thus, for very specific company objectives a technically passive role can be effective.

Surprisingly, jointly performed technical roles were generally less effective than either single-performer roles or even a technically passive role. We cannot determine from this data just why jointly performed technical roles seem less effective, but it may be they require increased coordination and increased resources for project management. Joint technical roles may simply increase the benefit–cost denominator.

In terms of particular mixes or roles, we found companies are most effective in product development when they are performing applied research, product development, and product testing. Product marketing and improvement were associated with federal lab roles of precommercial research and testing. When economic benefit is the criterion, the greatest benefit results when federal labs perform basic research and when companies perform precommercial applied research.

Given that technical range is closely related to the effectiveness of federal laboratory–industry partnerships, it seems important to understand why companies choose a technical strategy that has breadth in terms of technical roles. The model developed to explain technical range focused on both objectives for the project and on firm attributes and was able to predict companies' technical range. Somewhat surprising was the significant negative association between company R&D personnel and technical range.

Technical range is only one of many technology and information acquisition strategies that should be evaluated as researchers seek to determine elements of the effectiveness of collaborative R&D and, in particular, federal laboratory–industry partnerships. Future research might well focus on such issues as the choice of substantive research and technical problems, the interaction of technical and nontechnical (such as marketing) resources, and the relationship of information and technology created in partnerships to firm's store of self-provided information and technology.

We feel this study demonstrates that collaborative research is neither virtue nor vice. It is not the act of technical partnership that is (or is not) effective; instead the technical strategy underlying the partnership must be considered. Policy-makers seeking simply to increase or thwart federal laboratory–industry collaborations would do well to look beyond the surface and begin to plumb the depths of collaborative strategy. Not all strategies are created equal.

Notes

1. A third 'obvious' effectiveness indicator is not used here. While we have data on job creation, the average number of jobs created per project is only 1.5 and there is insufficient variance in this variable for it to be of interest.
2. More detail about study procedures and methods is provided in Bozeman *et al* (1995) and in Bozeman and Papadakis (1995).
3. We use the term 'federal laboratory–industry partnership' broadly to include each of these activities.
4. Each questionnaire included a unique project description section so as to clearly anchor the responses.
5. Respondents seemed to have no difficulty distinguishing among these categories of activities. Recent evidence provided by Link (1996) indicates considerable convergent validity among experienced researchers making distinctions among the standard R&D categories.
6. Respondents were also asked about results in the development of processes and manufacturing but, in the interest of space, these items are not examined in this paper.

7. Of the 229 projects, 14% reported no cost sustained by the company.
8. The same analysis was performed on each of the three technical diversity variables. The Kendall's tau was near zero for the relationship between 'product' and, respectively, 'project technical diversity' and 'federal lab technical diversity.' An examination of the contingency tables revealed no noteworthy relationship.
9. Full data are available for 151 projects.

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