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The "Gradient Effect" in Federal Laboratory-Industry Technology Transfer Partnerships

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Based on data from 229 industry-federal laboratory projects, our research analyzes combinations of technical roles and laboratory characteristics to determine their relation to projects' effectiveness. The results show increased effectiveness when the combination of technical roles follows a "gradient." That is, performance is enhanced when the company plays a different technical role than the laboratory, but a role that is only a step away on the basic-applied-development spectrum. Effectiveness diminishes when both the company and the federal laboratory play the same technical role or when the technical roles are far apart on the basic-applied-development spectrum. The results may have general implications for public policy partnerships, suggesting that although partnership effectiveness requires distinctive roles, partner roles should not be so different as to undermine possibilities for coordination and integration.

1. Introduction

In the United States and throughout most of the world, many public goods and services are delivered by public-private partnership. Public-private partnerships are viewed as institutional arrangements that can "make things happen" (Rosenau, 2000) in a wide array of policy domains, including, among many others, child care (U.S. Department of Health and Human Services, 1998), transportation infrastructure (Lawther, 2000), public safety (Whiting, 1999), health care (Zelman, 1996), and housing (Payne, 1999). Such partnerships vary enormously with respect to their objectives, legal instrumentalities, interorganizational management structures, and the roles and relationships among partners (Lindblom, 1977). In some instances, government agencies work hand-in-glove with contractors, with explicit tasks and responsibilities enumerated in contracts. In other cases, informal consortia of government and private actors work together in a loose confederation. Other relationship forms include, for example, coproduction, public authorities, and interorganizational teams brokered by professional associations. To an increasing extent, policymakers view allocation choices not as market or government but as quasi-government or collaboration.

The study of federal laboratory-industry technology partnerships may be an instructive case study for the more general topic of intersector partnerships and

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collaboration. In the United States, as elsewhere, public-private partnerships for technology transfer have grown steadily during the last 15 years (Bozeman, 2000). From the perspective of government policy for technology development and research and development (R&D), partnerships between companies and federal laboratories have been of particular interest. Federal laboratory-industry relationships are far from being simple to understand. Typically, the partners have different research and technology management cultures, different technical and managerial strengths and weaknesses, and, all too often, different and even conflicting motives for the technology partnership. One result is that the evaluation of outcomes of these collaborations is inherently difficult.

Partnerships between government laboratories and industry seem to us a particularly fecund setting for understanding determinants of the effectiveness of partnerships as a policy instrument. First, these partnerships have existed for several years and number in the thousands (Crow & Bozeman, 1998). Second, they vary considerably in their magnitude, focus, and partnership structures. Third, although it is not easy to measure the effectiveness of these technology transfer partnerships, there are some standard approaches, such as benefit-cost assessments (Link, 1996), and some tangible outcomes, such as commercialized technology (Bozeman & Wittmer, 2001).

In this study, we focus on a quantitative but perceptual measure of effectiveness, industrial participants' estimates of the marginal benefit of the technology transfer partnerships they entered into with federal laboratories. We seek to account for technology transfer effectiveness in terms of the specific technical roles assumed by the respective partners. Myriad factors account for technology transfer effectiveness, but technical role is an especially important focus because of the strategic implications. Industrial organizations generally have discretion in choice of technical roles and, just as important, can choose federal laboratory partners on the basis of the fit of technical strengths. We are particularly interested in determining if there are optimal combinations of technical roles. For example, is it better for the federal laboratory to perform basic research while the industry partners perform applied research and technology development? Is it better for the partners to share technical roles or to specialize? In a related study focusing on different effectiveness measures (including the commercialization of technology), Bozeman and Wittmer (2001) found that increased technical range (i.e., more roles) performed on the part of the industry partner led to increased likelihood of product development. Few other studies have focused specifically on technical roles.

Based on questionnaire data from 229 U.S. federal laboratory-industry joint projects, we examine perceived "cost-benefit" from the point of view of the companies participating in the partnership. We seek to determine the relevance to effectiveness of the respective technical roles employed by the companies and the federal laboratories, as well as the *interactions* among roles. An understanding of the impact of technical roles on technology transfer effectiveness is particularly important because findings could be put to use by policymakers and by companies seeking partnerships with federal laboratories. Many of the determinants of technology transfer effectiveness have limited strategic relevance. For example, if one finds that larger firms benefit more from federal laboratory technical partnerships, small firms cannot grow larger just to enhance their technology transfer effectiveness. By contrast, firms and federal laboratories often have discretion with respect to the technical roles they choose in their partnerships. In many instances, it is a simply a matter of knowing which roles are most likely to provide benefit.

The general logic of our study may have relevance to broader issues of public-private partnership effectiveness. If it is determined that the fit between or among partners' roles is an important element to effectiveness, then a next step is to identify other policy domains in which similar sets of variables can be examined and, more ambitious, to begin to develop a theory of complementary roles of partners. We suspect that a more sophisticated understanding of not only partners' roles but also the nature and form of role interactions may provide useful insights into the performance of many types of public-private partnerships.

In section 2, we provide some background on public policy for technology transfer and the general issue of public-private partnerships in public policy. In section 3, we present a model for examining technology transfer effectiveness. In section 4, we present our research questions and hypotheses. Section 5 presents our findings, and we discuss broader implications in section 6, our conclusions.

2. Federal Laboratory Technology Transfer: Public-Private Partnerships and Public Policy

Until the past few decades, government technology policy certainly would not have been one of the first places one turned to understand public-private partnerships. Partnerships were actively discouraged by legal prohibitions designed to minimize possibilities for conflict of interest. With respect to intellectual property produced by government researchers, the law was premised on the idea that if the research had been paid for by tax dollars the result should be in the public domain.

In the 1980s, this reasoning was turned on its head. With fears of a "competitiveness crisis" the U.S. federal government cast about for ways to use public policy as a stimulus to innovation, in particular imitating Japanese government technology policies (or, more accurately, popular perceptions of these policies). During the 1980s and early 1990s, revolutionary "cooperative technology" policies (Crow & Bozeman, 1998) were developed that expanded the use of government technology (Patent and Trademark Laws Amendment, 1980), relaxed antitrust regulations and promoted cooperative research and development (National Cooperative Research Act, 1984; Patent and Trademark Amendments, 1980;), developed cooperative research centers and consortia (Berman, 1994; Devine, James, & Adams, 1987; Dill, 1990; Smilor & Gibson, 1991), and altered guidelines for disposition of government-owned intellectual property (Gillespie, 1988; Jaffee, 2000). 1

Among the cooperative technology policies attracting most attention were those aimed at enhancing the use of federal laboratories as partners to industry in the commercialization of technology (Herrmann, 1983; U.S. General Accounting Office, 2
1989). A variety of public policies (for an overview, see Crow & Bozeman, 1998) removed most of the limitations on U.S. federal laboratories' commercial activity,

changing intellectual property law and actively encouraging technology transfer through partnerships with industry, especially via cooperative research and development agreements (CRADAs).

Much of the research literature on federal laboratory-industry technical partnerships has focused on the effectiveness of technology transfer. Many purported determinants of effectiveness have been examined, including such factors as dollars invested in the partnerships, participation of top managers, geographic distribution of partners, and medium of technology transfer (see Bozeman, 2000, for an overview). Although the research on federal laboratory-industry technology transfer effectiveness is by this point extensive, relatively few of the studies are comparable. Many different technology transfer effectiveness measures have been employed, in part because notions of effectiveness are quite varied among participants and in part because of the difficulties of measuring partners' returns as well as social returns. Some researchers have analyzed the number of patents as a chief outcome of these partnerships (Adams, Chiang, & Jensen, 2002; Jaffe, Fogarty, & Banks, 1998). Others have focused on measuring the degree of commercial success (e.g., Brown, 1997; Kassicieh, Radosevich, & Senker, 1996). However, as Ham and
3 Mowery (1997) argue from their case studies, companies also obtain benefits that come rather indirectly from their partnerships with federal laboratories. In their case studies, they found that companies benefited from enhanced technical capabilities even when there was no direct benefit to product development. Moreover, product development, patenting and commercial success depend on much more than technology transfer efforts; factors such as marketing skills and ability to manufacture products are vitally important to commercial success. Thus, it is extremely difficult separately to evaluate the impacts of technology transfer on commercial success and, of course, determining social impacts is even more daunting.

3. Conceptual Framework: A Strategic Perspective on Federal Laboratory-Industry Partnerships

Empirical evidence shows that most laboratory-industry partnerships are initiated not by the federal laboratories but by companies. Bozeman and Papadakis (1995) found that 87% of projects were initiated either by companies' top management or by companies' research managers. Economic theory of the firm tells us that companies have strong motivations to seek information and make rational decisions about whether to engage in partnerships and, if so, with whom. Similarly, a strategic perspective tells us that firms are likely to give careful consideration to the role they play in the partnership and to finding a collaborative partner who can play a complementary role. Several studies (e.g., Eisenhardt & Schoonhoven, 1990; Niosi, 1995; Niosi & Bergeron, 1992; Pisano, 1991) indicate that companies typically understand the costs involved in technical partnerships, including opportunity costs.

A strategic perspective considers not just *whether* to engage in a partnership but also the allocation of technical tasks among partners (Roessner, 1993; Roessner & Bean, 1991). Companies' choice of technical partner is often based on ideas or plans pertaining to technical task roles. Thus, for example, some companies come to specific laboratories because the labs have equipment that permits scientific tests the company could not perform alone. Others hope to develop joint research. Still others plan to have the federal laboratory conduct basic research while the company focuses on development.

Decisions about technical roles are not made in isolation. Collaborative strategy is multi-faceted and includes, among other factors, issues pertaining to marketing (Piper & Naghshpour, 1996), R&D funding (Perchorowicz, Dakin, & Lindsey, 1991), intellectual property (Gillespie, 1988; Hertzfeld, Link, & Vonortas, 2001), and alternative sources of scientific and technical information (Daghfous & White, 1994). According to Ham and Mowery (1995, p. 72), "extended collaboration between labs and private firms will be needed to modify and apply most laboratory-developed technologies." This observation is counter to the "treasure chest" model (that federal labs have technology on the shelf ready for direct application to industry) and suggests that technology transfer effectiveness likely depends on having a viable technical strategy. Firms seem to know that federal laboratories' technologies are not immediately ready for the market, and relatively few firms search for products that can be marketed with little or no modification (Bozeman & Papadakis, 1995). Roessner (1993) found that firms' primary reason for interacting with federal laboratories is to develop "access to unique technical resources." Similarly, a recent study of the National Science Foundation's 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 & Roessner, 1995, p. 83). In sum, business firms adopt various strategies and roles in generating and acquiring technical information and new technologies.

A few studies have specifically focused on the impact of technical roles and technical strategy on innovation and commercialization of technology (Aram, Lynn, &
Reddy, 1992; Roessner, 1984; Bozeman & Wittmer, 2001). These studies suggest that 4
companies' choice of technical activity relates specifically to their business strategies. Thus, companies competing on the basis of manufacturing quality may focus on process technology, whereas those focusing on innovation and first-to-market may have more interest in tracking the cutting edge of science and technology. These bases of competition have very different implications for companies' choice of technology partners and for respective technical roles.

Taking into account these assumptions, we present Figure 1, a "conceptual model of technology partnering" for companies collaborating with federal laboratories. The model implies that the choice of technical partner (in this instance federal laboratories) depends on the particularities of the company's business strategy, the company's choice of the technical role it wishes to perform, the role anticipated for the partner, and the availability of partners with particular configurations of technical resources and capacity. Like all models, this one is a simplification, not identifying the many types of technical activities possible (only the most familiar categories) and not focusing on the proactive role of federal laboratories in shaping the technical relationship. We feel this is an acceptable simplification because we are chiefly interested here in the companies' technical choices.

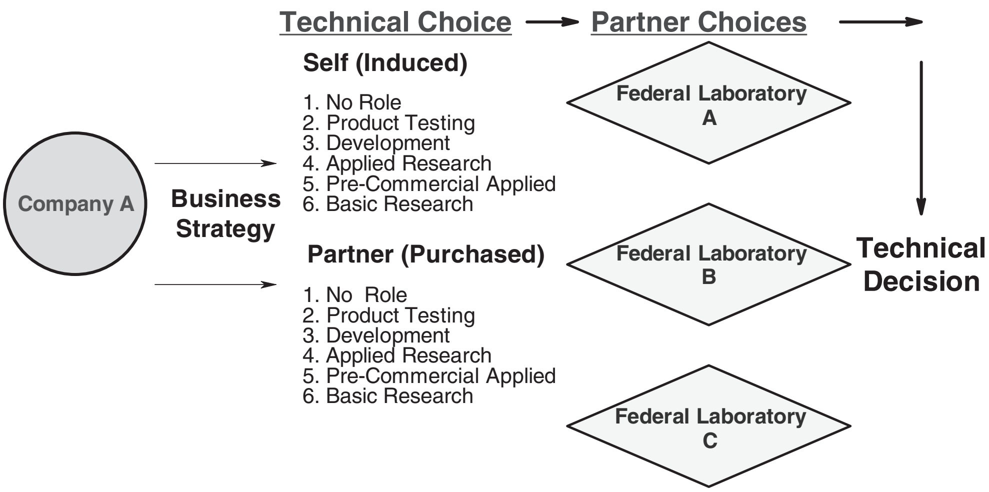

Figure 1. Conceptual Model of Technical Partner Choice.

4. Research Questions

Considering the model presented above, the implication is that companies seek to shape technical roles, for both themselves and their partners. We hypothesize that some combinations of roles may prove more effective. Using a cost benefit ratio as a measure of perceived effectiveness, we consider the following research questions:

1. Which interaction or combination of technical roles do companies and federal laboratories need to undertake to increase effectiveness (measured as a lower cost/benefit ratio)?

2. If we take into account that companies who pursue partnerships with federal laboratories differ in their motivations, how do combinations of technical roles affect their effectiveness?

3. Which federal laboratory characteristics determine effectiveness? More specifically, what are the impacts on effectiveness of the following factors: laboratory personnel understanding of companies' market requirements; skills and knowledge of laboratory scientists; and uniqueness of expertise (personal or facilities of the laboratory)?

Regarding technical roles, recent research using the same data set as we use in this study has examined the role of "basic research" and other technical roles in federal laboratory-industry partnership (Rogers & Bozeman, 1997; Bozeman & Wittmer, 2001). These studies found that basic research is generally more suitable for federal laboratories, whereas companies perform better on downstream tasks closer to product development. Bozeman and Wittmer (2001) found that increased technical range (number of technical roles played by companies) is positively associated with increased product development. A limitation of previous studies is that they did not present simultaneous controls for potentially relevant variables, making difficult the task of clearly identifying significant relationships about specific patterns of interaction among technical roles. We address this limitation.

5. Hypotheses

The questionnaire used in this study (Bozeman, Papadakis, & Coker, 1995) identifies five different technical roles, namely, basic research, precommercial applied research, commercial applied research, development and design product testing (exact wording and specifications are presented in Bozeman & Wittmer, 2001). In this context, a primary hypothesis is that there are sets of compatible technical roles that enhance the perceived technology transfer effectiveness. Our specific expectation, and the most important hypothesis for our study, is that effective combinations of technical roles follow a gradient whereby companies' technical roles are just one step prior to the laboratories' role in the basic-applied-development spectrum. That is, if a company is performing product testing, the federal laboratory should perform the role of development and design. Similarly, if the company is performing the role of precommercial applied research, the federal laboratory should perform basic research.

The basis for the gradient hypothesis is a complementarity assumption. The argument is straightforward. If the company and the federal laboratory are performing exactly the same technical role, (e.g., both primarily engaged in applied research), then there is less likelihood of comparative advantage and more likelihood of duplication and overlap. Although duplication can in some cases actually enhance effectiveness, it is more resource intensive and, by definition, less efficient. Since firms seek information within a range of cost, duplication generally is not preferred. At the same time, if the company technical role and the federal laboratory technical role are far removed from one another, then there is a knowledge gap that is not filled, at least not in any obvious way.

Perhaps the best metaphor for the gradient hypothesis is a relay race in which two runners pass the baton. If the two are running the same stretch of the race, there is an obvious problem, but if there is no one to pass the baton to at one leg of the race, there is also a problem. In short, there must be someone in place to move the baton (or the technical knowledge) to the next level.

One might well argue that the idea of a gradient effect assumes a linear model of technology. That observation is, strictly speaking, true. We do assume a set of stepwise technical roles. However, we are not assuming that the various technical roles must be performed in stepwise fashion, only that they must be performed at some point by someone. They may be performed in parallel; they may be performed simultaneously; they may be performed jointly—but the technical roles performed should be sufficiently close to one another, at any particular stage, to allow close communication and the movement of technical knowledge to the next level. We recognize that in today's world the time between basic research and commercialization often is compressed and the routes to technical products are varied. We nonetheless suggest that technical roles that are "adjacent" may well work best and, of course, that suggestion is falsifiable.

The following model is used to test our gradient hypothesis:

$$CBR_i = \beta_0 + \beta_1 Market_i + \beta_2 \textit{ Technical roles interactions}_i + \text{Control Variables} + \text{Ui.} \quad (1)$$

Additionally the same model but with a dependent variable that evaluates "overall experience" with the federal laboratory will be regressed to verify if the explanatory variables show the same pattern. The expectation is to have a similar pattern as the exposed in the first hypothesis.

$$labgood_i = \beta_0 + \beta_1 Market_i + \beta_2 \textit{ Technical roles interactions}_i + \text{Control Variables} + \text{Ui.} \quad (2)$$

Although it is our expectation that the technical roles performed by the company and the laboratory should be close to one another, there is a strong possibility of ineffectiveness when the company and the federal laboratory play the same technical role. (This is less likely to be problematical when there are multiple roles for both parties.) Consequently, our second hypothesis is that interaction of the same technical roles between companies and federal laboratories will increase the cost/benefit ratio. That is, it will reduce the perceived effectiveness for the company. In addition, it will be negatively correlated with the company's overall satisfaction with it partnership, tested through model (2). The rationale of this hypothesis is that overlapping of functions might decrease the company's learning from the laboratory. It might even create conflicts and ultimately incompatibility.

The third hypothesis, consistent with the first, is that these "gradient combinations" of technical roles work differently for companies with different objectives, having implications for perceived effectiveness. The questionnaire we employed depicts six different technical objectives, among which four seem to be the most important, at least in terms of response frequencies. These include the objective to improve an existing product, process or service; the objective to pursue precommercial research in a company's strategic area; the objective to develop a new product; and finally the objective to gain access to information, expertise and facilities unique to the federal laboratory.

Bozeman, Papadakis, and Coker (1995) showed that companies' objectives vary considerably when they look for a partnership. Consequently, we treat companies' expectations about cost and benefit, as one way to measure effectiveness, separately from objectives.

The fourth hypothesis is that "marketplace understanding" of the federal laboratory's personnel enhances effectiveness. Some of the background on this issue is provided by Mowery (1998). Based on case studies of cooperative research and development agreements (CRADAs), he argues that limited familiarity of laboratory's personnel about potential commercial users of the company's technology often times leads to more obstacles and less success in the collaboration.

Our fifth hypothesis asserts that the skills and knowledge of laboratories' scientists, and the unique expertise or facilities of the laboratory, enhance the perceived effectiveness of the companies' partnerships. Nevertheless, the positive effect of these variables is only significant as moderated by the objective originally pursued by the company in the partnership.

The following models capture all the hypotheses proposed above except the first. Model (3) captures the cost benefit ratio of companies that pursued the objective of improving and existing product.

$$cbrexist_i = \beta_0 + \beta_1 Market_i + \beta_2 Unique_i + \beta_3 skills_i + Technical\ roles\ interactions_i + \text{Control Variables} + \text{Ui.} \tag{3}$$

Model (4) captures the cost benefit ratio of companies pursuing pre-commercial research in an area of its strategic interest:

$$cbrstrategy_i = \beta_0 + \beta_1 Market_i + \beta_2 Unique_i + \beta_3 skills_i + Technical\ roles\ interactions_i + \text{Control Variables} + \text{Ui.} \tag{4}$$

Model (5) captures the cost benefit ratio of companies pursuing the objective developing a new product.

$$cbrnew_i = \beta_0 + \beta_1 Market_i + \beta_2 Unique_i + \beta_3 skills_i + Technical\ roles\ interactions_i + \text{Control Variables} + \text{Ui.} \tag{5}$$

Model (6), with the same explanatory variables of model (5) captures the cost benefit ratio of companies pursuing the objective of gaining access to information, expertise or facilities unique to the federal laboratory.

6. Data and Methods

Our research is based on data from questionnaires sent to companies and organizations that had collaborative partnerships with federal laboratories from the years 1989 to 1994 (Bozeman, Papadakis, & Coker, 1995). The data include 229 of partnerships, 69% of which are based on Cooperative Research and Development agreements (CRADAs). The remaining partnerships are distributed in various groups that include R&D consortiums and other joint and cooperative R&D projects (1).

The cost benefit ratio used divides the cost in dollar terms for the partnership in dollar terms for the company over its perceived benefits, likewise expressed in dollars. In the questionnaire, the question about cost in the questionnaire asks "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?" The question about benefit asks "Considering all the possible benefits (e.g., training of personal, developing products or manufactured processes, receiving technical assistance) but not the costs, what is your estimate of the dollar value (if any) of your company's interaction with the laboratory on this project?" We use the ratio between cost and benefit (cost/benefit) with the objective to normalize the data regarding the size of the projects, which varies sharply in the sample.

Model (1) uses the simple cost/benefit ratio as dependent variable for all observations. Model (2) uses a variable of perceived "overall experience" with the same set of explanatory variables of model (1) as a reinforcement to find out if the explanatory variables show the same pattern. Models (3), (4), (5) and (6) use as dependent variables the cost/benefit ratio multiplied by the variable of objective. Thus, each of these later models only captures relationships according to the particular objective that companies had when they joined the partnership. The study analyzes compatibility and interaction of technical roles.

All five models were regressed using Ordinary Least Squares. The choice of this method is appropriate for the characteristics of the dependent variables and the structure of the models, but OLS also keeps the regression analysis simple, important because the data are not robust. All models were tested changing control variables and other specifications. The coefficients were also tested for heteroskedasticity. All models have control variables to account for certain characteristics of firm. Variables controlled include size of the company and ownership. Previous research (Leyden & Link, 1999) shows that size is sometimes a determining factor in the composition of federal laboratory-industry technology transfer partnerships.

7. Findings

Technical Roles Interaction

Under the specification of model (1), the results show three interactions of technical roles between companies and federal laboratories that appear be statistically
5 significant. First, the interaction between precommercial applied research undertaken by the company and basic research undertaken by the laboratory has a negative correlation with the cost/benefit ratio. This means that this combination of roles enhances the perceived effectiveness of the partnership for the company.

The pattern is much the same for the interaction of the roles of development and design undertaken by the company and pre-commercial research by the federal laboratory. These results are interesting not only because they remain robust even while changing different control variables but also because the hypothesized "gradient effect" is observed in the interaction of technical roles.

The third significant interaction of technical roles is the case of companies playing development and design roles and federal laboratories playing the basic research role. This interaction is positively correlated with the cost benefit/ratio, which means that the interaction decreases the perceived effectiveness. This could be explained by the argument of the roles being "too far" from one another in the basic-applied-development spectrum (i.e., too distant in the gradient).

Model (2) uses the global satisfaction variable, whether the company perceived that its overall experiences with the federal laboratory was a good one. The findings are similar to those for model (1). The interaction between pre-commercial

Table 1. Results

Dependent vars. → Explanatory vars. (below) (*)	Model (1) *CBR*	Model (2) *labgood*	Model (3) *cbexist*	Model (4) *cbstrategy*	Model (5) *cbnew*	Model (6) *cbexpert*
market	−8.836659	0.4256281	−0.4815488	−2.542931		
	(−3.25)***	(6.51)***	(−1.77)+	(−2.03)**		
private	12.47245	0.2216821	0.72521	0.2845	0.38745	0.2147
	(2.23)**	(1.37)	(0.74)	(1.13)	(1.59)	(1.23)
rdemratio	2,727,211	−0.0068465				
	(0.49)	(−0.51)				
sales	−0.3619923	0.0149071	−0.3201357	−0.00585	−0.08465	−0.01485
	(−0.21)	(0.28)	(−2.01)**	(−0.59)	(−0.11)	(−0.99)
crada	6.928375	0.2468145				
	(1.60)	(1.80)+				
noprev	2.663066	−0.0008561				
	(0.60)	(−0.01)				
lbenchi	7.609606					
	(1.66)					
bcbl			1.23865			
			(2.40)**			
pcpl	6.495909	−0.1843902		6.252724	0.9239176	
	(1.13)	(−1.30)		(1.20)	(2.05)**	
acal	−2.129611		0.5929484			
	(−0.24)		0.61			
dcdl	−14.38233	−0.0059664				
	(−1.20)	(−0.03)				
tctl	−1.516758	0.0844789				
	(−0.28)	(0.50)				
pcbl	−12.19163	0.3612647	−6.118131		−0.0518732	
	(−2.09)**	(2.56)**		(−1.71)+	(−0.11)	
acbl	−8.27754	−0.1591451				
	(−1.23)	(−0.83)				
dcbl	15.37413	−0.0059664				
	(2.55)**	(−0.03)				
acpl	7.491801					
	(0.99)					
dcpl	−10.65097	0.0836665				
	(−1.76)+	(0.41)				
dcal	21.86771					
	(1.51)					
tcal	−19.5137		0.1353919	1.017673		
	(−1.35)		(0.15)	(0.16)		
tcdl	0.2246311	0.3281778			−0.7744732	
	(0.02)	(2.05)**			(−1.64)+	
unique					−0.253641	1.295655
					(−0.55)	(0.99)
skills			−1.007906		0.6200354	0.2013448
			(−2.17)**		(1.35)	(0.15)
basicl						−2.635727
						(−2.18)**
precoml						−2.015078
						(−1.73)+
R-square	0.20	0.33	0.18	0.11	0.21	0.09
No. of observations	55	90	90	115	91	115

(*)See full names of the variables in Appendix 1.
Number is parenthesis are t-test (t).
+Statistically significant at the 10% confidence level.
**Statistically significant at the 5% confidence level.
***Statistically significant at the 1% confidence level.

applied research undertaken by the company and basic research undertaken by the federal laboratory has a positive correlation with global satisfaction variable.

There is yet another technical role interaction statistically significant in both models (1) and (2)—the interaction in which the company has the role of product testing and the federal laboratory has the role of development and design. However, the variable does not hold robust when alternating controls variables.

Technical Roles Interaction Geared toward Companies' Objectives

Model (3) takes into account the different objectives of the companies, as these interact with technical roles. In model (3), which considers the cost/benefit ratio for companies that had the objective "to improve an existing product showed," one interaction is statistically significant. When both companies and federal laboratories perform basic research as technical role there is a positive correlation with the cost/benefit ratio (i.e. negative effectiveness). This supports the second hypothesis we presented, which argues that both partners having the same technical role results in reduced effectiveness of the partnership.

Model (5) considers the cost/benefit ratio for companies that had the objective to develop a new product. Here, the interaction of both companies and federal laboratories with the role of pre-commercial research shows a statistically significant positive correlation with the cost/benefit ratio. In other words, the ratio grows with the effect of this variable, diminishing perceived effectiveness of the partnership. The same model (5) shows a negative correlation with the cost/benefit ratio of the variable that represents the interaction of the company in the role of product testing and the federal laboratory in the role of development and design. While the result is significant at only the 10% confidence level it is consistent with findings from model (2).

Model (4) considers the cost/benefit ratio for companies that had the objective of pursuing precommercial research in a company's area of strategic interest. One interaction is statistically significant, the interaction between pre-commercial applied research undertaken by the company and basic research undertaken by the federal laboratory. The result is a negative correlation with the cost/benefit ratio. This also reinforces the result obtained in model (1). Apparently, this particular interaction enhances the companies' perceived effectiveness at this phase of the technical activities.

Finally, model (6) captures the effects for companies that had the objective "to gain access to information, expertise and facilities unique to the federal laboratory." None of the interactions has a significant effect on the cost/benefit ratio. It appears that when companies are not interested in the creation or production of any particular product, the interaction of technical roles of the partners does not matter.

Market Understanding

Model (1) examines the variable pertaining to the company's assessment that the federal laboratory personnel understand their (the company's) market. The regression for the model is statistically significant. It also shows the expected negative effect on the cost/benefit ratio, meaning that knowledge of the company's market in the federal laboratory increases perceived effectiveness. This result is in line with a study (Ham & Mowery, 1998) that shows the importance of relations between the federal laboratory staff and firms' customers. When regressed in model (2), with the dependent variable that expresses overall satisfaction working with the federal laboratory, the market understanding variable is again statistically significant. Apparently, this characteristic of federal laboratory staff not only enhances perceived effectiveness but the companies' overall satisfaction with the partnership.

Market understanding is statistically significant for the cost/benefit of companies pursuing precommercial research in an area of its strategic interest. This implies that even in early stages of product development this attribute of federal laboratories is important. The variable also shows significance for the cost/benefit of companies that pursued the objective of improving an existing product. However, the observed relationship is statistically significant at only the 10% confidence level. The variable is not statistically significant in the remaining two models.

Characteristics or Qualities of the Federal Laboratory

Regarding companies with the objective of improving an existing product, the regression shows that the "skills and knowledge of the laboratory's scientists" evidently reduces the cost benefit/ratio of the company (i.e., improves effectiveness). However, for companies with the objective of pursuing precommercial research in a company's strategic area, these special skills are not statistically significant. The same is true for companies with the objective of developing a new product. Contrary to expectations, the unique expertise or facilities of the federal laboratory seem not to have any effect on reducing the cost/benefit ratio for companies with the objective of "gaining access to information, expertise and facilities unique to the federal laboratory."

8. Conclusion

Our search for winning partnership strategies and "magic" technical roles (Bozeman & Rogers, 1997) met with at least some success. Apparently, certain combinations of technical roles enhance the effectiveness of the partnership from the point of view of the companies participating in them. Where companies and federal laboratory technical roles are just one or two steps away from each other, in a sort of gradient, a positive effect is measured.

When both partners perform the same role, the opposite results were observed, that is, a negative effect in terms of the cost/benefit ratio. These findings complement Bozeman and colleagues' (1997, 2001), despite that fact that in this study we use a different methodology and different dependent variables. Furthermore, we observed evidence that the interactions of roles act differently with different company objectives. Overall, different technical objectives seem to call for different strategies of interaction.

We also learned from the regressions performed in the models that some particular qualities of the laboratory are especially important for the company. The company's knowledge of the marketplace proved essential to enhanced effectiveness. This finding is consistent with evidence from case study-based research (Ham & Mowery, 1998; Mowery, 1998).

It seems that this is just the beginning of a puzzle that needs further work for its solution. Our research provides some evidence that interaction of technical roles is important, but further research needs to be performed on different sorts of partnerships and using different measures of technical success. There may be optimal combinations of technical roles, but it seems likely that optimality effects extend much beyond particular types of technical interactions or particular ideas about effectiveness. Indeed, there is some evidence that technical effectiveness constructs are not only distinctive, but that success on one may lead to failure on the other (viz. Bozeman and Wittmer's [2001] findings that increased rates of commercialization are associated with decreased levels of partner satisfaction).

Perhaps the most positive implication of our results is that policy and strategy seem to matter. Choice of technical roles is often within the control of managers; thus, the more we learn about technical role interactions and their impacts on various measures of technical effectiveness, the stronger the likelihood of improving technical partnerships.

Finally, we speculate that the general approach we have employed here may prove relevant for public-private partnerships in a wide variety of policy domains. Although in most policy domains there is no issue of fitting one type or research or technical activity to another, there is nonetheless a concern about role compatibility. There are endless possibilities, depending on the specific roles and the types of institutional partners. For example, in public-private economic development partnerships, do particular resource provider combinations determine effectiveness? In public-private social services partnerships, do particular combinations of service input determine effectiveness? By examining public-private partnerships from the perspective of specialization, fit, and interaction of partner roles it may be possible to test a more general set of hypotheses about partnership effectiveness.

6 **Pablo Saavedra** is
Barry Bozeman is

Appendix: Variables Codes and Names

Variable Code	Variables names
CBR	Cost benefit ratio (Costs and benefits derived from the partnership with the federal laboratory in dollar terms)
labgood	Indicates if on balance working with the federal laboratory proved to be a good use for the company.
cbrexist	Cost benefit ratio of companies that had the objective of improving an existing product, process or service, when entered into the partnership with the federal laboratory.

cbrstrategy	Cost benefit ratio of companies that had the objective of pursuing pre-commercial research in an area of strategic interest for them, when entered in the partnership with the federal laboratory.
cbrnew	Cost benefit ratio of companies that had the objective of developing a new product, process or service, when entered into the partnership with the federal laboratory.
market	Good marketplace understanding of federal laboratory personnel.
private	Ownership of the company-private.
rdemratio	Ratio of R&D employees to total number of employees in the company.
sales	Amount in dollar terms of annual sales of the company.
crada	Indicates if the company is a participant of Cooperative Research and Development Agreement Program (CRADA)
noprev	Indicates none previous experience of the company with the specific federal laboratory in partnership.
lbenchi	Indicates if federal laboratory's bench level scientists and engineers played a significant role as initiators and participant in the interaction.
bcbl	Interaction term of technical roles performed during the partnership: basic research role performed by the company and basic research role performed by the federal laboratory.
pcpl	Interaction term of technical roles performed during the partnership: pre-commercial applied research role performed by the company and pre-commercial applied research role performed by the federal laboratory.
acal	Interaction term of technical roles performed during the partnership: applied commercial research role performed by the company and applied commercial research role performed by the federal laboratory.
dcdl	Interaction term of technical roles performed during the partnership: development and design role performed by the company and development and design role performed by the federal laboratory.

Variable Code	**Variables names**
tctl	Interaction term of technical roles performed during the partnership: product testing role performed by the company and product testing role performed by the federal laboratory.
pcbl	Interaction term of technical roles performed during the partnership: pre-commercial applied research role performed by the company and basic research role performed by the federal laboratory.
acbl	Interaction term of technical roles performed during the partnership: applied commercial research role performed by the company and basic research role performed by the federal laboratory.

dcbl	Interaction term of technical roles performed during the partnership: development and design role performed by the company and basic research role performed by the federal laboratory.
acpl	Interaction term of technical roles performed during the partnership: applied commercial research role performed by the company and pre-commercial applied research role performed by the federal laboratory.
dcpl	Interaction term of technical roles performed during the partnership: development and design role performed by the company and pre-commercial applied research role performed by the federal laboratory.
dcal	Interaction term of technical roles performed during the partnership: development and design role performed by the company and applied commercial research role performed by the federal laboratory.
tcal	Interaction term of technical roles performed during the partnership: product testing role performed by the company and applied commercial research role performed by the federal laboratory.
tcdl	Interaction term of technical roles performed during the partnership: product testing role performed by the company and development and design role performed by the federal laboratory.
unique	Indicates that a reason for the company's decision to work with a specific federal laboratory was the laboratory's unique expertise or facilities.
skills	Indicates that a reason for the company's decision to work with a specific federal laboratory was the laboratory's scientists and engineers' skills and knowledge.
basicl	Laboratory performs a basic research role during the partnership.
precoml	Laboratory performs a pre-commercial applied research role during the partnership.

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