R&D ALLIANCES AND FIRM PERFORMANCE: THE IMPACT OF TECHNOLOGICAL DIVERSITY AND ALLIANCE ORGANIZATION ON INNOVATION

RACHELLE C. SAMPSON
University of Maryland

In this paper, I examine the impact of partner technological diversity and alliance organizational form on firm innovative performance. Using a sample of 463 R&D alliances in the telecommunications equipment industry, I find that alliances contribute far more to firm innovation when technological diversity is moderate, rather than low or high. Although this relationship holds irrespective of alliance organization, I find that hierarchical organization, such as an equity joint venture, improves firm benefits from alliances with high levels of technological diversity. Thus, alliance organizational form likely influences partner ability and incentives to share information, which affects performance.

Innovation has become the industrial religion of the late 20th century. Business sees it as the key to increasing profits and market share. . . . Yet there is still much confusion over . . . how to make it happen.

-The Economist, 1999

Increasingly, competition among firms turns on whether they can create and commercialize knowledge in a timely and cost-efficient manner. This observation is particularly true for technology-intensive industries, where the pace of technological development is increasing, product life cycles are shortening, and the expense of updating capital equipment is rising. In response to these competitive pressures, firms often look for alternatives to in-house R&D. Interfirm R&D collaboration represents one such alternative whereby firms may gain access to complementary capabilities, reap economies of scale in R&D, and shorten development time while spreading the risk and cost of such new developments (e.g., Mariti & Smiley, 1983; Powell, 1990).

The use of R&D alliances is evident and increasing (e.g., Morris & Hergert, 1987; Mowery, 1988), yet the performance of these alliances has often fallen short of expectations (e.g., Bleeke & Ernst, 1993; Kogut, 1989). Given the importance of effective knowledge sharing to outcomes from R&D alliances, here I focus on two factors that likely affect both the *ability* and the *willingness* of partners to share knowledge-based capabilities: differences between allying firm technological capabilities, and alliance organizational form. Below, I develop these ideas in more detail and identify how technological diversity and alliance organization affect outcomes from R&D collaboration. I argue that a

moderate level of technological diversity is ideal: allying firms that differ moderately from their partners gain more from their collaborative R&D than firms with either very high or very low diversity. Further, I examine how the choice of alliance organizational form affects the ability of firms to benefit from collaborative activities. Specifically, I examine how alliance organization affects the link between partner capability differences and firm innovation.

R&D collaborations present unique coordination challenges, since some sharing or transfer of knowledge over firm boundaries is usually required. Successful knowledge transfer is not assured, particularly where knowledge is tacit or complex. Beyond the ability to share knowledge among partners is the need to preserve incentives to share such knowledge, given the substantial moral hazard problems that typically accompany knowledge-based alliances. Concerns over unintended transfer of knowledge to a partner and, ultimately, erosion of the value of a firm's knowledge resources may prevent the firm from contributing adequately to an alliance. The form that alliance organization takes may affect how much firms reap from such collaborations, since organization can influence both the ability and willingness of partners to share knowledge-based capabilities.

The influence of organizational form on alliance outcomes may matter more when knowledge transfer or sharing between partners is particularly difficult. Diversity in partner capabilities, while increasing the possible number of new recombinations, makes knowledge transfer more difficult. The greater the diversity between two firms' resource pools, the less useful is one firm's absorptive ca-

pacity for transferring knowledge and resources. In these circumstances, alliance organization that eases knowledge flow and preserves incentives for knowledge sharing becomes more important. In a sample of 463 R&D alliances in the telecommunications equipment industry, I find strong support for these arguments. Alliance organizational form has a profound effect on a firm's ability to benefit from diverse partner resources: it is not just the efficiency of transfer mechanisms that matters for alliance performance, but also the incentives of partner firms to pool the resources necessary to achieve the aims of an alliance.

PARTNER CHARACTERISTICS AND PERFORMANCE IN ALLIANCES

Through their enhanced incentive alignment and monitoring features, alliances provide an alternative to spot contracts (that is, market exchange) for the sharing and transfer of technological capabilities. Further, alliances may provide a superior means to access or acquire capabilities, since capabilities are often organizationally embedded (Kogut, 1988). Ahuja (2000: 448) argued that alliances "serve as sources of resources and information" and demonstrated a positive link between the extent of a firm's alliance activity and firm patenting or innovation. Baum, Calabrese, and Silverman (2000) found that biotech start-ups were more innovative when they had many alliances, suggesting that alliances contribute to a firm's knowledge base.

Of course, transfer of organizationally embedded capabilities or resources is not assured, even within alliances. Partner characteristics have a strong influence on whether and how well the firms in an alliance learn from each other. For example, similarity in partner resources can improve alliance outcomes. Mowery, Oxley, and Silverman (1996) examined the effect of partner technological similarity on postalliance firm development and found that firms that cited each other's patents before allying tended to converge technologically afterward. Lane and Lubatkin (1998) argued that greater similarity in organizational properties and knowledge bases between pharmaceutical and biotech companies enhanced alliance success and found, for example, that the greater the number of common employee publication outlets, the greater the learning of a pharmaceutical firm. Ahuja (2000) found a conceptually similar result—that technological similarity between alliance partners increased firm patenting after their alliance. Although these studies examined different industries and measured partner similarity in very different ways, the underlying logic is the same: all rely on

absorptive capacity arguments to explain the benefits of partner similarity. Given that firms can only assimilate external knowledge closely related to prior knowledge, greater similarity eases knowledge sharing and transfer (Cohen & Levinthal, 1989).

Analogously, in the context of R&D alliances, highly diverse partner capabilities may actually reduce the innovative benefits a firm reaps from collaborative R&D, since firms can only assimilate capabilities that are sufficiently similar to their own. However, partners that are very similar may also experience reduced benefits from R&D collaboration. If innovation arises out of new combinations of existing capabilities (Schumpeter, 1934), then beyond a critical minimum level of R&D activities, the addition of similar capabilities does not increase innovation, since possible new combinations of existing capabilities have been exhausted. Partners with diverse capabilities have more to learn from each other than partners with very similar capabilities do. Pooling distinct perspectives and capabilities, or technological diversity between partners, encourages creativity and novel solutions to existing problems. Note that these arguments are conceptually similar to those made in the more micro diversity literature (e.g., Bantel & Jackson, 1989; Keller, 2001). Technological diversity is an idea that resembles functional diversity, except that the diversity considered here is based on the technological backgrounds of firms, rather than on an aspect such as individual sales experience or some other functional individual specialization. (For a recent review of the functional diversity literature, see Bunderson and Sutcliffe [2002]).

Empirical evidence seems to provide some support for these arguments, albeit in slightly different contexts. Powell, Koput, and Smith-Doerr (1996) argued that a diversity of alliance experience enhances firm learning; firms with different types of alliances in their portfolios, such as alliances for R&D, manufacturing, and/or marketing, are more likely to be central in an industry network and experience higher growth rates. Similarly, Baum, Silverman, and Calabrese (2000) found that biotech firms that allied with many different types of partners, such as pharmaceutical firms, universities, and government labs, were more successful after their initial public offerings (IPOs) than biotechs engaging in alliances with only single types of partners. Finally, Ahuja and Katila (2001) argued that technological similarity between targets and acquirers in the context of acquisitions bore a nonlinear relationship with acquirer patenting. They found that firms that cited similar patents or each other prior to the acquisition of one by the other

patented more after the acquisition. However, firms that had very substantial overlap between citation bases patented less after such an acquisition. Applied to the context of R&D alliances, this finding suggests that firms benefit most from R&D alliances when partner capabilities are diverse, creating a large number of possible combinations, but not so diverse so as to prevent efficient assimilation.

Note that, although technological diversity is an alliance-level construct, hypothesized outcomes are considered here at the firm level. This focus is in recognition of the fact that benefits from alliances can be both direct and indirect. Direct benefits include, for example, access to capabilities outside a firm that are critical to the successful product or process development that is the focus of a current alliance. Indirect benefits can include learning or development over the course of the alliance of new competences that are useful for other firm projects (i.e., nonalliance activities). Since the goal of many firms engaging in R&D alliances is to gain knowledge from partners that would be useful not only for alliance projects but also for later firm projects, both direct and indirect outcomes are important. Thus, I argue that partner technological diversity bears a nonlinear relationship with innovative outcomes at the firm level.

Hypothesis 1. R&D alliances with moderate diversity contribute more to firm innovation than alliances with very low or very high levels of capability diversity.

THE INFLUENCE OF ALLIANCE ORGANIZATION

In organizing their alliance activities, firms have several alternative forms to choose from. I focus here on two such alternatives: bilateral contract and equity joint venture. A bilateral contract is a contractual arrangement in which partners pool their capabilities for the purposes of collaborative R&D but do not form a separate legal identity for the alliance. Firms also pool capabilities under an equity joint venture, but in this case a new entity is created, jointly owned and operated by two or more collaborating firms (Oxley, 1997; Pisano, Russo, & Teece, 1988).[1] Alliance organizational form may affect firm innovative performance, since alliance

organization affects a firm's ability and incentives to share information with its partners.

Knowledge transfer in the context of alliances can occur via many mechanisms, but perhaps the most important and prevalent is the mobility of and/or contact between technical employees of the parent firms and between the parent firms and the alliance (in the case of equity joint ventures). In equity joint ventures in particular, the key mechanism for knowledge transfer between venture and parents is employee rotation and contact of employees of each firm with employees of the joint venture. When transferring knowledge and/or resources to a joint venture, parent firms typically also supply needed technical support, usually by making their technical staff available to the venture. This contact is a source of knowledge flows in both directions—that is, to the joint venture and back to the parent firms—since these technical staff members have contact with the joint venture operations. Naturally, this contact may vary from venture to venture, but generally in any joint technology development project, the parent firms must provide such technical support. Additionally, the employees of the joint venture are typically taken from the parent firms. These employees on occasion rotate back to the parent firms, taking their experience and new knowledge with them.[2] Organizational form then determines the effectiveness of such mechanisms for knowledge transfer.

Two complementary theoretical perspectives highlight the effect of alliance organizational form on firm benefits from R&D collaboration, particularly at high levels of technological diversity: the knowledge-based view and transaction cost economics. The knowledge-based view is founded on two key insights (Kogut & Zander, 1992). First: knowledge is difficult to transfer, particularly when it is complex, as in the case of much technological information. Second: Firms have particular characteristics that make knowledge sharing easier

---

[1] Since I examine alliances for collaborative R&D, in which two or more firms pool capabilities to realize mutual gains, I examine only bilateral (or multilateral) forms of alliance organization. More unilateral forms, such as licensing agreements, present different coordination issues and are beyond the scope of this paper.

[2] The foundation of these knowledge transfer mechanisms is labor mobility. A long-standing argument in research on spillovers is that labor mobility is one of the fundamental knowledge transfer mechanisms between firms (e.g., Arrow, 1962; Gilfillan, 1935; Moen, 2000). Song, Almeida, and Wu (2003) found that knowledge movement between organizations was correlated with labor mobility; as scientists and engineers move from firm to firm, they also diffuse knowledge by taking the experiences and expertise gained from one organization to another. More broadly, Almeida and Kogut (1999) showed that the movement of engineers influenced inter- and intraregional patterns of knowledge flow.

within firms than between firms. These insights have their roots in the work of Arrow (1974).

Arrow (1974) suggested several key advantages of hierarchical organization—that is, organization within a firm—including the ability to economize in communication via a common code and to coordinate activities via authority. As Arrow argued, "It is . . . easier to communicate with . . . individuals with whom one has a common approach or a common language" (1974: 42). Where such a common language is developed within firm boundaries, authority over employees' activities allows better coordination among interdependent roles: "Since the activities of individuals interact with each other, being sometimes substitutes, sometimes complements, and frequently compete for limited resources, joint decision on the choice of individuals' activities will be superior to separate decisions" (Arrow, 1974: 68). Kogut and Zander (1992) took these observations further and argued that, because of the characteristics of firms, hierarchical organization is a superior means of transferring knowledge or other tacit information. Within firms exist "a set of higher-order organizing principles [that] act as mechanisms by which to codify technologies into a language accessible to a wider circle of individuals" (Kogut & Zander, 1992: 389). Because of this common stock of knowledge and organizing principles, sharing knowledge, particularly complex or tacit knowledge, is easier within a firm than between firms.

Given that an equity joint venture is closer to a firm than the less hierarchical bilateral contract, these arguments suggest that sharing knowledge is easier within an alliance organized as an equity joint venture than within an alliance organized by bilateral contract. The equity joint venture has some consistent attributes that both distinguish it from the bilateral contract and allow more efficient knowledge sharing and transfer: formal joint management, exclusive assignment of some employees to the joint venture, and more efficient routine development than in a bilateral contract. Each of these characteristics provides superior coordination, which is required to transfer highly complex or diverse knowledge.

Every equity joint venture has a board of directors composed of members from all its partner firms (Killing, 1983). This joint board allows communication of pertinent information to and coordination of collaborative activities by the parent firm (Pisano, 1989; Pisano et al., 1988). As Pisano, Russo, and Teece noted, "The governing body of the venture, usually composed of representatives from both companies, can, if used properly, provide a channel for communicating pertinent infor-

mation and for coordinating the collaborative roles of the partners" (1988: 32). Beyond providing for top management, joint venture agreements typically also specify that the ventures' day-to-day activities are to be managed independently of the partner firms. For example, in one joint venture agreement for the development, manufacture, and marketing of flexible printed circuits, the partners stipulated that a general manager was to be appointed to and compensated by the joint venture and that the general manager would be responsible for the day-to-day management of the alliance. Such joint management provides a stronger link between partners and allows greater coordination of interdependent activities.

The assignment of employees to a joint venture also facilitates more efficient knowledge sharing between partners than a bilateral contract. Employees assigned to an equity joint venture often become the exclusive employees of the venture and cannot be easily recalled back to the parent firm. For example, Killing (1983) noted, in his study of Mexican joint ventures, that eight out of ten general managers were on the payroll of the joint ventures, rather than the parents. In only four out of ten ventures was the general manager's bonus tied to one parent's results. Less senior employees are even less likely to be officially tied to a specific parent. Other illustrations exist in joint venture agreements, taken from Securities and Exchange Commission (SEC) filings. For example, the agreement for a joint venture formed to develop, manufacture, and market thin-film heads for disk drive manufacturers explicitly prohibits partners from recalling an employee dispatched to the joint venture without the consent of alliance management. The joint venture form provides for joint management independent of partner firms day-to-day and puts venture personnel under the authority of this joint management, thus improving coordination toward alliance goals; given a collaborative R&D goal, these characteristics enhance the ability to transfer and share knowledge between partners. Finally, the creation of a separate legal entity via a joint venture (typically, such an entity has no formal termination date or a very long-term horizon) encourages investment in the development of routines, including routines for knowledge or information transfer. As a separate organization with independent management, an equity joint venture is better suited to the development of its own routines, skills, and common communication code, since the venture functions as a firm in its own right. Since the parent firms typically supply the top management for the equity joint venture, these routines, skills and communication code are often a function of the parent

firms'. In this sense, each parent can effectively recreate parts of its organization within a joint venture more easily than in a bilateral contract. As Kogut noted, "For transactions which are the product of complex organizational routines, the transfer of know-how can be severely impaired unless the organization is itself replicated" (1988: 323). Providing a structure to more efficiently replicate routines gives the joint venture a distinct advantage over the bilateral contract in sharing tacit or complex knowledge. Indeed, Kogut (1988) argued that joint ventures are a good vehicle by which tacit or organizationally embedded knowledge can be transferred. Each of these mechanisms enhances the ability to transfer knowledge back to the parent firm from an equity joint venture.

Although the knowledge-based view suggests that sharing knowledge is easier within an equity joint venture than under a bilateral contract, there has been little discussion of whether incentives to share knowledge are preserved under either organizational form. Firms entering alliances face considerable moral hazard problems, since partner firm behavior is often unobservable, and the costs of opportunism are potentially high (Oxley, 1997). This threat of opportunism arises because knowledge-based assets are imperfectly protected (see, e.g., Cohen, Nelson, & Walsh, 2002) and outcomes from R&D activities are highly uncertain (Holmstrom, 1989), making it difficult for a firm to infer what its partner contributes to the alliance. As a result of these threats, firms may be *able* but not *willing* to share their knowledge-based capabilities. Thus, there is a distinction between the existence of mechanisms to transfer knowledge and a firm's willingness to use these mechanisms. Here, one can use transaction cost logic to identify organizational forms that minimize threats of opportunism that would otherwise hinder cooperation.

Incentives to share knowledge and cooperate are often influenced by the governance attributes of organizational forms (Williamson, 1991). Equity joint ventures have some fairly consistent governance attributes compared to bilateral contracts that likely affect firm incentives to share knowledge. Above I discussed the communication and coordination provided by the joint board of directors in an equity joint venture; such joint management also provides explicit powers of control over alliance activities. Monitoring and control are enhanced with such joint management, since partners have veto rights over strategic decisions regarding joint venture operations (Killing, 1983). Greater control means firms can more confidently contribute their knowledge-based capabilities to alliance activities.

Partner firms also have a greater incentive to work through disputes privately under an equity joint venture, since courts have less explicit guidance from the partner firms concerning how to deal with such disputes than exists with a contract. The use of a more hierarchical form of organization, such as the equity joint venture, relieves partners of the need to specify contractual arrangements completely (Williamson, 1991). Without fully specified contractual arrangements, however, courts have less information on the intentions of the partners. The desire to resolve disputes privately improves communication and coordination over the course of the alliance.

The governance characteristics of the equity joint venture form—a joint board of directors and relief from full contractual specification—enhance the monitoring and control of alliance activities and improve information sharing over the course of the alliance. Fundamentally, greater monitoring and control ease concerns about opportunism and preserve firm incentives to share knowledge with their partners. Firms can more confidently pool their capabilities with their partners'. Both the knowledge-based view and transaction cost economics arguments, therefore, point to more hierarchical organization as a means to promote information sharing. When firms can share information easily and incentives to share are preserved by alliance organization, firms can better assimilate their partners' capabilities.

In contrast, alliances organized by bilateral contract are characterized by more decentralized decision making; all but the most critical decisions in an alliance organized via bilateral contract take place at the firm level, rather than the alliance level. Although this style of day-to-day decision making may be faster and allow more timely responses to issues that arise over the course of the alliance, such decentralization can lead to inefficient outcomes when coordination is required. Additionally, since coordinated adjustments are easier under an equity joint venture than under a bilateral contract over the life of an alliance, it is more important for firms to specify rights and obligations at the outset under a bilateral contract. To the extent that firms are not able to fully specify these terms up front, the potential for misunderstandings and costly miscommunication arises. Thus, as technological diversity rises and coordination becomes more important, the bilateral contract becomes less attractive than the equity joint venture.

The information-sharing and incentive-aligning mechanisms of equity joint ventures likely ease knowledge sharing in all types of alliances; however, they are likely more important to alliance

success where partner knowledge bases are diverse. Where knowledge is codifiable, simple, or closely related to a partner's knowledge base, an equity joint venture likely provides less benefit, since knowledge sharing is straightforward in these situations. Further, although joint management can facilitate communication and coordination, it can slow decision-making processes considerably as firms jointly making decisions (via a joint board of directors) seek to reach agreement. Such delays can thwart the creative process and slow progress on R&D projects, ultimately dampening innovative performance. In contrast, management of joint projects under bilateral contracts is typically distributed in such a way that each firm makes independent decisions on how best to meet alliance obligations. Ultimately, this arrangement means that, although equity joint ventures have explicit processes and structures for coordination and communication, alliances managed via bilateral contract may be more nimble and able to make more timely decisions than alliances managed via equity joint venture.[3] Innovative performance may be enhanced as a result, since timely decisions allow faster responsiveness to unforeseen challenges that arise over the life of an R&D project. Given these limitations and that the costs of set up and negotiation of an equity joint venture typically exceed those of a bilateral contract (e.g., Oxley, 1997; Pisano, 1989), use of the equity joint venture is reserved for situations in which knowledge sharing and transfer are more difficult.

Thus, I focus on the interaction between organizational form and diversity of partner capabilities, rather than on the effect of organizational form alone, since I do not expect one organizational form to be dominant in all circumstances. The effects of organizational form on performance are conditional on various characteristics of an alliance; here, technological diversity between partners is the characteristic of interest. This logic is similar to that put forth by Shaver (1998) and Masten (1993). Differences between the two organizational forms are most pronounced when alliance outcomes depend on the ability to transfer or share diverse knowledge. These insights lead to my second hypothesis, which highlights the role of diversity as a contingency factor:

Hypothesis 2. At high levels of technological diversity, alliances organized by equity joint venture contribute more to firm innovation than alliances organized by bilateral contract.

EMPIRICAL ANALYSIS

Empirical Design, Data, and Sample

In my empirical investigation, I measure firm innovation as a function of alliance characteristics and relevant control variables. More specifically, I test the hypotheses stated above by examining the impact of partner capability diversity and alliance organization on firm innovative performance after alliance commencement. I first estimate the effects of technological diversity on firm innovative performance without the influence of alliance organizational form. I then interact technological diversity and relevant controls with alliance organizational form (bilateral contract or equity joint venture) and estimate firm innovative performance as a function of these variables. Thus, although the unit of analysis is the alliance, the focal dependent variable is firm-level performance, since I am interested in both direct and indirect firm outcomes from alliance participation. I use strong firm controls to isolate those direct and indirect benefits from alliance participation as much as possible.

For these empirical tests, I constructed a data set comprising the alliance and patenting activities of firms in the telecommunications equipment industry (i.e., SIC classes 3661, 3663, and 3669). In response to the rapid pace of technology development in this industry (Pisano et al., 1988), firms frequently collaborate in R&D to gain access to complementary capabilities, reap economies of scale, and spread the risk and expense of development. Further, patents are an important means for appropriating the returns from innovation for firms in the telecommunications equipment industry (Hall & Ziedonis, 2001; Levin, Klevorick, Nelson, & Winter, 1987), an important criterion for sample choice, given that several of the key measures in this study are based on patent data.

I construct this data set from two main sources: the Securities Data Company (SDC) Database on Joint Ventures and Alliances and the MicroPatent database. The SDC database contains information on all types of alliances and is compiled from publicly available sources, including SEC filings, industry and trade journals, and news reports. Consistent data collection efforts by the SDC extend primarily from 1988 onwards. Coverage is inevitably incomplete, since firms are not required to report alliance activities. Nevertheless, the database is among the most comprehensive sources of information on alliances and is one of the only sources

---

[3] This point is analogous to that made by Powell (1990), who noted that more intermediate or network forms of organization may be nimbler than their hierarchical counterparts.

available for large-scale empirical studies on alliance activity (see Anand & Khanna, 2000). Two key steps were taken to increase the reliability of the SDC data. First, all deals for which the alliance announcement date is estimated, rather than known, are removed from the sample, since these alliances may never have materialized. Second, data are taken from 1991 onwards since SDC coverage of alliances is more comprehensive from about 1990.

The sample includes all R&D alliances for firms in the telecom equipment industry that commenced during the years 1991–93, inclusive. Each alliance involves joint R&D activities either exclusively or in addition to marketing, production, and/or supply activities. These criteria lead to selection of 463 R&D alliances, involving 487 firms in 34 nations.[4] Eighty-five percent of the sample firms are from either the United States (60%), Japan (12%), or Europe (13%). This pattern is consistent with prior observations (Hergert & Morris, 1988; Oxley, 1999). The sample includes both same-nation alliances (48%), in which all partner firms are headquartered in the same nation, and international alliances (52%), in which all partner firms are not headquartered in the same nation. The high incidence of international alliances is not surprising, since leading firms in the telecommunications equipment industry are widely distributed across countries. For example, of the market leaders during this time frame, Motorola is American, Vodafone is British, and Ericsson is Swedish. All three firms are leaders in the telecom equipment industry with substantial market shares.

I combine these data on firm alliances with data from MicroPatent, which contains all information recorded on the front page of every U.S. patent granted since 1975, including assignee name, inventor name, and patent technological classification. Since I wish to test how partner capability diversity and alliance organization affected firm innovative performance, capabilities of each entire firm rather than of single subsidiaries have to be measured. Further, since firms do not always assign patents to the subsidiaries in which innovations took place, looking at corporate or entire firm-level portfolios is particularly important. For example, of the patents assigned to firms in my sample, 73 percent are assigned to the ultimate

parent firm, but 27 percent are assigned to various levels of subsidiaries. Failure to capture patents assigned to all units in a corporate structure leads to an extremely noisy measure of firm capabilities and, consequently, biased parameter estimates (Kennedy, 2003). To avoid this, I construct a patent portfolio for each firm based on patents assigned to the parent firm as well as those assigned to all of its subsidiaries. First, I use the *Directory of Corporate Affiliations* to identify all subsidiaries of firms in the sample. The *Directory* contains information on the subsidiaries and affiliates of both public and private, U.S. and non-U.S. firms. I then draw all patents from the MicroPatent database assigned to any of these parents or subsidiaries and aggregate the patents drawn to the entire-firm, or corporate, level.

Ideally, one would capture only those patents that are clearly linked to each alliance. However, given the obstacles to obtaining information on the intellectual origins of specific patents, linking patents with specific collaborations poses a serious challenge. One alternative to the approach used here would be to classify each patent as related or unrelated to a specific alliance, on the basis of the alliance's activities. However, such classification is highly subjective and inevitably arbitrary. As Hall, Jaffe, and Trajtenberg noted with respect to assigning patents to aggregate technology categories, an issue analogous to the assignment of patents to an alliance, "There is always an element of arbitrariness in devising an aggregation system and in assigning the patent classes into the various technological categories, and there is no guarantee that the resulting classification is 'right', or adequate for most uses" (2001: 13). Although each approach has its limitations, here I rely on strong firm controls and alliance variables to empirically tease out the firm versus alliance effects, rather than attempting to identify specific patents attributable to specific alliances.

Measures

Dependent variable: Postalliance patents. Using the compiled patent data, I measure each firm's innovative output after alliance commencement. Patents are strongly correlated with new products (Comanor & Scherer, 1969), literature-based invention counts (Basberg, 1982), and nonpatentable innovations (Patel & Pavitt, 1997). As such, patents are reasonably reliable indicators of innovative performance and are generally better measures of the output of R&D activities than R&D spending (Comanor & Scherer, 1969; Griliches, 1990).

Of course, simple patent counts do not accurately

---

[4] Sixty-nine (69) percent of the sample firms are involved in only 1 R&D alliance during 1991–93. Thirteen (13) percent are involved in 2 alliances; 6.5 percent, in 3; and the remaining 11.5 percent, in anywhere from 4 to 62 alliances during the time period.

capture the *value* of underlying innovations (Griliches, 1990). To address this heterogeneity in patent value, I assign a weight to each patent using citations made by later patents. When a patent is granted, the inventor (and/or patent examiner) notes all of the previous patents that the granted patent is based upon. These citations of previous patents identify the technological lineage of the invention and effectively define the property rights granted by the patent (Jaffe & Trajtenberg, 1996). Empirical evidence shows a strong correlation between the ex post citations of a patent and the estimated value of the underlying invention (e.g., Trajtenberg, 1990). As such, citation weighting provides a less noisy measure of innovation than simple patent counts (Trajtenberg, 1990). Thus, I measure firm innovative performance via a count of citation-weighted firm patents in a four-year post-alliance window, which is labeled "postalliance patents."[5] For example, if an alliance commenced in 1993, *postalliance patents* was constructed from weighted patents applied for in 1994–97, inclusive. I used the patent application date, since this date is the earliest point at which we can identify new firm capabilities, and a one-year lag between alliance commencement and firm patenting, since research shows a contemporaneous relationship between R&D efforts and patenting (e.g., Hausman, Hall, & Griliches, 1984).[6]

This measure differs substantially from those used in past research on the contribution of alliances to firm innovation. The estimations reported below are set up to capture how a firm's innovative activities change with variance in alliance activity, rather than how partners converge or diverge fol-

lowing an alliance using patent cross-citations between partners (e.g., Mowery et al., 1996) or alliance success as captured by survey-based questions on the extent of interfirm learning (e.g., Lane & Lubatkin, 1998). Although these and other past studies add considerably to understanding of the effect of alliances on firm outcomes, a more direct test of whether particular types of R&D alliances increase firm innovation rates will improve understanding of how alliance characteristics influence performance.

Focal independent variables. I measure the diversity of partner technological capabilities by examining the extent to which partners patent in the same technology classes (Jaffe, 1986). This measure, *technological diversity*, effectively captures the technological position of one partner firm relative to another. The fact that patents are categorized according to underlying technology and not the end products per se is a distinct advantage for this study. Similar products can have very different underlying technologies and, thus, can reflect very different capabilities; for example, a firm producing standard cathode ray tube televisions does not necessarily have the technological capabilities to produce a plasma screen television or an LCD screen, despite the fact that all of these products would be categorized as visual displays. Thus, using patent technology classes, one can capture similarities in technological capabilities between firms in different industries as well as technological differences among firms in the same industry.

To construct this variable, I first generate each partner's technological portfolio by measuring the distribution of its patents across patent classifications, year by year. This distribution is captured by a multidimensional vector, $F_i = (F_i^1 \ldots F_i^s)$, where F_i^s represents the number of patents assigned to partner firm i in patent class s. Diversity of partner firm capabilities is then:

$$\text{Technological diversity} = 1 - \frac{F_i F_j{}'}{\sqrt{(F_i F_i{}')(F_j F_j{}')}}$$

where $i \neq j$. Technological diversity varies from 0 to 1, with a value of 1 indicating the greatest possible technological diversity between partner firms. A simple numerical example illustrates how the measure works. Assume two firms, *i* and *j*, and four patent classes, A, B, C, and D, with the count of patents across classes for the two firms as follows:

---

[5] Estimations using simple patent counts (i.e., unweighted by ex post citations) yield results very similar to those in Tables 2 and 3.

[6] Since my patent data run only until 1997, ex post citations are necessarily truncated for firms with alliances commencing in later years (i.e., 1993 rather than 1992 or 1991). Patents applied for in 1997, for example, will be cited far less than patents applied for in 1995. Longer citation spans are more ideal than the short span used here, but Lanjouw and Schankerman noted that "for the purposes of measuring the initial expectations about the quality of a patented innovation, it is not necessary or even helpful to use very long citation spans" (1999: 15). However, to control for the effect of this citation truncation, I include dummy variables for the year an alliance commenced. Later years mean later windows for measuring the dependent variable and, inevitably, a greater number of patent citations that are yet unobserved in the data set. These controls are discussed in more detail below.

Class	Firm *i*	Firm *j*
A	1	0
B	2	1
C	3	4
D	0	0

The numerator for technological diversity is:

$$(1 \quad 2 \quad 3 \quad 0)\begin{pmatrix} 0 \\ 1 \\ 4 \\ 0 \end{pmatrix} = 0 + 2 + 12 + 0 = 14.$$

The denominator is:

$$\sqrt{(1 \quad 2 \quad 3 \quad 0)\begin{pmatrix} 1 \\ 2 \\ 3 \\ 0 \end{pmatrix} \times (0 \quad 1 \quad 4 \quad 0)\begin{pmatrix} 0 \\ 1 \\ 4 \\ 0 \end{pmatrix}} =$$

$$\sqrt{(1 + 4 + 9 + 0) \times (0 + 1 + 16 + 0)} = 15.968.$$

Technological diversity is then:

$$1 - \frac{14}{15.968} = 0.123.$$

This measure calculates diversity between a pair of firms. For an alliance involving more than two firms, I calculate this measure for every combinatorial pair of firms in the alliance and take the average.[7] This measure is not sensitive to the number of patents in a class and captures differences between partners based on diversity rather than volume of patents in the same class.[8] Technological

_____

[7] Note that if all firms in an alliance do not patent, the vectors contain all 0 values, and the technological diversity measure is equal to 1 (i.e., the maximum diversity score). (To avoid an undefined result from dividing by 0, where the denominator is equal to 0, the program calculating technological diversity sets the value of the fractional term to 0. This 0 is then subtracted from 1, leading to a value of 1 for technological diversity.) Of the 463 alliances in the sample, 64 consist of firms that do not patent at all. To see whether results are sensitive to the inclusion of these firms that did not patent in the four years prior to alliance commencement, I reestimate the results given in Tables 2 and 3 (below). Results are qualitatively the same as those reported here and are available on request.

[8] Although firms may suggest patent technical classifications on patent applications, examiners are the ultimate arbiters of class assignments on patents. Further, most firms file patent applications via experienced patent attorneys, who typically suggest the appropriate patent classes for a particular application. The use of such specialists (i.e., patent attorneys and examiners), as well as the correspondence that usually takes place between these specialists during the patent examination

diversity (as measured here) is akin to measuring the angle between the individual vectors that represent the patent portfolios of allying firms. To capture the expected nonlinear relationship between capability diversity and partner firm innovation, I also include the square of this measure, *technological diversity squared.*

Note that this measure does not control for the fact that some technology classes are more similar to each other than others. New classes emerge when existing classes are inadequate to categorize new technologies. There is no satisfactory means, however, of measuring the differences or similarities between classes; given the obstacles to obtaining information on the degree of relatedness of various patent classes, estimating the distance between them poses a serious challenge. Any reclassifications would be highly subjective and inevitably arbitrary. It is very unlikely, however, that any measurement error that results from the variance in the similarity of patent classes would affect the results; likely the distribution of noise from this type of measurement error is random and, therefore, has no effect (that is, the relatedness of classes is likely not systematically correlated with the independent or control variables). Although this system has its flaws, the use of top-level patent classes instead of subclasses (which is similar to using a two-digit SIC code instead of a four-digit SIC code) reduces this problem to the extent possible.

From information provided by SDC, I create a dummy variable to capture *alliance organizational form.* This variable equals 1 when an alliance is organized by equity joint venture, and 0 when it is organized by bilateral contract.

Control variables. To control for firm and partner R&D efforts, or the "innovativeness" of the allying firms, I include measures of *prealliance firm patents* and *partner patents*. Prior patents capture the impact of technological acquisitions, prior R&D spending, and a firm's propensity to patent (Trajtenberg, 1990), as well as a firm's technological capabilities (Patel & Pavitt, 1997; Silverman, 1999). For each firm, I measure prealliance patents by summing the firm's own prealliance patents and its partner's patents in a four-year, prealliance window. Unweighted or simple patent counts are likely a better measure of innovative inputs; R&D spending is more strongly correlated with simple patent counts than with weighted patent counts. (Note that this is in contrast to measuring R&D

_____

process, minimizes risks of misclassification of patents and virtually ensures that there is no systematic misclassification.

outputs, where the value of such outputs is more strongly correlated with citation-weighted patents than with unweighted patents.) Using various time lags between R&D spending and patent counts, Trajtenberg (1990) found that the correlation between R&D spending and patents ranged from .83 to .93; this correlation is highly significant at all lags ($p < = 0.0008$ for all lags). Given the correlation of simple patent counts with other measures of a firm's technological capabilities along with the ability to measure such technological capabilities among a wide range of firms (i.e., public and private, where typically one is unable to obtain information on R&D spending let alone the technological areas a firm operated in), patents represent one of the best means for capturing firm capabilities and technological positions relative to other firms. Although not reported here, results are substantially similar with citation-weighted versions of these measures.

R&D alliance activities range from very narrow projects, where the focus is on development of new products based on existing technology, to very broad projects where firms seek to develop the "next generation" of a particular product. Naturally, one would expect a firm to reap more from very broad, ambitious projects than from very narrow projects. Thus, I include measures of alliance scope, based on the synopses of alliance activity provided by the SDC database. I use three dummy variables to capture narrow, intermediate, and broad alliance scope. These categories were developed in concert with the R&D manager of a U.S. multinational firm. *Narrow alliance scope* refers to alliance activities focused on developing new products based on existing technology. Activities that go beyond mere customization of an existing product to a new user but fall short of developing next-generation technology are categorized under *intermediate alliance scope*. Finally, alliance projects for developing next-generation technology are placed in the category *broad alliance scope*. Two independent coders categorized the sample, achieving greater than 70 percent concordance. Cohen's kappa for interrater reliability is 0.53 and highly significant, indicating that I could reject the hypothesis that the coders were making their determinations randomly. As *intermediate alliance scope* is the most common category for breadth of activity, I use it as the reference category in the analysis.

Multilateral alliances (that is, those with more than two partners) may differ from bilateral alliances in two ways. First, multilateral alliances may be larger than bilateral alliances. Second, multilateral alliances may be more difficult to manage than bilateral ones, since monitoring becomes more dif-

ficult with the addition of more partners (Oxley, 1997). To capture the existence of a *multilateral alliance,* I construct a dummy variable equal to 1 if the number of partner firms exceeds 2. Eighty-two percent of all R&D alliances in the sample involve only 2 partners. Of the remaining alliances, 9.5 percent involve 3 firms, 3 percent involve 4, and the remaining 5.5 percent involve anywhere from 5 to 12 partner firms.

Over the course of prior alliances with the same partner, a firm may gather information on the partner's capabilities, behavior, and managerial style. This additional information may reduce adverse selection problems in alliance formation (Balakrishnan & Koza, 1993). Further, communication and coordination may be enhanced in the current alliance, improving alliance outcomes. To control for this effect, I include a count of prior and concurrent alliances between the partner firms in each focal alliance, *prior links*.

Two year dummies are included, *year 1992* and *year 1993*, because ex post patenting for later alliances (those commencing in 1992 or 1993) is likely lower than for earlier alliances (those commencing in 1991). I expect both year dummies to be negative, reflecting this data truncation.

Prior experience may enhance the impact of an alliance on innovative performance, since firms with experience may better manage their alliance activities than firms without (Anand & Khanna, 2000). For this reason, I include a dummy, *prior experience*, to capture whether a firm had prior alliance experience.[9]

Patent rates likely differ between firms that have multiple ongoing alliances and firms with only one current alliance. A dummy variable is included to control for this potential difference: *Other alliance* equals 1 if a firm is involved in more than one alliance in the sample period (1991–93), 0 otherwise. For a robustness check, I also include a dummy to capture other concurrent alliances during the period 1994–97, given that some patents measured might be attributable to later alliances. Results including this additional measure are qualitatively the same as those reported in Tables 2 and 3 below.

International alliances—those in which partners are not headquartered in the same nation—may

---

[9] I use a dummy variable rather than a count because the difference between 0 and 1 prior alliance is likely substantially greater than the difference between, say, 15 and 16 prior alliances. However, for a robustness check, I reestimate the specifications in Tables 2 and 3 below using the count variable and obtain materially similar results on all key variables.

present more substantial coordination challenges and, thus, adversely affect postalliance patenting. Thus, in the analysis below, the control variable *international alliance* equals 1 if an alliance involves partners not headquartered in the same nation, and 0 otherwise.

Statistical Method

As I measure firm innovative performance via citation-weighted firm patenting (*postalliance patents*), the empirical model has to accommodate the nature of these counts as positive, integer values. Two other issues also arise: the preponderance of zero values and the small integer values of many firm patent counts. To account for these issues, I use a negative binomial specification (Hausman et al., 1984). Zero and small values of the dependent variable are naturally incorporated into the model. To capture the hypothesized interaction between alliance organization and technological diversity, I interact my variable for alliance organizational form with the independent and control variables discussed above.

Note that in this model, not all disturbances are independent. Some firms have multiple observations representing their participation in multiple alliances, since I include an observation for each alliance a firm is involved in. I correct for this lack of independence between some observations using a technique developed by Huber (1967). Where a firm is involved in more than one alliance during the sample period, I sum the likelihood scores used to calculate standard errors for that firm to create a "super observation" (Huber, 1967). That is, a single likelihood score is calculated for each *firm*, rather than one likelihood score for each *alliance* the firm is involved in. Standard errors are then calculated from this summed likelihood score. Without this correction, standard errors would not be independent between observations for firms in multiple alliances in the sample window. By calculating the variance-covariance matrix according to the summed likelihood score of all observations for each firm, I create independence between observations for the purposes of calculating standard errors and hypothesis testing. No adjustment to parameter estimates is necessary, since maximum likelihood estimates are still unbiased and consistent when the assumption of independence is violated (Greene, 2003).[10]

It is also necessary to correct for possible self-selection bias. The empirical approach above might provide biased estimates of the effect of alliance organizational mode on performance if firms select alliance organizational form systematically (Masten, 1993). Estimates are unbiased only if: (1) firms select alliance organizational form randomly or (2) I include all determinants of firm patenting and organizational choice in the empirical model. Failing to fulfill one of these two criteria leads to an omitted variables bias (Heckman, 1979). To correct for this potential self-selection bias, I use a common econometric technique. In the first stage, I estimate a probit model capturing the decision to organize alliance activities under a bilateral contract or an equity joint venture. In the second stage, firm patenting performance is estimated as a function of identified variables, correcting for self-selection using an index generated from the probit results. This index is often referred to as the inverse Mills ratio, $\Lambda = \dfrac{f(z)}{F(z)}$, where z is the estimated value from the first-stage organization model and f and F are the standard normal density and cumulative distribution functions, respectively (Heckman, 1979). Thus, estimates from this second stage are negative binomial estimates, corrected for possible selection bias via inclusion of this term.[11] In keeping with prior work on the effects of self-selection (e.g., Shaver, 1998), this correction is very important here, since estimates differ dramatically depending upon whether this correction is made.

---

observations *per alliance*, since each alliance typically involves more than one firm observation. Inclusion of an alliance dummy is not possible, since the alliance variables (such as technological diversity) do not vary between firms in the same alliance. To ensure that results are not sensitive to a possible alliance effect, I reestimate Tables 2 and 3 below with only one randomly chosen observation per alliance. These estimations yield results very similar to those reported below.

[11] Note that in addition to including a self-selection correction index, I also need to correct standard errors, as the variance (from which standard errors are calculated) is downward biased in the presence of self-selection bias, which may lead to spurious findings of significance in hypothesis testing (Heckman, 1979). To make this correction, I follow Murphy and Topel (1985), who demonstrated the selection correction for standard errors in the context of a count model. Errors in this estimation are also corrected for nonindependence of observations, as described above.

---

[10] This correction of standard errors ensures that inclusion of multiple observations per firm is not driving significant findings. There are still, however, multiple

TABLE 1
Descriptive Statistics[a]

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Postalliance patents															
2. Technological diversity	−0.38														
	0.00														
3. Technological diversity squared	−0.38	0.99													
	0.00	0.00													
4. Prealliance firm patents	0.83	−0.36	−0.36												
	0.00	0.00	0.00												
5. Partner patents	0.07	−0.25	−0.29	0.05											
	0.03	0.00	0.00	0.13											
6. Narrow alliance scope	−0.03	0.08	0.08	−0.04	−0.02										
	0.31	0.02	0.01	0.23	0.47										
7. Broad alliance scope	−0.02	−0.08	−0.08	0.04	0.10	−0.28									
	0.56	0.01	0.01	0.18	0.00	0.00									
8. Multilateral alliance	0.03	−0.07	−0.10	0.02	0.50	0.01	0.12								
	0.33	0.03	0.00	0.54	0.00	0.68	0.00								
9. Prior links	−0.03	0.03	0.00	−0.02	0.47	0.06	0.07	0.59							
	0.39	0.41	0.90	0.61	0.00	0.07	0.02	0.00							
10. Year 1992	0.15	−0.11	−0.11	0.15	0.01	0.01	0.00	−0.01	0.01						
	0.00	0.00	0.00	0.00	0.85	0.77	0.95	0.81	0.64						
11. Year 1993	−0.20	0.10	0.10	−0.09	0.07	−0.11	0.06	0.05	0.08	−0.68					
	0.00	0.00	0.00	0.01	0.03	0.00	0.08	0.14	0.01	0.00					
12. Prior experience	0.25	−0.19	−0.20	0.24	0.02	0.02	−0.07	0.04	−0.02	0.07	−0.08				
	0.00	0.00	0.00	0.00	0.49	0.61	0.02	0.18	0.51	0.03	0.01				
13. Other alliance	0.26	−0.20	−0.21	0.25	0.05	0.01	−0.10	0.07	0.03	0.08	−0.08	0.91			
	0.00	0.00	0.00	0.00	0.13	0.66	0.00	0.03	0.34	0.01	0.01	0.00			
14. International alliance	0.08	0.00	−0.01	0.13	0.17	0.03	−0.01	0.22	0.22	−0.03	0.03	−0.02	−0.01		
	0.01	0.92	0.68	0.00	0.00	0.31	0.73	0.00	0.00	0.34	0.28	0.45	0.82		
15. Alliance organizational form	−0.02	0.08	0.07	0.03	0.23	0.13	0.10	0.26	0.29	0.05	−0.02	−0.06	−0.05	0.24	
	0.53	0.01	0.02	0.40	0.00	0.00	0.00	0.00	0.00	0.10	0.60	0.06	0.08	0.00	
Mean	461.68	0.94	0.90	357.95	1275.84	0.35	0.12	0.34	5.43	0.56	0.27	0.71	0.68	0.59	0.19
Median	13.00	1.00	1.00	5.00	218.00	0.00	0.00	0.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00
Minimum	0.00	0.13	0.02	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	6,420.00	1.00	1.00	4,822.00	7,887.00	1.00	1.00	1.00	66.00	1.00	1.00	1.00	1.00	1.00	1.00
s.d.	974.73	0.14	0.21	771.76	1780.33	0.48	0.33	0.47	10.48	0.50	0.44	0.46	0.47	0.49	0.39

[a] $n = 1,005$. Significance levels appear below correlations.

RESULTS

Of the 463 R&D alliances in the sample, 398 are bilateral contracts, and 65 are equity joint ventures. These alliances involve 487 firms. I create a single observation for each alliance a firm is involved in, obtaining a sample of 1,005 observations, where 817 involve firms in alliances organized by bilateral contract and 188 involve firms in alliances organized by equity joint venture. Table 1 presents descriptive statistics for all variables.[12]

---

[12]Given the high correlation between the variables for other alliance and prior experience, multicollinearity could be a concern. In a robustness check, I reestimate Tables 2 and 3 dropping the other alliance variable. Results are nearly identical to those presented below. The primary

TABLE 2
Negative Binomial Estimates for Technological Diversity and Performance[a]

Variables	Model 1: No Controls	Model 2: Firm Controls Only	Model 3: Alliance Controls Only	Model 4: All Controls	Model 5: Alliance Organizational Form Added
Technological diversity	6.57**	14.20***	7.13*	13.77***	14.14***
	(2.36)	(2.82)	(2.82)	(3.31)	(3.42)
Technological diversity squared	−7.05***	−11.26***	−7.43***	−11.04***	−11.32***
	(1.72)	(1.97)	(2.18)	(2.39)	(2.48)
Alliance organizational form					0.22
					(0.91)
Prealliance firm patents		0.00***		0.00***	0.00***
		(0.00)		(0.00)	(0.00)
Partner patents			0.00	0.00	0.00
			(0.00)	(0.00)	(0.00)
Narrow scope			−0.03	−0.26[†]	−0.27
			(0.19)	(0.14)	(0.17)
Broad scope			−0.10	−0.35[†]	−0.38
			(0.20)	(0.20)	(0.24)
Multilateral alliance			0.46[†]	0.04	−0.02
			(0.27)	(0.18)	(0.22)
Prior links			−0.01	0.01	0.01
			(0.01)	(0.01)	(0.01)
Year 1992			0.25	−0.40[†]	−0.40[†]
			(0.28)	(0.21)	(0.21)
Year 1993			−1.03***	−1.13***	−1.13***
			(0.27)	(0.22)	(0.22)
International alliance			0.38	0.04	−0.06
			(0.36)	(0.21)	(0.23)
Prior experience		1.03*		0.91*	0.96*
		(0.43)		(0.40)	(0.41)
Other alliance		0.46		0.46	0.41
		(0.43)		(0.40)	(0.41)
Inverse Mills ratio					−0.23
					(0.49)
Intercept	6.12***	−0.21	5.77***	0.67	0.61
	(0.75)	(0.98)	(0.74)	(1.06)	(1.08)
Wald χ^2	80.4***	150.8***	135.2***	236.4***	250.0***
df	2	5	10	13	15

[a] The dependent variable is the citation-weighted patents issued to each firm in a postalliance period. Positive coefficients indicate increased patent output. Robust standard errors are in parentheses. $n = 1,005$.

[†] $p < .10$
* $p < .05$
** $p < .01$
*** $p < .001$

Technological Diversity and Innovation

I first estimate a model of firm patenting, using the variables described above, without including the effect of alliance organizational form. Table 2 sets out results from this estimation.

consequence of multicollinearity is to inflate standard errors and, thus, make hypothesis testing of the collinear variables more difficult. However, dropping a variable such as other alliance to "solve" the multicollinearity problem can lead to omitted variables bias, particularly if there is a compelling reason to include the variable in a model (Greene, 2003; Kennedy, 2003). For these reasons, both variables are included in the specification below.

The results under model 4, which includes all firm and alliance controls, suggest a curvilinear relationship between technological diversity and firm innovation after an alliance. Technological diversity is positive, technological diversity squared is negative, and both effects are significant. Initially, rising capability diversity increases firm patenting but, beyond a certain level of diversity (0.62),[13] this relationship turns negative. This re-

---

13 $\frac{\partial Postalliance\_patents}{\partial Technological\_diversity} = 0$ when technological diversity = 0.62.

FIGURE 1
Effect of Technological Diversity on Firm Patenting
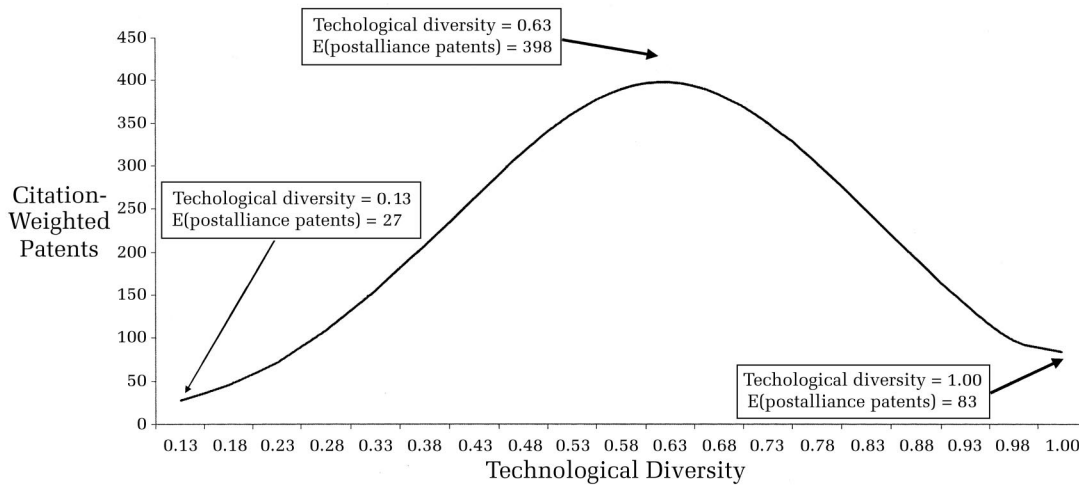
sult is robust across specifications (that is, whether or not firm and alliance controls are included).

To get an idea of the actual impact of rising diversity on firm innovative performance, I then calculate a firm's expected (citation-weighted) patents at all levels of technological diversity. To calculate this patent count, I first take the estimates from Table 2, model 4, and evaluate them at the median values of the independent and control variables. For the negative binomial model, the expected value of postalliance patents for a given firm is $e^{\beta'X}$, where X represents the vector of independent and control variables and β represents the parameter estimates from Table 2, model 4 (Cameron & Trivedi, 1986: 33). After calculating this value, I then vary technological diversity over all levels: from its lowest value (0.13) to its highest value (1.00). The results of these calculations are graphed in Figure 1.

The figure clearly shows that increasing technological diversity initially improves firm innovative performance but, beyond some moderate level (here, 0.62), reduces firm innovative performance. Further, from the calculations at various points on the graph, it can be seen that alliances with moderate diversity contribute far more to firm innovative performance than alliances with very low or very high levels of technological diversity. Moderately diverse alliances contribute *over 13 times more* than alliances with very low diversity (398 compared to 27) and *over 3 times more* than alliances with very high diversity (398 compared to 83). The results from Table 2 and Figure 1 provide support for absorptive capacity arguments: although diversity means partners have more to learn

from each other, partners require some common capabilities to assimilate those they do not have in common. This result goes beyond prior findings of similarity or diversity between partners and alliance outcomes. Although, for example, prior research has shown that partner similarity on dimensions such as compensation schemes and organizational structure is positively related to alliance success and learning (Lane & Lubatkin, 1998), and other work has emphasized the positive benefits of a diversity of partners (e.g., Baum et al., 2000), results here suggest that the relationship between partner similarity and alliance outcomes is more nuanced. Some similarity is required for absorptive capacity, but too much similarity means that partners have less to learn from each other: a moderate level of diversity appears best. This pattern of findings suggests strong support for Hypothesis 1.

Several interesting findings emerge regarding the control variables. Preexisting firm patents (*prealliance patents*), a proxy for firm capabilities, positively influence firm patenting after the beginning of an alliance. In contrast, although preexisting *partner* firm patents suggest a larger alliance capability pool, the variable *partner patents* is not significant. One possible interpretation is that the benefits of collaborative activities depend more on a firm's ability to learn from its partner rather than on the stock of the partner's capabilities. This ability, in turn, depends on the firm's own capabilities or absorptive capacity (Cohen & Levinthal, 1989).

The primary effect of alliance organizational form on performance (that is, the effect when form is not interacted with technological diversity) is not

significant in model 5 of Table 2. This result is consistent with Hypothesis 2: the effect of organizational form on performance depends on the degree of technological diversity between partners. The influence of organizational form on performance, independent of alliance characteristics, is ambiguous; each organizational form is likely the most suitable or the best-performing form under certain circumstances, but not in all cases. This result is consistent with prior work on choice of organizational form: for example, Shaver (1998) found no effect of entry mode alone on the performance of foreign direct investment, once self-selection was controlled for.

The coefficients on narrow and broad alliance scope are both negative and significant. The effect of narrow R&D activity on firm patenting is expected; when R&D activities are very limited, firms pool fewer capabilities and realize fewer gains. Interestingly, broad R&D alliances also have a negative impact on postalliance firm patenting, relative to alliances with intermediate scope. Broad collaborative projects may have minor effects on firm innovative performance because such breadth signals riskier projects. It appears, empirically at least, that moderately ambitious projects may have the greatest payoff in the short to medium term.

The other control variables perform largely as expected. *Multilateral alliance* is positive but not significant. Similarly, the variable for prior links among partner firms is positively but not significantly related to postalliance patenting. A firm's prior alliance experience positively and significantly influences postalliance patenting. One interpretation of this relationship is that firms gain experiential knowledge from prior alliances that allows these firms to better manage their current alliance activities. Alternatively, firms with prior experience may have better collaborative opportunities, since such experience may signal that they are attractive partners. Similarly, *other alliance* is positive and significant; the existence of concurrent alliances positively influences firm patenting rates. The effects of later alliance commencement are also consistent with expectations; both *year 1992* and *year 1993* are negative and significant. Finally, firm patenting does not bear a significant relationship with whether or not an alliance is international; *international alliance* is not significant.

The Impact of Alliance Organization

To evaluate the effects of alliance organizational form, conditional on technological diversity, I estimate the same model of firm patenting with interaction terms to capture the effect of alliance organization (if any). I interact alliance organizational form, which equals 0 or 1 depending on whether an alliance is organized by bilateral contract or equity joint venture, respectively, with technological diversity and control variables. I include the squared technological diversity term in the variables interacted with organizational form, since this allows the relationship between alliance organization and performance to be nonlinear depending on the level of technological diversity.

Note that I do not center the variables in this analysis. The regression coefficient for interactions is the same whether one uses centered or noncentered variables (Aiken & West, 1996). Ordinarily, the coefficients only differ with centering for noninteracted terms. However, since here alliance organizational form is a dummy variable with meaningful zero values, centering would make no difference in the estimates of the variables when they are not interacted. This is because the effect of centering is to estimate the effect of one of the interaction terms on the dependent variable, given that the other interaction term is zero. Since alliance organizational form is a dummy variable, the interpretation of the variables that are not interacted is the effect of those variables on innovative performance, given that organization is by bilateral contract (i.e., = 0).

As outlined above, I correct for the fact that firms may select organizational form on the basis of expected alliance performance under that form using a common econometric technique (Heckman, 1979). When estimating performance as a function of independent variables that may be chosen strategically, such as organizational form, such corrections are necessary to avoid self-selection bias (effectively omitted variables bias). To calculate the inverse Mills ratio, which accounts for unobserved heterogeneity in a choice, I first estimate a probit model capturing how firms select alliance organizational form. This estimation is very similar to those in earlier empirical studies on alliance organizational form selection (e.g., Oxley, 1997; Pisano, 1989). Specifically, drawing on transaction cost arguments, I estimate the choice between bilateral contracts and equity joint ventures as a function of variables capturing the contracting difficulties associated with an alliance. The results from this probit estimation are consistent with the prior empirical literature. I do not emphasize this analysis here as it is beyond the scope of the paper and is only relevant for the construction of the inverse Mills ratio. Further, the results are consistent with prior literature in the area (Oxley, 1997;

Pisano, 1989). Consistent results are obtained with alternative specifications of this organization selection model.[14] The Mills ratio is a function of observable variables and unobservable variables and effectively controls for those unobserved factors that might affect both the choice of organizational form and the ultimate performance of an alliance.

Using the inverse Mills ratio as a control variable, I then estimate the firm innovative performance measure, postalliance patents, using the variables described above plus the interaction terms. Table 3 reports results from this estimation. Note that the coefficients on the interaction terms (reported in the second column) represent the *difference* between the slopes of the bilateral contract and equity joint venture equations. By interacting organizational form with the independent and control variables, I relax the assumption that the relationship between the independent and control variables and performance is the same under both organizational forms. Although my hypotheses focus on the interaction between technological diversity and organization, I allow the slope for the performance equations to vary between the bilateral contract and equity joint venture. This approach relaxes the constraint that the independent and control variables have the same effect on innovative performance irrespective of organizational form chosen; however, it introduces the potential issue of multicollinearity, since all of the variables are interacted with alliance organizational form. To ensure that results are not sensitive to this estimation approach, I reestimate the analysis reported in Table 3 in two additional ways. First, I interact organizational form only with technological diversity and technological diversity squared. Second, I split the sample according to organizational form and estimate two regressions, one for each form. The results from these two additional robustness checks are very consistent with those reported in Table 3, suggesting that the additional interaction terms (that is, the control variables) do not affect the key results in any meaningful way. These results are not reported here in the interest of brevity but are available from the author on request.

In keeping with the results from Table 2, the effect of technological diversity on firm patenting is nonmonotonic (that is, the relationship changes sign as technological diversity increases). Increasing diversity initially increases postalliance firm patenting but, beyond a certain level of diversity, this relationship turns negative. This critical level is 0.63 for bilateral contracts and 0.76 for equity joint ventures. The substantial difference between these maxima, given a data range of 0.13 to 1.00, suggests that alliances governed by equity joint ventures benefit from greater levels of capability diversity (up to 0.76) than do bilateral contracts. Substantial differences in the magnitude of these coefficients between bilateral contracts and equity joint ventures provide further support.

To highlight the interactive effects of organizational form and technological diversity, I calculate patenting rates under both organizational forms. I then vary technological diversity over all levels (low [0.13] to high [1.00]) to examine the impact on firm innovative performance. I graph these calculations in Figure 2. From this figure, it can be seen that when technological diversity exceeds 0.53, firms benefit more from alliances organized by equity joint venture than by bilateral contract. The magnitude of the difference between the organizational forms changes over the range of 0.53 to 1.00, but it remains positive throughout the range. At moderate diversity (0.68), firms benefit 35 times more from alliances organized by equity joint venture than from those organized by bilateral contract (11,274 versus 306). At high diversity (1.00), this number increases: firms benefit over 100 times more from alliances organized by equity joint venture than from those organized by bilateral contract (441 versus 4).[15] The converse also holds: at low

---

[14] To summarize, firms more likely choose an equity joint venture when: (1) alliance activities involve marketing, manufacturing, or supply in addition to joint R&D; (2) the alliance involves more than two partner firms; (3) the scope of the joint R&D activities is broad or narrow, rather than intermediate; (4) the intellectual property regimes of partner firms' home nations are weak; and (5) the legal systems of partner firms' home nations are nontransparent and corrupt. These variables make organizing via bilateral contract more difficult than organizing via equity joint venture (i.e., the variables are proxies for difficulties in specifying rights and obligations of partners, monitoring specified obligations, and/or enforcing those rights and obligations.) These results are available from the author on request.

[15] Given the magnitude of the effects of technological diversity on performance, a natural concern is that a few observations with substantial patenting activities may be driving the results. Prior to undertaking the current analysis, I remove several outliers from the sample. For an additional robustness check, I reestimate the results in Tables 2 and 3, removing observations that exhibit substantial leverage, according to several different statistics. Running a simple ordinary least squares model, I am able to calculate the Cook's D and the hat ratio, which help identify individual observations that have particularly

TABLE 3
Negative Binomial Estimates for Alliance Organizational Form, Technological Diversity, and Performance[a]

Variables	Simple Effects	Interactions with Alliance Organization Form
Technological diversity	11.79***	81.56**
	(3.32)	(24.82)
Technological diversity squared	−9.31***	−52.02**
	(2.38)	(15.89)
Alliance organizational form	−27.69**	
	(9.73)	
Prealliance firm patents	0.00***	0.00
	(0.00)	(0.00)
Partner patents	0.00	0.00
	(0.00)	(0.00)
Narrow scope	−0.15	−0.48
	(0.19)	(0.56)
Broad scope	−0.21	−0.49
	(0.25)	(0.73)
Multilateral alliance	0.39[†]	−2.19**
	(0.22)	(0.75)
Prior links	0.00	0.05*
	(0.01)	(0.02)
Year 1992	−0.32	−0.56
	(0.23)	(0.63)
Year 1993	−1.15***	0.41
	(0.24)	(0.74)
Prior experience	0.67	2.05
	(0.53)	(1.43)
Other alliance	0.67	−1.53
	(0.52)	(1.21)
International alliance	0.22	−0.39
	(0.26)	(0.69)
Inverse Mills ratio	0.67	−1.90[†]
	(0.61)	(1.07)
Intercept	0.87	
	(1.12)	
Wald χ^2		605.97***
df		29

[a] The dependent variable is citation-weighted patents issued to each firm in a postalliance period. Positive coefficients indicate increased patent output. Robust standard errors are in parentheses. $n = 1,005$.

† $p < .10$
* $p < .05$
** $p < .01$
*** $p < .001$

levels of technological diversity (that is, below 0.53), firms benefit more from alliances organized by bilateral contract than from those organized by equity joint venture. The magnitude of this effect,

great influence over the results. Having identified and removed 26 influential observations, I then reestimated the specifications in Tables 2 and 3. Results are very similar to those reported in Tables 2 and 3, both in terms of coefficient sign and significance.

however, is not as great as the difference between organizational forms in alliances with high technological diversity between partners.

In view of transaction cost economics and knowledge-based arguments, these findings suggest that the equity joint venture form preserves incentives to share information and allows strong information flow among partners, which is more important in alliances where technological diversity is high than in those where it is low. These results should not be taken to imply that the equity joint venture is the

FIGURE 2
Effect of Alliance Organization on Firm Patenting
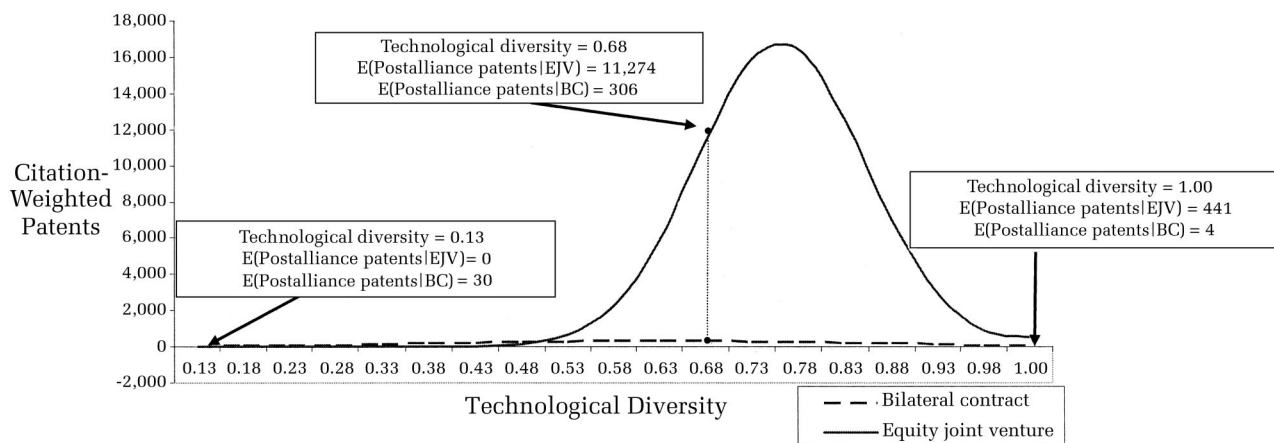
optimal choice of organizational form in all cases, however. First, as just discussed, bilateral contracts appear to be more effective when technological diversity is low. Second, firms may choose an organizational form for reasons unrelated to patenting performance. For example, firms may avoid antitrust scrutiny by selecting a bilateral contract over an equity joint venture, and the value of this avoidance may exceed any losses in patenting output, even at high levels of diversity. Further, firms may seek to avoid the bureaucracy that often accompanies more hierarchical organization forms like the equity joint venture. Bureaucracy may be hostile to more uncertain projects or those that require great creativity (e.g., Holmstrom, 1989: 323).[16]

Results on the control variables are largely consistent with the Table 2 results. The coefficients on narrow scope and broad scope are negative for both bilateral contracts and equity joint ventures, though not significant for either. Multilateral alliance is positive and significant for bilateral contracts, suggesting that firms get more out of their collaborative R&D when involved with more than one partner. Multilateral alliance may simply be another proxy for the size of the alliance capability pool: a greater capability pool leads to greater innovative performance. When the positive coefficient for the bilateral form is compared with the

negative and significant coefficient on multilateral alliance under the equity joint venture form, a second interpretation emerges. The difference between these estimates suggests that it may be easier to manage alliances with multiple partner firms under a bilateral contract than under an equity joint venture. Decision making may be more difficult under an equity joint venture because of its pooled management structure. With a greater number of partner firms, more autonomous decision making may be preferable.

Another interesting finding is the difference in the effect of prior links on patenting performance between the bilateral contract and the equity joint venture. Prior links is not significant for bilateral contracts, suggesting no real change from Table 2. However, the effect of prior links is positive and significant for firms allying under equity joint ventures. One possible interpretation is that, given the pooled management under the equity joint venture, information on a partner's behavior from prior alliances may be more important for the coordination of activities organized under equity joint ventures than under bilateral contracts.

Other control variables performed as expected. Prior experience was positive and significant, but for equity joint ventures only, suggesting that prior alliance experience matters more for firms entering equity joint ventures than bilateral contracts. Other alliances is positive and significant for alliances organized under both modes. The effects of later alliance commencement are consistent with findings in Table 2; both year 1992 and year 1993 are negative and significant. Finally, alliance outcomes do not appear to be linked to whether the alliance is international or not, as the variable for international alliances is not significant.

---

[16] Given that the distribution of technological diversity is skewed to the right (i.e., many alliances are characterized by high levels of technological diversity), I reestimate Tables 2 and 3 with a reduced sample, deleting observations where technological diversity equals 1. Results from this estimation show very similar results (in terms of sign and significance) to those reported in Tables 2 and 3. These results are available on request from the author.

DISCUSSION AND CONCLUSION

Research in the strategy literature has increasingly focused on the ability of firms to create new knowledge and capabilities in a timely and cost-effective manner, yet understanding of how effectively firms use collaborative strategies to meet this goal lags far behind. The limited empirical evidence on characteristics of alliances that influence performance has prevented researchers from understanding which alliances contribute most to firm innovative performance and, more generally, how firms can best use alliances as part of their knowledge creation strategies. Although prior work has shown that alliances do matter for firm performance (e.g., Ahuja, 2000), the current research demonstrates that some alliances contribute more than others and identifies two key factors that drive such differences. Put simply, how *much* a firm has to learn and how well a firm is *able* to learn from its partner(s) matter for innovative performance.

The empirical results support these arguments. First, firms benefit more from alliances when they have some, but not all, technological capabilities in common with their partners. This result was highly significant; alliances with moderately diverse partners contributed over 13 times more to firm innovation than alliances with minimally diverse partners and over 3 times more to firm innovation than their highly diverse counterparts, providing strong support for the first hypothesis. This finding suggests that some diversity between partners is good, even required, for innovation, lest firms find they have nothing to learn from their partners. However, when partners are too diverse, firms have difficulty learning from their partners. This result holds irrespective of the alliance organizational form chosen. Supporting the absorptive capacity hypothesis, partners require some sort of common stock of knowledge to utilize knowledge/resources that are not common to both parties.

Alliance organization also matters; although some understanding of how firms choose among organizational forms for their alliance activities exists, there is little guidance on the impact of these choices. This paper suggests that organizational form influences the ability and incentives of partners to share information, which in turn affects firm innovative performance. The empirical results presented above are consistent with this argument: firms benefit from organizing alliances under the equity joint venture form when technological diversity between them is higher. Benefits from collaborative activities organized by equity joint venture are over 30 times greater with moderate diversity and 100 times greater with high diversity than are benefits from collaboration under the bilateral contract counterparts. This result holds even when corrections for self-selection are made. These findings provide support for both knowledge-based and transaction cost economics arguments. More hierarchical organization (here, equity joint venture) provides better information flow between partners and preserves incentives for firms to share information, both of which are particularly important when firms confront diversity. These arguments suggest a complementarity between the two theoretical approaches; to understand the impact of organizational choices on firm innovative performance, researchers should examine the implications of organization for both information flow among parties and incentives to allow or facilitate such information flow. Ultimately, it appears that it is both operational mechanisms and the incentive systems that define the effectiveness of an organizational form in a particular setting.

These results also hint at the limitations of various organizational forms. Alliance outcomes are improved with more hierarchical organization (i.e., the equity joint venture) when firms are more technologically diverse, yet the absolute benefits of such organization are sharply diminished at the highest levels of diversity between partners (see Figure 2). This finding suggests that the benefits of hierarchical organization may be inadequate to fully overcome the difficulties associated with cross-utilization of very diverse partner resources. Although hierarchy can improve incentives to collaborate with mechanisms that align incentives and improve information flow, such mechanisms may hinder responsiveness and fast decision making, which may be more important to alliance success when partners are very diverse. This suggestion is consistent with prior research suggesting that bureaucracy can be hostile to innovation (e.g., Holmstrom, 1989). However, given that alliance outcomes are still better with the equity joint venture rather than the bilateral contract even at this very high level of diversity, it would seem that hierarchical organization still offers benefits when technology sharing/transfer is more challenging, but that the benefits over all organizational forms are reduced when partners are very technologically diverse. Projects involving very diverse partners may simply be much more challenging to manage under either organizational form.

This result provides further evidence on the importance of absorptive capacity: if partners are very diverse, though incentives to share information/knowledge still matter, the ability to share information/knowledge may be more important to alliance outcomes. In this sense, the effect of organization

on innovative performance is contingent on absorptive capacity. Further work exploring when absorptive capacity matters most, perhaps utilizing finer-grained measures of absorptive capacity to better understand the types of projects in which absorptive capacity is most important, would be a useful extension to the work here. For example, is it the diversity of their resources that makes it difficult for partners to effectively work together, or is it the selection of a very ambitious project that requires such diverse resources (and, thus, partners) that dampens innovative outcomes? Perhaps it is when a project requires a very extensive or intense interaction, such as the cross-partner integration of complex systems, that absorptive capacity becomes critically important.

Several other interesting findings emerge from the empirical analyses. In keeping with the findings of Anand and Khanna (2000), I found that a firm's prior alliance experience improved its gains from current alliances. This prior experience mattered more when a current alliance was organized via equity joint venture (versus bilateral contract). Additionally, prior experience with *the same partner* influenced what a firm reaped from its collaborative activities but, interestingly, only when the alliance was organized by equity joint venture. These findings together suggest that prior alliance experience and greater partner knowledge are very important when allying via an equity joint venture. An equity joint venture requires a more substantial commitment among allying firms and, therefore, firms may benefit from their prior understandings of how to manage alliance activities and the behavior of a specific partner. Additional work in this area may help determine whether these effects vary according to the extent and type of prior experience (e.g., Sampson, 2005).

These results have important practical implications, most notably regarding the choice of partner and organizational form for an alliance. R&D alliances appear to contribute most to firm innovation when partners have moderately different technology portfolios. This observation suggests that, when entering alliances for new technological development and given a choice of acceptable partners, firms should choose partners that are not identical to themselves in technological capabilities. However, this diversity should be moderate (if possible, given the project), else the difficulties in knowledge transfer between the partners may dampen the collaborative benefits realized from pooling distinct perspectives and resources. Second, organizational form should not be an afterthought in an alliance formation process, left to in-house counsel after a deal is struck. From the

results presented herein, it appears that alliance organization is a strategic variable that influences the ease of knowledge transfer, particularly when partners have little overlap in technology portfolios. When technological diversity is high, barriers to effective knowledge transfer rise, as the low overlap between the partners implies a lack of the absorptive capacity necessary for easy transfer. Under such circumstances, more hierarchical organization can both alleviate fears of knowledge leakage and provide enhanced mechanisms for knowledge transfer. Hierarchical organization—the equity joint venture, in the context of alliances—is not without cost, however, and its use is thus best reserved for situations in which diversity between partners is high.

Naturally, this research has important limitations. Partner selection is often multifaceted, depending not only on the capabilities or resources one partner has to bring to alliance activities, but also on the preexisting relationship that the potential partners have with each other. Firms generally prefer to work with other firms with whom they have relationships (Granovetter, 1985), assuming that the relationships are positive ones. So, although the results presented here suggest that outcomes from R&D collaborations are improved by having partners that are moderately diverse in technologies or resources, this consideration may be outweighed by others. These other considerations include the existence of a prior relationship, future plans for collaboration in other areas such as manufacturing or marketing, where other capabilities may be more important, or simply a lack of better alternatives (that is, more or less diverse partners may not exist or be available). Similarly, firms may be reluctant to form equity joint ventures when projects are fairly narrow in scope or likely to be of a short duration, even when partners are very diverse, given the costs of setting up and disbanding a joint venture after project completion. Thus, the practical implications of this research are contingent on circumstances presented to firms and should not be interpreted as absolutes.

Care must also be taken in generalizing these findings to other settings. The alliances examined here are those pertaining to joint technological development, and although while technological overlap and alliance organization may well be relevant factors in the outcomes from R&D alliances, these factors may be less (or more) important in other types of alliances, such as marketing, manufacturing, or supply alliances. Similarly, the results herein may be most relevant to high-technology industries, such as telecommunications equipment, where the pace of development is rapid and,

consequently, innovative performance is critical to firm outcomes. R&D alliances present unique coordination challenges, which may mean that optimal organizational form differs for alliances set up for other purposes.

Two other limitations are primarily empirical. First, my main measure, technological diversity, was constructed from patents. To the extent that patents do not capture firm technological portfolios, this measure will not capture the technological diversity between allying partners. Similarly, I considered only two discrete choices of alliance organizational form here: equity joint venture and bilateral contract (that is, nonequity alliance involving two or more partners for joint development). Variance clearly exists in the organizational design within each of these broad groupings, and many different mechanisms for dealing with the various coordination challenges inherent in R&D collaborations exist within each of these organizational forms. Thus, my analysis may have missed some of the finer-grained solutions that firms devise to resolve alliance coordination challenges. Finally, puzzles still remain; given the startling difference between the bilateral contract and equity joint venture, why don't all firms choose the equity joint venture at high levels of technological diversity? Either managers make mistakes, or they are selecting alliance organization for reasons other than the performance effects captured here. More work is required to understand why firms select various organization forms, given the forms' different performance attributes.

Even with these limitations, the results of this research offer several broad implications. These ideas apply beyond the context analyzed here— R&D alliances—to innovation within a firm. Frequently, innovation results from combining capabilities from different parts of an organization. Thus, individuals or divisions within a firm must be both able and willing to share their capabilities or resources with other parts of the organization. Typically incentives to share are more aligned within a firm than across firms, but differences between firm divisions can be substantial. Internal competition between divisions for resources can lead these internal actors to restrict access to their capabilities, new technologies, or knowledge bases. Further, in diversified firms, within-firm technological diversity can be significant, so that the ability to share knowledge is also hampered. A useful extension of the present study in this context would be to examine within-firm innovation as a function of technological relatedness between divisions/areas, as well as the incentive structures and transfer mechanisms or routines set up to encour-

age such sharing. The results of such a study would have substantive implications for the process of innovation within larger firms.

Although much more work is required to understand how firms can improve collaborative benefits, this paper is one step toward a greater understanding. In view of the recent rapid growth in interfirm collaborations, hopefully this research will help guide managers in using collaborative strategies more effectively.

REFERENCES

Ahuja, G. 2000. Collaboration networks, structural holes and innovation: A longitudinal study. *Administrative Science Quarterly,* 45: 425–457.

Ahuja, G., & Katila, R. 2001. Technological acquisitions and the innovation performance of acquiring firms: A longitudinal study. *Strategic Management Journal,* 22: 197–220.

Almeida, P., & Kogut, B. 1999. The localization of knowledge and the mobility of engineers in regional networks. *Management Science,* 45: 905–917.

Anand, B. N., & Khanna, T. 2000. Do firms learn to create value? The case of alliances. *Strategic Management Journal,* 21: 295–315.

Arrow, K. J. 1962. Economic welfare and the allocation of resources of invention. In R. Nelson (Ed.), *The rate and direction of inventive activity: Economic and social factors:* 609–625. Princeton, NJ: Princeton University Press.

Arrow, K. J. 1974. *The limits of organization.* New York: Norton.

Balakrishnan, S., & Koza, M. P. 1993. Information asymmetry, adverse selection and joint-ventures. *Journal of Economic Behavior and Organization,* 20: 99–117.

Bantel, K. A., & Jackson, S. E. 1989. Top management and innovations in banking: Does the composition of the top team make a difference? *Strategic Management Journal,* 10: 107–124.

Basberg, B. L. 1982. Technological change in the Norwegian whaling industry: A case study in the use of patent statistics as a technology indicator. *Research Policy,* 11(3): 163–171.

Baum, J. C., Calabrese, T., & Silverman, B. S. 2000. Don't go it alone: Alliance network composition and start-ups' performance in canadian biotechnology. *Strategic Management Journal,* 21: 267–294.

Bleeke, J., & Ernst, D. 1993. *Collaborating to compete.* New York: Wiley.

Bunderson, J. S., & Sutcliffe, K. M. 2002. Comparing alternative conceptualizations of functional diversity in management teams: Process and performance effects. *Academy of Management Journal,* 45: 875–893.

Cameron, A. C., & Trivedi, P. K. 1986. Econometric models based on count data: Comparisons and applications of some estimators and tests. *Journal of Applied Econometrics,* 1: 29–53.

Cohen, W. M., & Levinthal, D. A. 1989. Innovation and learning: The two faces of R&D. *Economic Journal,* 99: 569–596.

Cohen, W. M., Nelson, R. R., & Walsh, J. P. 2002. Links and impacts: The influence of public research on industrial R&D. *Management Science,* 48: 1–23.

Comanor, W. S., & Scherer, F. M. 1969. Patent statistics as a measure of technical change. *Journal of Political Economy,* 77: 329–398.

Gilfillan, S. C. 1935. *The sociology of invention.* Chicago: Follett.

Greene, W. H. 2003. *Econometric analysis.* Englewood Cliffs, NJ: Prentice-Hall.

Griliches, Z. 1990. Patent statistics as economic indicators: A survey. *Journal of Economic Literature,* 27: 1661–1707.

Hall, B. H., Jaffe, A. B., & Trajtenberg, M. 2001. *The NBER patent citations data file: Lessons, insights and methodological tools.* NBER Working Paper #8498, Cambridge, MA.

Hall, B. H., & Ziedonis, R. H. 2001. The patent paradox revisited: An empirical study of patenting in the US semiconductor industry, 1979–1995. *Rand Journal of Economics,* 32: 101–128.

Hausman, J., Hall, B. H., & Griliches, Z. 1984. Econometric models for count data with an application to the patents-R&D relationship. *Econometrica,* 52:909–938.

Heckman, J. J. 1979. Sample selection bias as a specification error. *Econometrica,* 47: 153–161.

Hergert, M., & Morris, D. 1988. Trends in international collaborative arrangements. In F. J. Contractor & P. Lorange (Eds.), *Cooperative strategies in international business:* 99–109. Lexington, MA: Lexington Books.

Holmstrom, B. 1989. Agency costs and innovation. *Journal of Economic Behavior and Organization,* 12: 305–327.

Huber, P. J. 1967. The behavior of maximum likelihood estimates under non-standard conditions. *Proceedings of the Berkeley Symposium on Mathematical Statistics and Probability,* 1: 221–233.

Jaffe, A. B. 1986. Technological opportunity and ppillovers of R&D: Evidence from firms' patents, profits and market value. *American Economic Review,* 76: 984–1001.

Jaffe, A. B., & Trajtenberg, M. 1996. Flows of knowledge from universities and federal labs: Modeling the flow of patent citations over time and across institutional and geographic boundaries. *Proceedings of the National Academy of Sciences,* 93: 12671–12677.

Keller, R. T. 2001. Cross-functional project groups in research and new product development: Diversity, communications, job stress and outcomes. *Academy of Management Journal,* 44: 547–555.

Kennedy, P. 2003. *A guide to econometrics.* Cambridge, MA: MIT Press.

Killing, J. P. 1983. *Strategies for joint venture success.* London: Croom Helm.

Kogut, B. 1988. Joint ventures: Theoretical and empirical perspectives. *Strategic Management Journal,* 9: 319–332.

Kogut, B. 1989. The stability of joint ventures: Reciprocity and competitive rivalry. *Journal of Industrial Economics,* 38(2): 183–198.

Kogut, B., & Zander, U. 1992. Knowledge of the firm, combinative capabilities and the replication of technology. *Organization Science,* 3: 383–397.

Lane, P. J., & Lubatkin, M. 1998. Relative absorptive capacity and interorganizational learning. *Strategic Management Journal,* 19: 461–477.

Lanjouw, J. O., & Schankerman, M. 1999. *The quality of ideas: Measuring innovation with multiple indicators.* NBER working paper no. 7345, National Bureau of Economic Research, Cambridge, MA.

Levin, R. C., Klevorick, A. K., Nelson, R. R., & Winter, S. G. 1987. Appropriating returns from industrial research and development. *Brookings Papers on Economic Activity,* 3: 783–831.

Mariti, P., & Smiley, R. H. 1983. Co-operative agreements and the organization of industry. *Journal of Industrial Economics,* 41: 437–451.

Masten, S. E. 1993. Transaction costs, mistakes, and performance: Assessing the importance of governance. *Managerial and Decision Economics,* 14: 119–29.

Moen, J. 2005. Is mobility of technical personnel a source of R&D spillovers? *Journal of Labor Economics,* 23: 81–114.

Morris, D., & Hergert, M. 1987. Trends in international collaborative agreements. *Columbia Journal of World Business,* 22(2): 15–22.

Mowery, D. C. 1988. Collaborative ventures between US and foreign manufacturing firms: An overview. In D. C. Mowery (Ed.), *International collaborative ventures in U.S. manufacturing:* 1–22. Cambridge, MA: Belknap.

Mowery, D. C., Oxley, J. E., Silverman, B. S. 1996. Strategic alliances and inter-firm knowledge transfer. *Strategic Management Journal,* 17: 77–91.

Murphy, K., & Topel, R. 1985. Estimation and inference in two step econometric models. *Journal of Business and Economic Statistics,* 3: 370–379.

Oxley, J. E. 1997. Appropriability hazards and governance in strategic alliances: A transaction cost approach. *Journal of Law, Economics and Organization,* 13: 387–409.

Oxley, J. E. 1999. Institutional environment and the mechanisms of governance: The impact of intellectual property protection on the structure of interfirm alliances. ***Journal of Economic Behavior and Organization,*** 38: 283–309.

Patel, P., & Pavitt, K. 1997. The technological complexities of the world's largest firms: Complex and path-dependent, but not much variety. ***Research Policy,*** 26: 141–156.

Pisano, G. P. 1989. Using equity participation to support exchange: Evidence from the biotechnology industry. ***Journal of Law, Economics and Organization,*** 1: 109–126.

Pisano, G. P., Russo, M. V., & Teece, D. C. 1988. Joint ventures and collaborative arrangements in the telecommunications equipment industry. In D. C. Mowery (Ed.), ***International collaborative ventures in U.S. manufacturing:*** 23–70. Cambridge, MA: Ballinger.

Powell, W. W. 1990. Neither market nor hierarchy: Network forms of organization. In B. M. Staw & L. L. Cummings (Eds.), ***Research in organizational behavior,*** vol. 12: 295–336. Greenwich, CT: JAI Press.

Powell, W. W., Koput, K. W., & Smith-Doerr, L. 1996. Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. ***Administrative Science Quarterly,*** 41: 116–145.

Sampson, R. C. 2005. Experience effects and collaborative returns in R&D alliances. ***Strategic Management Journal,*** 26: 1009–1031.

Schumpeter, J. A. 1934. ***Theory of economic development.*** Cambridge, MA: Harvard University.

Shaver, J. M. 1998. Accounting for endogeneity when assessing strategy performance: Does entry mode choice affect FDI survival? ***Management Science,*** 44: 571–585.

Silverman, B. S. 1999. Technological resources and the direction of corporate diversification: Toward an integration of the resource-based view and transaction cost economics. ***Management Science,*** 45: 1109–1124.

Song, J., Almeida, P., & Wu, G. 2003. Learning-by-hiring: When is mobility more likely to facilitate interfirm knowledge transfer? ***Management Science,*** 49: 351–365.

Trajtenberg, M. 1990. A penny for your quotes: Patent citations and the value of innovations. ***Rand Journal of Economics,*** 21: 172–187.

Williamson, O. E. 1991. Comparative economic organization: The analysis of discrete structural alternatives. ***Administrative Science Quarterly,*** 36: 269–296.

———————M̂—————————

Rachelle C. Sampson *(rsampson@rhsmith.umd.edu)* is an assistant professor of business and public policy at the R. H. Smith School of Business, University of Maryland. Her research focuses on strategic alliances and the organization of corporate R&D. Her recent studies examine alliance structure and partner selection in the telecommunications equipment industry, legal contracting for alliances, and optimal organization for innovation. She received her Ph.D. in business administration at the University of Michigan.

———————M̂—————————