

# Fishing upstream: Firm innovation strategy and university research alliances

Janet E.L. Bercovitz<sup>a,1</sup>, Maryann P. Feldman<sup>b,\*</sup>

<sup>a</sup> College of Business, University of Illinois at Urbana-Champaign, 1206 S. Sixth Street, Champaign, IL 61820, United States

<sup>b</sup> Institute for Higher Education, University of Georgia, Athens, GA 30602, United States

Received 14 March 2006; received in revised form 20 March 2007; accepted 21 March 2007

Available online 23 May 2007

## Abstract

This paper examines how innovation strategy influences firms' level of involvement with university-based research. Our results suggest that firms with internal R&D strategies more heavily weighted toward exploratory activities allocate a greater share of their R&D resources to exploratory university research and develop deeper multifaceted relationships with their university research partners. In addition, firms with more centralized internal R&D organizations spend a greater share of their R&D dollars on exploratory research conducted at universities. In contrast to other external partners, we find evidence suggesting that universities are preferred when the firm perceives potential conflicts over intellectual property.

© 2007 Elsevier B.V. All rights reserved.

*Keywords:* R&D strategic alliances; University–industry technology transfer; Organizational learning

Firms face two interrelated decisions when they engage in innovation. The first is the strategic decision as to what balance to strike between the exploration of new opportunities and the exploitation of existing capabilities (March, 1991; Levinthal and March, 1993; Tushman and O'Reilly, 1996). The most successful firms are ambidextrous, developing ideas for new products and investing in new capabilities for growth while simultaneously refining existing products to maximize current capabilities (O'Reilly and Tushman, 2004). The balance selected is influenced by internal research and development (R&D) organizational structure (Argyres and Silverman, 2004) and differentiates the firm's innovation strategy from

that of other firms in the same industry (Tushman and O'Reilly, 1996). The second, and related, decision is how to best allocate scarce R&D resources between internal activities and external alliances (Pisano, 1991; Chesbrough, 2003). While large firms conduct significant amounts of internal R&D, cross-boundary alliances provide access to specialized knowledge that may be difficult, if not impossible, to bring into the firm. R&D alliances augment and extend firms' internal efforts to achieve strategic objectives. In sum, the firm's challenge is to determine the relative weight to be given to exploration versus exploitation, and then judiciously select among potential external partners in order to benefit from the diverse explore and exploit capabilities of these entities.

There has been substantial growth in all types of cross-boundary research alliances—firm–firm, firm–university, or firm–government laboratory—in the recent past. Firms vary, however, both in the degree to

\* Corresponding author. Tel.: +1 706 542 0581.

E-mail addresses: [jbercov@uiuc.edu](mailto:jbercov@uiuc.edu) (J.E.L. Bercovitz), [mfeldman@uga.edu](mailto:mfeldman@uga.edu) (M.P. Feldman).

<sup>1</sup> Tel.: +1 217 2650696.

which they engage in R&D alliances and the nature of the activities pursued in these alliances (Arora et al., 2001; Rosenfeld, 1996; Link, 1996; Koza and Lewin, 1998).<sup>2</sup> Some alliances focus on exploitation—incrementally building on the firm’s existing internal knowledge with an external partner’s specific capabilities. Other alliances emphasize exploration—tapping external knowledge to aid in investigating trajectories that are new to the firm (Rosenkopf and Nerkar, 2001; Ahuja, 2000). In general, when selecting external partners, firms appear to value diversity for exploration and complementarity for exploitation.

Prior research on cross-boundary alliances focuses mainly on inter-firm alliances (Arora et al., 2001; Rosenfeld, 1996). Although the literature mentions universities as strategic research partners, it does not delve deeply into the unique character of university–firm alliances and tends to investigate these alliances from the perspective of the university, rather than from the perspective of the commercial partner. When universities are considered as strategic partners, the focus is typically on start-up firms, not the large corporations that account for three-quarters of R&D funding in the economy and fund the majority of industry-sponsored research conducted at academic institutions. Moreover, the typical conceptualization of innovation, the linear model, places universities at the earliest stage of knowledge creation and upstream from firms’ more applied R&D (Rothaermel and Deeds, 2004). Yet, in practice, university research involves a rich mix of scientific discovery, clinical trials, beta testing, and prototype development. While many university breakthroughs address fundamental scientific questions, they may simultaneously provide practical implications for current commercial products (Stokes, 1997). The university–firm dyad is a particularly unique mechanism for cross-boundary learning for firms as universities operate with different incentives, goals, routines, decision-making structures than for-profit entities. An open question is if, or how, the balance a firm maintains with the R&D conducted in-house influences the firm’s proclivity to pursue external alliances in general, and university-based alliances in particular.

The purpose of this paper is to gain a better understanding of university–firm research alliances and the role these alliances play in the R&D efforts of large,

research-intensive firms. One key question is how a firm’s innovation strategy, in terms of both internal focus and internal organization, influences the decision to engage in R&D alliances with universities. Drawing on previous research in innovation and learning, we develop a set of predictions that link firms’ internal innovation strategy and internal R&D organization to the level of involvement and the intensity of the R&D relationship firms maintain with universities (March, 1991; Levinthal and March, 1993; Cohen and Levinthal, 1990; Argyres and Silverman, 2004). We argue that firms pursuing internal R&D strategies more heavily weighted toward exploratory activities and those firms with more centralized internal R&D organizations will make greater use of exploratory university-based research alliances and engage in more multifaceted relationships. We test our predictions with original data drawn from a survey of executives at R&D-intensive firms in Canada. Our empirical analysis confirms that universities are preferred as partners when firm’s internal R&D strategy emphasizes exploration and the development of new capabilities. In contrast to other external partners, universities are preferred when the firm’s R&D strategy emphasizes long-term exploratory projects and when it perceives potential problems protecting the knowledge created through the alliance.

The paper proceeds as follows. In the next section, we briefly review the concepts of exploration and exploitation particularly in the context of university–firm alliances. In the third section, we develop four predictions linking firm R&D strategy and internal R&D organization with the degree of university research activity. We also consider factors that may influence the relative use of university-based alliances as compared to other cross-boundary alliances by innovating firms. The fourth section of this paper describes our data and methodology. Empirical results are presented in the fifth section. Conclusions and suggestions for further research are offered in the sixth section.

## 1. Exploration, exploitation, and university-based alliances

Innovation is the ability to create economic value from new ideas and the pursuit of innovation requires firms to define a strategy.<sup>3</sup> A central concern in designing an innovation strategy is the balance between the

<sup>2</sup> The U.S. National Science Foundation (NSF, 2001, p. A4-73) estimates that the percentage of funds spent on R&D alliances was 6.3% compared to what was spent in-house for all industries. The range was from 13.4% for chemicals (NAICS 31–33) to 0.3% for computer and electronic products (NAICS 334).

<sup>3</sup> Christensen (2002) makes a distinction, which we follow, between the management of innovation and the management of technology. The management of innovation is concerned with the strategic and organizational context for producing successful products and processes

exploration of new ideas and the exploitation of existing competencies and well-developed expertise (March, 1991). To be precise, R&D can be characterized as either explorative or exploitive, where exploration spurs new discoveries, while exploitation refines current capabilities. A second dimension concerns the sourcing of useful knowledge and the most basic dichotomy is either internal or external to the firm. While the majority of R&D is done internally, external R&D alliances are important because critical knowledge and resources for both exploration and exploitation reside in diverse organizations, such as upstream suppliers, downstream customers, academic institutions, and national laboratories (Leonard-Barton, 1995). Our focus is on the use of universities as strategic external R&D partners. This section of the paper details the key concepts of exploitation and exploration and considers how firms may pursue each of these goals internally or via university-based alliances.

Both exploration and exploitation are essential for organizational learning; however, these activities compete for scarce resources. Firm strategy involves finding a balance that simultaneously allows for organization survival and the generation of competitive advantage (Tushman and O'Reilly, 1996). Indeed, Levinthal and March (1993, p. 105) note that, "The basic problem confronting an organization is to engage in sufficient exploitation to ensure its current viability and, at the same time, to devote enough energy to exploration to ensure its future viability. Survival requires a balance, and the precise mix of exploitation and exploration that is optimal is hard to specify." Differences in the balance of explore and exploit between firms in the same industry is the essence of innovation strategy and may contribute to observed differences in performance.

Exploitation represents the refinement, extension, and intelligent use of existing competencies (March, 1991; Levinthal and March, 1993). R&D activities focused on exploitation are typically incremental and shorter term in orientation. Empirical evidence suggests that the majority of industrial R&D is exploitative in character with approximately 75% allocated to development activities, 20% committed to applied research, and only 5% targeting basic research (NSF, 2001).<sup>4</sup> Most inter-

nal R&D is capabilities deepening as in-house R&D departments concentrate on fine-tuning existing products and processes, or coming up with model enhancements (Argyres, 1996). For example, Henderson and Clark (1990, pp. 24–27) provide an in-depth analysis of Kasper Instrument's internal R&D focus on incremental improvements and extensions to their existing product line. Helfat (1994) documents the highly applied and firm-specific nature of R&D activity in the petroleum industry. Of course, an incremental R&D strategy aimed at exploitation allows firms to make the optimal use of existing complementary assets (Helfat, 1997).

Some cross-boundary alliances are formed specifically to exploit an existing capability of the firm and, in this sense, complement and extend the firm's internal R&D activities (Koza and Lewin, 1998; Rothaermel and Deeds, 2004). External partners may provide cost-effective access to specialized resources needed for incremental innovations. These resources may be so highly specialized that it is costly or impractical to bring them under the corporate umbrella. For example, when entering a market in a new country a firm may partner with a local firm that understands local customers and can successfully adapt an existing product for greater local market acceptance. Alternatively, a medical device firm may contract out prototype production to specialized design firms that refine their products for better customer acceptance and easier manufacturability. These cross-boundary alliances give a firm access to knowledge that differs from, but can complement, their existing technology activities.

Exploitation-based alliances with university partners are surprisingly common. In a survey of industrial R&D managers, Cohen et al. (2002a,b) find that more than one-third of their respondent firms use public research to address existing problems, suggesting the benefit of universities to assist the firm's ability to exploit existing capabilities. For example, a paper company that we interviewed sponsored a university-based project to optimize their current process of removing contaminants from recycled paper. Similarly, the pharmaceutical manufacturer Eli Lilly sponsors academic research to improve its existing product line in insulin. For the university, the research creates knowledge that provides new findings and potential scientific breakthroughs. However, for the firm, this knowledge improves an existing product line that allows it to better deploy its existing capabil-

while economizing on time and resources. In contrast, the management of technology focuses on the capabilities underlying the portfolio of existing and prospective technologies.

<sup>4</sup> It is important to recognize that there is not a one-to-one correspondence between basic research and exploration and applied R&D and exploitation. Basic research asks fundamental questions, without direct concern about practical applications and encompasses experimental or

theoretical work. Applied research focuses on specific applications with a direct concern for using the results. Applied R&D may advance the findings of basic research towards some commercial object.

ities and increase its market share in a known product space. Pharmaceutical and biotechnology firms regularly engage in sponsored research agreements with universities having strong medical schools and hospitals to conduct clinical trials and analyze trial data of drugs developed in-house. This phenomenon extends broadly across industrial sectors: Feller et al. (2002, p. 465) report that 63% of the companies that participated in Engineering Research Centers (ERCs) received direct technical assistance from university researchers.

Exploration refers to the search, discovery, and development of knowledge that is new to a firm (March, 1991; Levinthal and March, 1993). The returns to exploratory R&D are “uncertain, distant, and often negative” (March, 1991, p. 85). Exploration is associated with capabilities-broadening activities in which innovation arises from the synthesis of distinct streams of knowledge (Argyres, 1996). Often driven by dissatisfaction with current performance, firms may shift the R&D balance toward more experimental projects to search for new ideas and new technologies that may be successfully commercialized (Holmqvist, 2004). As exploration generates the potential for exploitation, many firms recognize the importance of conducting some exploratory research in-house (Cohen, 1994; Tripsis and Gavetti, 2000). Internal exploratory activities include long-term projects to develop new capabilities and new product platforms. Well-known examples of firms that have conducted exploratory research internally include Xerox with Palo Alto Research Center (PARC), AT&T with Bell Labs, IBM, and 3M. The other face of this strategy is that firms that invest R&D resources on exploration internally develop absorptive capacity, the ability to “identify, assimilate and exploit knowledge from the environment” (Cohen and Levinthal, 1989, p. 569). A firm’s investment in internal exploration positions it to act on new discoveries from external sources.

Linking with external entities has been shown to be a key element of successful exploration strategies (Rosenkopf and Nerkar, 2001; Von Hippel, 1988; Mowery et al., 1996). Competitors, upstream suppliers or downstream customers, as well as national laboratories, and academic institutions are potential R&D alliance partners (Leonard-Barton, 1995). These cross-boundary alliances provide access to knowledge currently not existing within the firm (Lane and Lubatkin, 1998; Dussauge et al., 2000). The integration of new external knowledge extends the firm’s technology portfolio and may lead to path-breaking innovation (Nagarajan and Mitchell, 1998; Ahuja, 2000).

Many firm–university alliances are exploratory in character, as demonstrated by Table 1. Universities have

Table 1  
Firm allocation between explore/exploit and choice of external partner

|                                    | % exploration | % exploitation |
|------------------------------------|---------------|----------------|
| Internal R&D                       | 36.0          | 64.0           |
| External (non-academic) alliances  | 48.7          | 51.3           |
| External university-based projects | 66.7          | 33.3           |

Source: Author’s original data collection described in the text.

long served as a source of foundational scientific and technical knowledge; however, the discovery of breakthroughs with significant commercial potential such as biotechnology, computer science, material science, and nanotechnology is driving increased industry sponsorship of university research (Geuna, 1999; Mowery et al., 2001). In interviews, firms reported that they fund university projects in order to tap academic experts and to enhance the technological vitality of the company’s projects. In a survey of R&D managers, Mansfield (1998) found that, in the absence of academic research, approximately 14% of new product introductions in seven industries would not have been developed without substantial time delay. In addition, firms fund research at universities to promote experimentation and to investigate new research directions. For example, General Motors Corporation funds university research projects on hydrogen fuel cells and related technologies at different universities in order to develop capabilities in this technology and explore the possible introduction of new product. Of course, simultaneously General Motors is also devoting internal resources to absorb and extend this knowledge.

In addition to research type, university–industry interactions may differ in terms of level of ongoing involvement. A firm’s R&D alliances with universities may involve either single transactions such as individual projects, or in-depth long-term relationships as another part of R&D strategy. Single transactions are common for university research results that are basically “ready to use” (Colyvas et al., 2002). A company may have a research target in mind and then transact with a number of different universities in order to create a portfolio of ideas. For example, the company AbioMed is developing an artificial heart, and their product prototype blends elements from research projects at a variety of different universities. Their objective is to define a unique product and their strategy is to vet multiple potential sources of technology. In this case, the firm may allocate a significant portion of their budget to university-based projects, but because these resources are spread across

many research teams, the overall mode of interaction is more transactional than relational in character.

In contrast, relationships are bundles of linked transactions. For example, relationships exist when a firm engages in several activities such as funding multiple sponsored research projects, hiring graduate students, participating in research centers, and providing endowment funding. A commonly seen example occurs when a firm has strong ties to a particular faculty member, funds numerous open-ended projects, licenses the resulting inventions, and then hires the graduate students that worked in the professor's laboratory. In other instances, firms that are leaders in certain technologies may make long-term commitments to universities that have related strong expertise such as the Bell Labs Project at the University of Toronto. Another example occurs when a company establishes close ties to a university through an alumni connection. An example would be the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech University which has numerous links with the Coulter Corporation, a manufacturer of medical devices and diagnostics, and the associated non-profit Coulter Foundation.

## 2. Firm's R&D strategy and university research

The balance between the exploration of new capabilities and the exploitation of existing capabilities differentiates the innovation strategies of firms. Moreover, firms are heterogeneous in the ways they organize their R&D activities. In this section, we develop a set of predictions to explore how firm's R&D strategy and structure may influence the university–industry R&D interface. We focus on the subset of university-based alliances first, addressing the overarching question as to when university-based alliances are the preferred vehicle for tapping external knowledge as compared to other types of external alliances in the final part of this section.

### 2.1. Firm strategy and university interactions

Consider two firms, one in which the majority of internal research is exploitative and another that places much greater emphasis on exploration internally. Which firm would be more likely to seek university partners for an exploration-focused alliance? One strand of the literature on university–firm alliances contends that a division of innovative labor is common and suggests that university–firm interactions are driven, to a large extent, by the need to “trade in knowledge and technologies between those sectors with complementary comparative advantages at different points in the inno-

vation process” (Graff et al., 2002, p. 95). Given that university researchers are the largest performers of basic research, while the majority of applied and developmental research is conducted in industrial laboratories, this perspective implies that firms with greater emphasis on exploitation activities would be most apt to partner with university players.

The research on search, absorptive capacity, and organizational learning, on the contrary, implies that pursuing university interactions to tap such expertise is likely to be more highly valued by firms with innovation strategies that emphasize exploration (Cyert and March, 1963; March, 1991; Cohen and Levinthal, 1989). First, exploration is aided by variation and diversity (March, 1991). As such, a firm with significant internal investments in exploratory activities may seek to enhance this investment by accessing external sources of variation. Both universities and other firms in the value chain (supplier, buyer, or competitor) may hold knowledge that is distinct from the knowledge or capabilities of the focal firm. However, it is possible that there will be substantial overlap in the knowledge base of the firm and the knowledge base of others in its value chain as these entities operate in the shadow of the same dominant industry technology paradigm. The university players, on the other hand, are somewhat isolated from competitive demands and thus may search more broadly and subsequently offer a more unique set of know-how. Academic researchers, in particular, perform a great deal of foundational research. The new knowledge generated by university research may provide important breakthroughs with longer-term commercial potential (Rosenberg and Nelson, 1994). The attractiveness of universities as research partners is further enhanced if, as Greve and Taylor (2000) argue, the innovations of competitors catalyze firms to widen their search in a non-mimetic response.

Second, firms with little internal exploration will be poorly positioned to either recognize or assimilate knowledge generated externally as compared to firms that are actively generating new and diverse know-how internally (Cohen and Levinthal, 1989). A firm's investment in internal exploration builds absorptive capacity that positions the firm to take advantage of cross-boundary exploratory alliances. The need to invest in generating absorptive capacity is particularly acute when tapping university-based resources. As Cohen and Levinthal (1990, p. 140) note, “When outside knowledge is less targeted to the firm's particular needs and concerns, a firm's own R&D becomes more important in permitting it to recognize the value of knowledge, assimilate and exploit it. Sources that produce less targeted knowledge would include university labs involved

in basic research, while more targeted knowledge may be generated by contract research labs, or input suppliers.”

The organizational learning literature links internal exploratory activity to increases in a firm’s valuing of variation and development of absorptive capacity. There is an implied complementarity between internal exploration and the use of university exploratory research. This suggests that the greater the proportion of its internal R&D expenditures that a firm allocates to exploratory projects, the greater will be the share of its total research budget allocated to exploratory university-based research projects.

The mode of external interactions is also believed to be influenced by firm’s innovation strategy. Our interviews with firm’s R&D executives, university technology-transfer officials, and others involved in the university–industry interface suggest that university–firm interactions can be roughly segregated into two categories: transactions and relationships.<sup>5</sup> Transactions are arms-length, limited agreements. For example, the stand-alone license of a university invention that is not linked to either previous research sponsored by the firm or an ongoing faculty–consulting contract would constitute a transaction. In contrast, longer term, bundles of multiple transactions represent relationships. Two attributes, stage of technology development and ease of knowledge transfer, are believed to interact to affect the choice of either a transaction or relationship interaction mode. In general, early stage technologies require more extensive research investment to reach commercial viability. The likely need for follow-on research suggests that relationships will be required in early stage, exploratory projects (Thursby and Thursby, 2004). Turn-key transactions or arms-length contracts may be viable, however, with exploitative research that focuses on more incremental technological advances or proof of concept projects. Further, while the transfer of knowledge across organizational boundaries is always challenging, the challenge is intensified when the recipient has limited direct experience with the technology to be transferred (Cohen and Levinthal, 1990). As Mowery and Rosenberg (1989, p. 7) note, “a new technology is a complex mix of codified data and poorly defined “know-how.” The successful transfer of the tacit component of this new knowledge generally requires close and ongoing interactions between the inventor and the purchaser (Teece, 1985; Kogut, 1988; Levin et al., 1987). For example, Thursby and Thursby (2004) find that an estimated 40%

of the inventions licensed from universities could not be commercialized without ongoing faculty involvement. Relationships provide partner-specific absorptive capacity that increases the ability to recognize and assimilate knowledge for a particular partner (Dyer and Singh, 1998; Mowery et al., 1996). Such knowledge develops informally over time as individuals within the allied organizations get to know one another and understand how to best work together.

Exploratory research, by definition, is concerned with the development of new knowledge, defined as knowledge or technology that differs substantially from the knowledge base held by the firm. The need for additional development and hands-on transfer of substantially new knowledge implies multiple transactions. Type of research arguably has a significant role in determining type of interaction maintained. In this respect, how the firm allocates its university-based expenditures between exploratory projects and exploitation projects should be related to the depth of the relationship. This suggests that the greater the proportion of external academic R&D expenditures the firm allocates to exploratory projects, the more it will use relational-based interaction modes with universities.

## 2.2. Firm’s R&D organization and university interactions

Firms also have different ways of organizing internal R&D that may further affect interactions with universities. In some firms, the R&D function is centralized with all research coordinated through a small number of linked R&D units that report directly to a corporate-level executive. In other firms, the R&D organization is decentralized with research activities conducted by rather autonomous divisions of the firm, often in geographically disparate locations. Yet other firms operate with a hybrid structure that melds the other two organizational modes. In practice, we observe that companies are differentiated by the centrality of the control and coordination in organizing their R&D (Gassman and von Zedtwitz, 1999). These alternative organizational forms certainly have differing competencies and as such may lead to, and support, different research strategies (Argyres, 1995, 1996; Feller et al., 2002).

However, to date there has been little empirical examination of the organization of R&D. The incentive and coordination attributes of centralized R&D are believed to support longer-term capabilities-broadening research (Argyres and Silverman, 2004). Generally organized as cost centers, centralized R&D units are shielded to some degree from immediate market pressures. Centralized

<sup>5</sup> Other researchers have alluded to this distinction (Colyvas et al., 2002; Feller, 1990; Duysters and Man, 2003; Shane, 2002).

R&D units operate under the broader mission of innovating so as to improve the long-term performance of the firm as a whole. Concomitant with this broader mission is greater discretion in the selection of both the problem to be solved and the approach for solving the identified technological challenges. In addition, centralized structures serve as knowledge repositories integrating and coordinating information acquired across the firm's product-lines. Christensen (2002) argues that corporations with central coordination are more likely to engage in synergistic activities focusing on upstream relationship involving science-based R&D.

In contrast, decentralized structures may excel in the pursuit of incremental improvement. A decentralized R&D operation will typically have incentives that are more closely tied to immediate outcomes. Specifically, in decentralized facilitates, R&D personnel operate closer to the marketplace and are assumed to have a better understanding of customer needs and product performance (Jensen and Meckling, 1992). This motivates capabilities-deepening research efforts that are directly linked to the goals of increasing demand and market share (Kay, 1988). The broader focus, greater decision-making authority, and more diverse knowledge base of the centralized R&D unit favor exploratory research. Given our previous arguments that link external alliances with exploratory research, we expect that firms with more centralized R&D organizations will allocate a greater percentage of their budget to exploratory university research.

A firm's internal R&D organization may also reflect the manner in which the firm interacts with its university partners. With respect to internal organization, the propensity to form relationships as opposed to engaging in transactions is believed to depend on two factors—recognition of potential research synergies across projects and allocation of decision-making authority. With respect to the first factor, the broader focus and more diverse knowledge base of the centralized R&D unit enhances a firm's ability to bring together and evaluate disparate pieces of information (Argyres and Silverman, 2004). As such, a centralized R&D organization should be more likely to recognize situations where it is rational to build relationships by linking or extending existing university–firm transactions. BASF, a company noted to have one of the most administratively centralized R&D operations of European chemical companies, provides an example of such relationship building. The company recently announced the opening of a research laboratory at the Institut de Science et d'Ingenierie Supramoleculaires (ISIS), Louis Pasteur University, Strasbourg, France (Milmo,

2003). The focus will be on developing novel nanostructured polymer materials with the stated goal of linking its R&D activities to cutting edge academic research. Centralized organizations in general, and centralized R&D organizations in particular, have the further advantage of operating with definitive decision-making authority (Williamson, 1991). With decentralized R&D, potentially costly cross-laboratory negotiations would be required to allocate financial contributions and determine the terms of any add-on sponsored research projects or subsequent licenses. This favors transactions rather than relationships. Thus, it seems likely that firms with more centralized R&D organizations will make more use of relational-based interaction modes than their decentralized counterparts.

### 2.3. *Universities as preferred exploratory partners*

A background question concerns the fundamental reasons why firms choose to partner with universities. Given the variety of available external partners, what is unique about universities and why do firms chose research alliances with universities over alliances with other firms? Universities, because they have limited incentives to act opportunistically, may be preferred as research partners when firms face appropriability concerns.

It is well known that firms are not able to fully appropriate the value of the knowledge created through their R&D investments. The decision to engage in R&D partnerships heightens this appropriation challenge. While a collaborative research endeavor may enhance the potential for discovery, it also enhances the potential for a loss of control over the intellectual property generated as the outcome of joint research is often known to, and subsequently claimed by, both parties. This challenge is particularly salient in firm-to-firm alliances as research partners who hold complementary assets are in an advantaged position to exploit potential commercial value. In the worse case, a commercial partner could act opportunistically withholding and/or skewing data in order to independently file for a patent after the project is complete.

Firms that have strong concerns about the loss of control over intellectual property may choose not to engage in external alliances, instead concentrating their R&D efforts internally. Of course, this is an extreme strategy that limits the firm's access to external knowledge. The best strategy may be to seek external alliances that minimize the potential loss of intellectual property. For exploitation projects contractual rights may be negotiated if the results are more easily determined in advance.

The uncertainty associated with exploratory research makes it very difficult to specify and price property rights *ex ante* as the intellectual property does not yet exist (Mowery and Rosenberg, 1989).

Universities are in a unique position as R&D partners. Not only are universities a source of exploratory research but they also lack the complementary assets to compete directly in commercial markets. While universities have recently asserted their rights to ownership of intellectual property, the emphasis on making profits are much weaker for universities than for firms and a minor objective compared to the university's primary functions of education, research, and service. Concerns about universities behaving opportunistically with intellectual property can be addressed contractually: the firm may either be granted the rights to any intellectual property developed during the research project or the university may retain intellectual property ownership. If the university retains ownership then the industry partner is routinely given the right of first refusal to negotiate a license. Universities have an interest in licensing any subsequent intellectual property developed that extend the research because licenses are their primary means for creating economic returns from the generation of new ideas (Shane, 2004).

At first glance, it may appear that university alliances would be leaky. After all, publishing research findings is critical for academic advancement. However, research contracts with industry typically contain standard clauses that provide firms with pre-publication review and the potential to delay publication for a limited period of time in order to secure intellectual property rights. In addition, the material published in scientific journals is abstract and seeks to advance the academic literature rather than provide direct commercial relevance. Only firms that have made the requisite investments in absorptive capacity will be in a position to potentially benefit. Moreover, to the extent that the knowledge created in the research project has a tacit component, the firm that contracted for the research will be advantaged in realizing its commercial potential.

While we may debate specific cases, it seems that universities, because of their mission, limited market presence and lack of complementary assets, offer an advantage to firms in appropriating joint research project results, particularly for projects involving exploratory research. Thus, we expect that universities may be preferred research partners when firms have concerns about appropriating the returns to cross-boundary research.

The next section presents the data and empirical model that we employ to examine the relationship between firm strategy and university research alliances.

### 3. Empirical analysis: data and methods

Data for this study was collected via a Web-based survey during the summer and fall of 2004. We contacted R&D executives at each company included in Research Infosource Inc.'s, *Canada's 100 Top Corporate R&D Spenders List 2003*. Though the population from which the sample is drawn is small, we chose not to extend our sampling frame as the amount of R&D expenditures dropped significantly for companies below this cut-off point. A cover letter sent to these individuals explained that the purpose of the survey was to gain an understanding of the firm's perspective on working with universities in R&D activities and to assess how university interactions compare to other forms of R&D outsourcing employed by the firm. The survey instrument was created based on in-depth interviews with industry R&D professionals and university technology transfer personnel. The instrument incorporated the language of the informants, drawing upon their knowledge in order to elicit responses that accurately reflect the organization's viewpoint (Campbell, 1955). The survey required about 20 min to complete, and began by asking respondents to verify information collected about their company from data available from *CompuStat*. The respondents were guaranteed anonymity of their responses and were offered a summary report in exchange for their participation.

Forty-nine individuals responded to the survey. After omitting those surveys with incomplete or unusable responses, our sample totals 45, giving us an effective response rate of 45%. In all cases, respondents were asked if they had the information required to complete the questionnaire or to refer the questionnaire to the individual in the corporation who would have the appropriate information. As a group, the respondents were highly experienced R&D professionals with two-thirds of the respondents reporting directly to Board level executives. The majority of the respondents held the rank of Vice President (27 or 60%) with titles such as VP–Technology & Innovation, VP–Research & Development, or VP–Business Development. Another 11 (24%) of the respondents held positions at the rank of Director or Associate Director with titles such as Director–Technology Development, Director–External R&D Partnerships, or Director–Research & Development. Six respondents (13%) were in upper management with titles like Manager–Research Initiatives, or Manager–Strategic Innovation. The remaining respondent was from Media Relations. One issue to examine is that positional level of the respondent may influence the questionnaire

responses. We will address this concern in our empirical results.

Non-response bias was considered by comparing early (first 75%) to late (last 25%) responses (Armstrong and Overton, 1977). Independent sample *t*-tests of dependent and independent variables indicated no statistically significant differences between the early and late responses. As a further test of non-response bias, we compared the *CompuStat* data on revenue and R&D spending of the companies that responded with those that did not respond. Again, independent sample *t*-tests confirm that there are no statistically significant differences between the two groups on these dimensions.

Table 2 summarizes the variables and provides their operational definitions. We now describe how the variables are constructed.

### 3.1. Dependent variables

Our first dependent variable, University-based Exploration, is measured as the average percentage of the firm's total R&D expenditures that was allocated to exploratory research conducted at universities or other academic institutions over a 3-year period (2001–2003). Firms were asked to report the internal allocation of their R&D budget among exploration and exploitation, using definition from March (1991). Next, we asked about the extent of external alliances for universities and others. Respondents were then asked to allocate external R&D to explore/exploit by type of external partner. We find that, on average, firms in the sample commit approximately six and one-half percent of their R&D budget to university-based projects, with approximately two-thirds of this six and one-half percent going to exploratory projects and one-third committed to projects with an exploitation focus.

Our second dependent variable, Mode of Interaction, seeks to capture the depth of the firm's interactions with universities. Using a five-point Likert scale, we asked respondents to rate the average depth of their firm's relationships with universities over the past 3 years with a rating of 1 corresponding to "only limited, arms-length transactions" and a rating of 5 corresponding to "on-going, multifaceted relationships." Recognizing the firms may use a combination of transactions and relationships, responses covered the full range of 1–5, with an average response of 2.82.

To explore when universities are preferred alliance partners, we create two additional dependent variables. The first, External Exploration Comparison, is calculated as the percentage of the firm's total research budget allocated to universities for exploratory research projects

Table 2  
List of variables

| Dependent variables              | Description   |
|----------------------------------|---|
| University-based exploration     | Average percent of the firm's exploratory R&D expenditures allocated to research conducted at universities or other academic institutions over a 3-year period (2001–2003)  |
| Mode of Interaction              | Likert measure of firm's level of involvement with universities with 1 indicating limited transactions and 5 indicating multifaceted relationships  |
| External Exploration Comparison  | Percentage of the firm's total research budget allocated to universities for exploratory research projects minus the percentage of the firm's total research budget allocated to other external partners for exploratory research   |
| External Exploitation Comparison | Percentage of the firm's total research budget allocated to universities for exploitative research projects minus the percentage of the firm's total research budget allocated to other external partners for exploitative research |
| Independent variables            | Description   |
| Internal Exploration             | Percentage of the firm's internal R&D expenditures (research done in-house by the firm) allocated to exploratory—search, discovery, and development of new knowledge and products—activities. Key measure of R&D strategy           |
| University Exploration           | Type of university research: Percentage of university expenditures that the firm characterizes as exploratory   |
| R&D Structure                    | A measure of the (locational) centralization of the firm's R&D activities calculated as a Herfindahl concentration index based on the distribution of research activities across internal laboratories: $Structure = \sum_i S_i^2$  |
| Decision-making Authority        | Factor created by principal component analysis using two Likert scale variables on discretion in technology focus and choice of research projects   |
| Patent Effectiveness             | Average effectiveness of patents for product and process innovations (Cohen et al., 2000)   |
| Control variables                | Description   |
| R&D Dollars (ln)                 | Size control: log of RD expenditures (2002); from <i>CompuStat</i>  |
| Relative R&D Intensity           | The difference between firm R&D ratio and industry average R&D ratio normalized by the industry average R&D ratio: calculated from <i>CompuStat</i>   |
| Sales (ln)                       | Size control: log of company sales (2002); from <i>CompuStat</i>  |

Table 2 (Continued)

| Control variables | Description  |
|-------------------|--|
| Pharmaceuticals   | 0/1 Industry dummy: pharmaceutical/drugs                 |
| Communications    | 0/1 Industry dummy: communications/telecom equipment     |
| Electronics       | 0/1 Industry dummy: electronics and electrical equipment |
| Energy            | 0/1 Industry dummy: primary energy, power, utilities     |
| Mining            | 0/1 Industry dummy: mining and metals                    |

minus the percentage of the firm's total research budget allocated to other external partners for exploratory research. Similarly, we create a second dependent variable, External Exploitation Comparison, calculated as the percentage of the firm's total research budget allocated to universities for exploitative research projects minus the percentage of the firm's total research budget allocated to other external partners for exploitative research.

### 3.2. Independent variables

Two key independent variables in this study relate to the firm's innovation strategy. A central component of a firm's innovation strategy is the relative emphasis placed on exploration versus exploitation. To measure this distribution, each respondent was asked to specify the percentage of R&D dollars committed to exploration—the search, discovery, and development of new knowledge and products and alternatively the percentage of R&D dollars earmarked for exploitation—the refinement and extension of firm's existing competencies and products, for their firm's internal R&D, university-based R&D, and other externally conducted R&D. Two innovation strategy variables are derived from the data provided. First, the variable Percent Internal Exploration is the overall share of the firm's internal R&D expenditures allocated to exploratory activities. On average, the firms in our sample maintain a 36:64% balance between exploration and exploitation for research conducted in-house. A second, more focused measure of the firm's university-based innovation strategy is Percent University Exploration, a variable that captures the percentage of the firm's research budget that is allocated to projects with universities which the firm designates as exploratory.

The two other theory-driven independent variables capture aspects of the firm's R&D organization. The first variable, structure, provides a measure of the firm's internal R&D configuration. R&D organizations can be (1)

highly centralized with the majority of all research conducted at a small number of R&D laboratories, (2) highly decentralized with R&D taking place at a large number of facilities, or (3) a hybrid mix conducting significant operations in a moderate number of locations (Argyres and Silverman, 2004; IRI, 1995). Our structure measure is calculated as a Herfindahl concentration index based on the distribution of research activities across internal laboratories:

$$\text{Structure} = \sum_i S_i^2$$

where  $S_i$  is the share of total company R&D expenditures accounted for by location  $i$ . Respondents were asked to list their R&D facilities and note the share of R&D conducted at each facility. The higher the value of structure, the more centralized the company's R&D organization.

The second organization variable, authority, reflects R&D decision-making autonomy within the firm. Decision-making authority was identified using two items querying the degree of discretion the laboratory was allowed in (1) choosing technology focus and (2) selecting specific research projects within a technical area. Responses were based on a Likert scale from 1 to 5, with 1 corresponding to "no discretion" and 5 to "total discretion." The scale reliability coefficient for this set of items is 0.71.

Finally, to test questions of external partner selection, we employ data from the Carnegie Mellon Survey (Cohen et al., 2000) that details the perceived effectiveness of patents as an appropriability mechanism for product and process innovations. Using data at the three-digit Standard Industrial Classification (SIC) industry, Cohen et al (2000, pp. 5–6) provide a "response scale (that) reflects how central a mechanism is to firms' strategies of appropriating rents to their innovations in the sense that it reflects both the frequency with which a mechanism is employed and the effectiveness of that mechanism given its use." We assigned the 45 firms in our sample to their three-digit industry, resulting in 16 unique industries.<sup>6</sup> Since exploratory R&D covers the spectrum of outcomes, our measure of patent effectiveness is constructed as averages of the reported effectiveness values with respect to product and process innovation.

### 3.3. Control variables

We control for industry effects using dummy variables for the following sectors—pharmaceutical/bio-

<sup>6</sup> Industry dummy variables are assigned at the more aggregate two-digit SIC level.

technology (9 companies), communication/telecom equipment (10 companies), electronics (8 companies), energy (6 companies), and minerals/mining (6 companies) with miscellaneous (6 companies) as the omitted category. The distribution of industries in our sample closely mirrors the population of top 100 R&D performers in Canada.

Though all of the firms in our sample are among the top 100 corporate R&D spenders in Canada, there are still significant differences in the R&D expenditure among firms. We control for these differences in R&D spending via two variables. The first, calculated as log of average total R&D dollars spent by the firm in 2001–2003, provides a direct measure of R&D budget. The second measures Relative R&D Intensity and is calculated as the difference between firm R&D ratio (R&D dollars/sales) and industry average R&D ratio normalized by the industry average R&D ratio. We also control for firm size using the log of sales.

Finally, when estimating mode of interaction, we also control for the total share of the firm's R&D budget allocated to university-based research (explore and exploit). This allows us to investigate whether type of research has a significant role in determining mode of interaction maintained independent of the firm's overall level of involvement in university-based research, using the following models:

$$\begin{aligned} \text{Mode of Interaction} = & \beta_0 + \beta_1 \text{ Percent University} \\ & \text{Exploratory} + \beta_2 \text{ Structure} + \beta_3 \text{ Decision-making} \\ & \text{Authority} + \beta_4 \text{ R\&D Dollars} + \beta_5 \text{ Relative R\&D} \\ & \text{Intensity} + \beta_6 \text{ Sales} + \beta_7 \text{ Pharm/Biotech} \\ & + \beta_8 \text{ Comm/Telecom Equipment} \\ & + \beta_9 \text{ Electronics} + \beta_{10} \text{ Mining} + \beta_{11} \text{ Energy} \\ & + \beta_{12} \text{ Total University Share} + \varepsilon_i \end{aligned}$$

Appropriability issues are examined using the following model:

$$\begin{aligned} \text{External Exploration/Exploitation Comparison} \\ = & \beta_0 + \beta_1 \text{ Percent Internal Exploratory} \\ & + \beta_2 \text{ Structure} + \beta_3 \text{ Decisin-making Authority} \\ & + \beta_4 \text{ R\&D Dollars} + \beta_5 \text{ Relative R\&D Intensity} \\ & + \beta_6 \text{ Sales} + \beta_7 \text{ Pharm/Biotech} \\ & + \beta_8 \text{ Comm/Telecom Equipment} + \beta_9 \text{ Electronics} \end{aligned}$$

$$\begin{aligned} & + \beta_{10} \text{ Mining} + \beta_{11} \text{ Energy} \\ & + \beta_{12} \text{ Average Patent Effectiveness} + \varepsilon_i \end{aligned}$$

Table 3 displays summary statistics and correlation coefficients for each of the variables. Correlations are generally low to moderate. Given that the first two dependent variables are bounded—level of involvement between 0 and 1 and mode of interaction between 1 and 5—the two-sided Tobit estimation model is used for the analysis of these models.<sup>7</sup> The models examining appropriability issues are estimated using OLS.

#### 4. Results

Table 4 reports the results of the Tobit estimation. University-based exploration is the dependent variable in Model 1 and Model 2. Model 1 contains just the control variables, of which only one shows significance. Not surprisingly, we find that pharmaceutical and biotechnology firms are more likely than firms in other industries to allocate a considerable share of their R&D budget to university-based exploration ( $p < 0.05$ ). This result is consistent with results from the Yale and Carnegie Mellon industrial R&D surveys (Cohen et al., 2002a,b; Klevorick et al., 1995) as well as other studies of innovation networks in the pharmaceutical and biotechnology industries (Powell et al., 1996; Zucker et al., 2002).

Model 2 incorporates the three primary covariates capturing firm innovation strategy and R&D organization: Percent Internal Exploration, Structure, and Decision-making Authority. The explanatory power of the model increases significantly with the addition of the independent variables of theoretical interest. A likelihood ratio test comparing Model 2 with Model 1 is significant with a  $p$ -value of less than 0.01. The coefficient on Percent Internal Exploration is positive and significant ( $p < 0.01$ ), indicating that the greater proportion of internal R&D expenditures the firm allocates to exploratory projects, the greater will also be the share of its total research budget allocated to exploratory university research. Firms with internal innovation strategies more heavily weighted toward exploratory activities allocate a greater share of their R&D dollars

<sup>7</sup> As a robustness check, we also estimated the main models using OLS rather than Tobit. In all cases, the signs on the coefficients are consistent, though we do see a slight reduction in significance for some of the independent variables. We also ran the VIF procedure following the OLS regression. In no case was multicollinearity an issue. For Model 2, the mean VIF was 2.20 with the highest value on any one variable 2.73. Similarly, for Model 4, the mean VIF was 2.31 with the highest value on any one variable 3.55.

Table 3  
Descriptive statistics

|   | Mean  | S.D.  | Minimum | Maximum | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    | 13    | 14    | 15   | 16   | 17    | 18   | 19 |
|---|-------|-------|---------|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|-------|------|----|
| 1 University-based Exploration          | 0.05  | 0.10  | 0.00    | 0.60    | 1.00  |       |       |       |       |       |       |       |       |       |       |       |       |       |      |      |       |      |    |
| 2 Mode of Interaction                   | 2.82  | 1.42  | 1       | 5       | 0.11  | 1.00  |       |       |       |       |       |       |       |       |       |       |       |       |      |      |       |      |    |
| 3 Internal Explore                      | 0.36  | 0.31  | 0       | 1       | 0.28  | 0.31  | 1.00  |       |       |       |       |       |       |       |       |       |       |       |      |      |       |      |    |
| 4 University Explore                    | 66.74 | 39.85 | 0       | 100     | 0.23  | 0.35  | 0.36  | 1.00  |       |       |       |       |       |       |       |       |       |       |      |      |       |      |    |
| 5 Structure                             | 0.58  | 0.28  | 0.17    | 1.00    | 0.19  | -0.07 | 0.13  | 0.03  | 1.00  |       |       |       |       |       |       |       |       |       |      |      |       |      |    |
| 6 Decision-making Authority             | 0.00  | 0.73  | -1.53   | 1.05    | -0.01 | -0.17 | -0.07 | 0.16  | -0.08 | 1.00  |       |       |       |       |       |       |       |       |      |      |       |      |    |
| 7 R&D Dollars (ln)                      | 3.89  | 1.50  | -1.20   | 8.16    | -0.14 | 0.32  | 0.01  | 0.05  | -0.30 | -0.19 | 1.00  |       |       |       |       |       |       |       |      |      |       |      |    |
| 8 Relative R&D Intensity                | 0.05  | 0.66  | -0.95   | 2.63    | -0.21 | -0.15 | 0.03  | -0.07 | 0.08  | -0.30 | 0.05  | 1.00  |       |       |       |       |       |       |      |      |       |      |    |
| 9 Sales (ln)                            | 1.79  | 1.94  | -2.57   | 5.40    | 0.00  | 0.46  | -0.06 | 0.07  | -0.24 | -0.10 | 0.53  | -0.41 | 1.00  |       |       |       |       |       |      |      |       |      |    |
| 10 Pharmaceuticals                      | 0.18  | 0.39  | 0       | 1       | 0.45  | 0.02  | 0.04  | -0.01 | -0.14 | -0.33 | 0.10  | 0.04  | -0.04 | 1.00  |       |       |       |       |      |      |       |      |    |
| 11 Communications                       | 0.22  | 0.42  | 0       | 1       | -0.13 | -0.08 | 0.00  | -0.03 | 0.12  | 0.12  | 0.22  | -0.10 | -0.09 | -0.25 | 1.00  |       |       |       |      |      |       |      |    |
| 12 Electronics                          | 0.18  | 0.39  | 0       | 1       | -0.14 | -0.31 | 0.06  | 0.19  | -0.23 | 0.40  | -0.11 | -0.02 | -0.20 | -0.22 | -0.25 | 1.00  |       |       |      |      |       |      |    |
| 13 Energy                               | 0.16  | 0.37  | 0       | 1       | -0.08 | 0.10  | 0.03  | 0.03  | 0.31  | -0.09 | -0.09 | 0.10  | -0.13 | -0.21 | -0.23 | -0.20 | 1.00  |       |      |      |       |      |    |
| 14 Mining                               | 0.13  | 0.34  | 0       | 1       | 0.03  | 0.05  | -0.19 | -0.16 | -0.00 | -0.00 | -0.39 | -0.09 | 0.17  | -0.18 | -0.20 | -0.18 | -0.17 | 1.00  |      |      |       |      |    |
| 15 University percentage of R&D Dollars | 6.45  | 11.79 | 0.00    | 60.00   | 0.90  | 0.06  | 0.14  | 0.08  | 0.18  | -0.07 | -0.08 | -0.23 | 0.08  | 0.50  | -0.18 | -0.19 | -0.05 | 0.07  | 1.00 |      |       |      |    |
| 16 External Exploration Comparison      | -0.00 | 0.101 | -0.30   | 0.40    | 0.49  | 0.12  | 0.26  | 0.15  | 0.08  | -0.06 | 0.30  | -0.20 | 0.10  | 0.29  | 0.12  | -0.05 | -0.14 | -0.26 | 0.35 | 1.00 |       |      |    |
| 17 External Exploitation Comparison     | -0.03 | 0.09  | -0.32   | 0.15    | -0.00 | 0.10  | 0.19  | 0.05  | 0.03  | 0.10  | 0.18  | 0.05  | 0.11  | -0.22 | 0.17  | 0.11  | -0.18 | 0.12  | 0.07 | 0.40 | 1.00  |      |    |
| 18 Average Patent Effectiveness         | 29.51 | 9.06  | 18.27   | 44.36   | 0.27  | 0.03  | -0.03 | -0.02 | -0.27 | -0.38 | 0.13  | 0.04  | 0.05  | 0.72  | -0.53 | -0.07 | 0.17  | -0.32 | 0.32 | 0.27 | -0.23 | 1.00 |    |

Table 4  
Firm strategy and university-based exploration alliances: results of the Tobit estimation

| Independent variable                       | Dependent variable           |                 |                     |                 |
|--|------------------------------|-----------------|---------------------|-----------------|
|  | University-based Exploration |                 | Mode of Interaction |                 |
|  | Model 1                      | Model 2         | Model 3             | Model 4         |
| Internal Exploration                       |                              | 0.123 (0.043)** |                     |                 |
| University Exploration                     |                              |                 |                     | 2.273 (0.719)** |
| R&D Structure                              |                              | 0.121 (0.055)*  |                     | −0.257 (1.109)  |
| Decision-making Authority                  |                              | 0.033 (0.023)   |                     | −0.242 (0.459)  |
| R&D Dollars (ln)                           | −0.013 (0.017)               | −0.001 (0.015)  | 0.261 (0.320)       | 0.311 (0.292)   |
| Relative R&D Intensity                     | −0.029 (0.029)               | −0.024 (0.027)  | −0.379 (0.593)      | −0.525 (0.545)  |
| Sales Dollars (ln)                         | 0.006 (0.014)                | 0.008 (0.012)   | 0.261 (0.273)       | 0.109 (0.241)   |
| Pharmaceuticals                            | 0.139 (0.057)*               | 0.159 (0.051)** | −0.676 (1.225)      | −0.923 (1.118)  |
| Communication                              | 0.012 (0.060)                | −0.011 (0.052)  | −1.449 (1.145)      | −1.634 (1.016)  |
| Electronics                                | 0.002 (0.060)                | −0.005 (0.055)  | −2.136 (1.181)      | −2.592 (1.102)* |
| Energy                                     | 0.016 (0.059)                | −0.010 (0.052)  | −0.165 (1.107)      | −0.453 (0.982)  |
| Mining                                     | 0.002 (0.064)                | 0.041 (0.056)   | −0.117 (1.191)      | 0.315 (1.067)   |
| University percentage of total R&D Dollars |                              |                 | −0.000 (0.030)      | −0.007 (0.028)  |
| Constant                                   | 0.044 (0.068)                | −0.120 (0.079)  | 1.940 (1.271)       | 0.850 (1.537)   |
| <i>N</i>                                   | 45                           | 45              | 45                  | 45              |
| Left-censored observations                 | 8                            | 8               | 13                  | 13              |
| Uncensored observations                    | 37                           | 37              | 27                  | 27              |
| Right-censored observations                | 0                            | 0               | 5                   | 5               |
| log likelihood                             | 27.997                       | 34.572          | −69.916             | −64.902         |
| LL ratio improvement                       |                              | 6.575**         |                     | 5.014*          |

\*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ . Two-tailed tests for controls, one-tailed tests for variables of interest.

to exploratory research conducted at universities. These cross-boundary research relationships appear to be an important means for linking to sources of new knowledge. Firms with active exploratory research agendas in-house are likely to have both an interest in tapping university-based expertise and to have developed the absorptive capacity necessary to digest university-based exploratory research (Cohen and Levinthal, 1989). The marginal effect of a 10% increase in internal exploratory activity, evaluated at the mean of the independent variables, translates into a 0.5% increase in exploratory research with universities.

The coefficient for R&D Structure is also positive and significant at the  $p < 0.05$  level, indicating an important strategy–structure link. Firms with more physically concentrated R&D configurations have greater levels of involvement with university-based exploratory research activities. Having a more centralized R&D organization where a large share of the firm's research personnel interact seems to facilitate use of university alliances for non-local search. The coefficient on the Decision-Making Authority variable, while positive, does not reach significance. It does not appear that R&D organizations with greater discretion in the selection of research paradigms use academic research resources more extensively.

Mode of Interaction is the dependent variable in the second set of models (Model 3 and Model 4) in Table 4. Model 3 is the baseline model containing control variables only. Model 4 includes the independent variables of interest: Percent University Exploration, R&D Structure, and Decision-making Authority. The change in the log-likelihood  $\chi^2$  statistic between Model 3 and Model 4 is significant, with  $p < 0.05$ . In Model 4, the coefficient for exploration at universities is positive and significant ( $p < 0.01$ ). The more a firm uses its university interactions to pursue exploratory projects, the more likely these projects will be handled as part of an ongoing relationship rather than as an arms-length transaction. Relationships are believed to be important for the transfer of tacit knowledge (Dyer and Singh, 1998). The structure of internal R&D organization and the allocation of decision-making authority do not appear to influence depth of interaction. There is some evidence, however, that that Mode of Interaction differs across industry sectors with firms in the electronics sector having significantly less depth in their university interactions. This is consistent with the idea that firms in rapidly changing environments use more transitory alliances to acquire very specific knowledge in a swift manner (Duysters and Man, 2003).

Table 5  
Results of the OLS estimation

| Independent variables        | Dependent variable              |                  |                                  |                 |
|------------------------------|---------------------------------|------------------|----------------------------------|-----------------|
|                              | External Exploration Comparison |                  | External Exploitation Comparison |                 |
|                              | Model 1a                        | Model 1b         | Model 2a                         | Model 2b        |
| Average Patent Effectiveness |                                 | 0.009 (0.004)**  |                                  | 0.005 (0.003)   |
| Internal Exploration         |                                 | 0.092 (0.045)*   |                                  | 0.077 (0.042)*  |
| R&D Structure                |                                 | 0.155 (0.063)**  |                                  | 0.087 (0.060)   |
| Decision-making Authority    |                                 | 0.024 (0.024)    |                                  | 0.023 (0.023)   |
| R&D Dollars (ln)             | 0.024 (0.017)                   | 0.037 (0.016)*   | 0.016 (0.015)                    | 0.024 (0.015)   |
| Relative R&D Intensity       | −0.049 (0.029)                  | −0.042 (0.028)   | 0.012 (0.026)                    | 0.019 (0.027)   |
| Sales Dollars (ln)           | −0.011 (0.014)                  | −0.013 (0.013)   | −0.000 (0.013)                   | −0.001 (0.012)  |
| Pharmaceuticals              | 0.054 (0.057)                   | −0.042 (0.067)   | −0.027 (0.051)                   | −0.079 (0.064)  |
| Communication                | −0.003 (0.060)                  | 0.062 (0.062)    | 0.037 (0.053)                    | 0.074 (0.059)   |
| Electronics                  | −0.017 (0.060)                  | 0.010 (0.057)    | 0.044 (0.053)                    | 0.053 (0.054)   |
| Energy                       | −0.026 (0.058)                  | −0.076 (0.056)   | −0.015 (0.052)                   | −0.043 (0.053)  |
| Mining                       | −0.032 (0.063)                  | 0.079 (0.067)    | 0.070 (0.056)                    | 0.141 (0.064)*  |
| Constant                     | −0.070 (0.066)                  | −0.512 (0.156)** | −0.115 (0.059)                   | −0.383 (0.149)* |
| <i>N</i>                     | 45                              | 45               | 45                               | 45              |
| <i>R</i> <sup>2</sup>        | 0.251                           | 0.451            | 0.180                            | 0.307           |

When are university-based alliances preferred?

To test for respondent bias due to the position of the respondent within the organization, we ran Model 2 and Model 4 with a dummy variable equal to 1 if the respondent reported directly to a board-level executive and 0 otherwise. The estimations results did not change for the variables of interest, while the dummy variable on organization position was not statistically significant. We verified that multicollinearity was not an issue using the VIF procedure on OLS versions of these models.

#### 4.1. The uniqueness of universities as external research partners

The above analyses provide support for the argument that firms pursuing exploratory R&D strategies in-house are also likely to fund university-based exploratory research projects to augment internal search efforts. Universities, however, are not the only external partners that a firm may tap to gain new knowledge. The question thus becomes one of selection. Namely, when do firms prefer to engage in strategic research partnerships with universities rather than with other (non-academic) external alliances? What is unique about university-based research partnerships?

Table 5 reports the results for our investigation of partner selection. Our dependent variable for Models 1a–1b, External Exploration Comparison, is calculated as the percentage of the firm's total research budget allocated to universities for exploratory research projects minus the percentage of the firm's total research budget allo-

cated to other external partners for exploratory research. Similarly, our dependent variable for Models 2a–2b, External Exploitation Comparison, calculated as the percentage of the firm's total research budget allocated to universities for exploitative research projects minus the percentage of the firm's total research budget allocated to other external partners for exploitative research. Models 1a and 2a are the baseline estimations of the exploration and exploitation comparisons, respectively. Interestingly, none of the control variables are significant in these two models. Industry sector and/or R&D levels and intensity do not seem to directly influence the type of external partner preferred. Models 1b and 2b add the independent variable of interest—average patent effectiveness. The coefficient on patent effectiveness is positive and significant ( $p < 0.01$ ) when External Exploration Comparison is the dependent variable (Model 1b). The more effective patents are in protecting product and process innovations, the greater the use of university alliances for exploratory projects when compared to the use of other types of cross-boundary alliances. The coefficient is smaller and just below statistical significance in the External Exploitation Comparison Model (Model 2b). The effectiveness of patents does not lead to a preference for university partners when projects are exploitative in nature. Much of the literature on cross-boundary alliances suggests that strong property rights enable firms to make better use of cross-boundary alliances by reducing appropriability hazards. It may be that when firms see the potential

of economic gains through patent-protected intellectual property, they seek partners that provide the greatest assurance that the firm will be able to garner these important rights at a reasonable cost. Further, this assurance is of greater importance in projects with an exploratory focus.

## 5. Discussion and conclusions

The ability to tap external sources of knowledge has become increasingly important for firms seeking to gain competitive advantage through innovation. Though academic research institutions have long served as a key external source of scientific and technical knowledge for industrial firms, the growing level of activity at the university–industry interface makes it imperative that we augment our understanding of how university interactions fit within firms' broader R&D strategy. This study investigates the links of firm innovation strategy and internal R&D structure with the firm's level and degree of involvement with university research partners. Consistent with predictions, we find a strong relationship between firm innovation strategy and firm–university research interactions. Firms spend a greater share of their R&D dollars on university-based research projects and these projects are more likely to be considered part of an ongoing relationship when the firm is pursuing an internal innovation strategy more heavily weighted toward exploration and when a greater share of the research conducted at universities is exploratory, respectively. The link found between firm R&D organization and firm–university research interactions is somewhat weaker. While a more centralized R&D function is related to greater involvement with exploratory university-based research, the depth of these university-based interactions appear to be independent of the firm's internal R&D organizational structure.

This paper also sheds light on the factors that differentiate university partners from other external partners. Although firms may leverage all types of cross-boundary alliances to gain distinct knowledge, our evidence suggests that universities are preferred partners when there are concerns about the perceived ability to fully appropriate the results. This is particularly true for exploration-based projects. Firms that focus on exploratory research are engaging in a risky, long-term strategy. The firm may be attempting to develop new platform capabilities and be engaged in a competitive race with significant consequences. As a result, the firm needs to protect its R&D investment by establishing legal ownership of intellectual property through patenting (Laursen and Slater, 2005).

The fact that universities have different objectives from firms may provide unique strategic partnering opportunities. Notably, in R&D alliances there is the potential that commercial partners may behave opportunistically, appropriating knowledge created through the alliance to their own advantage. In contrast, the fundamental differences between private sector and university objectives, coupled with the lack of complementary market-oriented assets, limit the risk that a university research partner may opportunistically attempt to benefit commercially from the knowledge created in the alliance. Industry research contracts with universities typically include the right of first refusal to license intellectual property resulting from the project and since licensing is the primary way that universities derive revenue from their intellectual property, they have an incentive to negotiate a license. In sum, universities may be privileged R&D strategic partners for exploration for large R&D performers.

The results suggest a more nuanced understanding of firm strategy based on the balance of firms' allocation of R&D funds to exploratory and exploitative efforts and its use of external partners in general and universities specifically. Our consideration of the role university-based alliances play in the R&D efforts of large, research-intensive firms informs the broader exploration/exploitation literature in three ways. First, we demonstrate that choice of external partner is explicitly linked to the firm's internal R&D allocation. Even after controlling for industry, we find variation in firm strategies that may be an important source of subsequent performance heterogeneity. Second, by considering the perspective of large R&D performers, those firms that conduct the majority of R&D in any economy, we add to the burgeoning literature on university–industry relationships. This paper considers strategy at the firm level, changing the focus from prior studies that examine laboratory managers or R&D directors. Rather than ask firms to enumerate why they partner with universities, we provide empirical evidence that firms that focus on exploration internally and have more centralized R&D operations make greater use of university research. Finally, we provide evidence that universities are the preferred partner when firms are concerned about appropriability. This finding suggests that universities have a unique role in the system of innovation and larger policy concerns about industrial competitiveness.

A limitation of this study is the relatively small data sample which may give rise to concerns about the representativeness of our results. Though small, the current sample mirrors industry distribution and characteristics of the population of Canada's top 100 R&D spenders. A

mitigating factor of its small size, however, is the unique content that our data set provides. Through the survey, we have been able to collect detailed data on firm innovation strategy, internal R&D organization, and firm–university interactions that are seldom available from secondary sources. These data are generally hard to obtain given the secrecy concerns of firms whose competitive advantage is strongly linked to the competence of their R&D efforts (Cohen, 1995). Our results suggest that a larger scale study across different national contexts and across firms of varying sizes is warranted in order to establish the generalizability of our findings.

There are other clear opportunities for further research. Our study shows that the balance between exploration and exploitation the firm chooses for its internal research activities is related to the focus of the firm’s cross-boundary research activities. Causality is always difficult to establish and it is possible that some common underlying factor drives both greater internal exploration and greater use of university exploratory alliances. Certainly this is a fruitful area for additional research. The small sample size limits our ability to run a two-stage model that might clarify this issue. One other way to untangle issues of causality is to conduct longitudinal studies. The absorptive capacity literature highlights the important role of exploration as a precursor to exploitation (Cohen and Levinthal, 1989, 1990). When successful, exploration can catalyze performance-enhancing exploitation, which could conceivably lead to a shift in the focus of cross-boundary research alliances. The explore/exploit literature, on the other hand, highlights challenges associated with the “myopia of learning” (Levinthal and March, 1993). Namely, positive feedback may drive an organization toward excessive exploration or excessive exploitation, both of which have the potential to dampen subsequent performance. In such a situation, the focus of cross-boundary alliance may remain static even in the face of declining performance. The questions of when performance signals will trigger changes in the external explore/exploit balance and whether these changes will lead or follow internal changes in this balance merit study.

Our study also finds a positive relationship between centralized internal R&D organizations and firm involvement with exploratory university-based research. Previous research has shown that R&D organization may change substantially over time—moving from centralized to decentralized and back again (Argyres and Silverman, 2004; DeSanctis et al., 2002). A longitudinal study that investigates how changes in R&D organization affect the focus of cross-boundary alliances—namely,

whether the effect is direct or whether it comes in response to structurally induced changes of the internal explore/exploit balance—would also be of interest.

Finally, it would be useful to expand our understanding of the factors that differentiate university partners from other external alliance partners. The university–industry technology transfer landscape is continually changing. Several of our industry respondents mentioned their unease over the increasingly strong assertion of intellectual property rights by their university partners. If, as our study suggest, concerns about the ability to appropriate the returns from cross-boundary research alliances influence the choice of partner, aggressively claiming ownership over the resultant intellectual property may decrease relative desirability of academic partners. Lacking other differentiating factors, firms might shift their resources to other external partners or to the expansion of internal exploratory efforts. Universities need to understand whether in their rush to garner immediate economic returns from industry interactions they may significantly limit their opportunities in the long term.

## Acknowledgements

We wish to acknowledge support for this paper from the Andrew W. Mellon Foundation as part of a larger project on evolving university–industry relationships. Additional support has been received from the U.S. National Science Foundation and the Canadian Social Science Research Council. We are indebted to the individuals both at universities and companies for generously sharing their time and expertise in identifying salient issues. Connie Liu provided valuable research assistance. This paper benefited from discussions with participants at the Georgia Tech Roundtable on Engineering Education Research and the Danish Research Unit on Industrial Dynamics (DRUID) Summer Meetings.

## References

- Ahuja, G., 2000. Collaboration networks, structural holes, and innovation: A longitudinal study. *Administrative Science Quarterly* 45, 425–455.
- Argyres, N., 1995. Technology strategy, governance structure, and interdivisional coordination. *Journal of Economic Behavior and Organization* 28, 337–358.
- Argyres, N., 1996. Capabilities, technological diversification and divisionalization. *Strategic Management Journal* 17, 395–410.
- Argyres, N. and Silverman, B., 2004. R&D, organization structure, and the development of corporate technological knowledge (special issue). *Strategic Management Review* 25, 929–958.

- Armstrong, J.S., Overton, T.S., 1977. Estimating nonresponse bias in mail surveys. *Journal of Marketing Research* 14, 396–402.
- Arora, A., Fosfuri, A., Gambardella, A., 2001. *Markets for Technology: The Economics of Innovation and Corporate Strategy*. MIT Press, Cambridge, MA.
- Campbell, D.T., 1955. The informant in quantitative research. *American Journal of Sociology* 60 (1), 339–342.
- Chesbrough, H., 2003. *Open innovation: the new imperative for creating and profiting from technology*. Harvard Business School Publishing, Boston, MA.
- Christensen, J.F., 2002. Corporate strategy and the management of innovation and technology. *Industrial and Corporate Change* 11 (2), 263–288.
- Cohen, W., 1994. Fortune favors the prepared firm. *Management Science* 40 (2), 227–251.
- Cohen, W., 1995. Empirical studies of innovative activity. In: Stoneman, P. (Ed.), *Handbook of the Economics of Innovation and Technological Change*. Blackwell, Oxford, England, pp. 182–264.
- Cohen, W., Levinthal, D., 1989. Innovation and learning: the two faces of R&D. *Economic Journal* 99 (397), 569–596.
- Cohen, W., Levinthal, D., 1990. Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly* 35, 128–152.
- Cohen, W., Nelson, R., Walsh, J., 2000. Protecting their intellectual assets: appropriability conditions and why U.S. manufacturing firms patent (or not). National Bureau of Economic Research Working Paper 7552.
- Cohen, W., Nelson, R., Walsh, J., 2002a. Links and impacts: the influence of public research on industrial R&D. *Management Science* 48 (1), 1–23.
- Cohen, W., Goto, A., Nagata, A., Nelson, R., Walsh, J., 2002. R&D spillovers, patents and the incentives to innovate in Japan and the United States. *Research Policy* 31(8–9), 1349–1367.
- Colyvas, J., Crow, M., Gelijns, A., Mazzoleni, R., Nelson, R.R., Rosenberg, N., Sampat, B.N., 2002. How do University Inventions get into Practice? *Management Science* 48 (1), 61–72.
- Cyert, R.M., March, J.G., 1963. *A Behavioral Theory of the Firm*, 2nd ed. Blackwell Publishers, Malden, MA.
- DeSanctis, G., Glass, J., Ensing, M.I., 2002. Organizational designs for R&D. *The Academy of Management Executive* 16 (3), 55.
- Dussauge, P., Garrette, B., Mitchell, W., 2000. Learning from competing partners: outcomes and durations of scale and link alliances in Europe, North America and Asia. *Strategic Management Journal* 21 (2), 99–126.
- Duysters, G., Man, A., 2003. Transitory Alliances: an instrument for surviving turbulent industries? *R&D Management* 33, 49–58.
- Dyer, J., Singh, H., 1998. The relational view: cooperative strategy and sources of interorganizational competitive advantage. *Academy of Management Review* 23, 660–679.
- Feller, I., Ailes, C.P., Roessner, J.D., 2002. Impact of research universities on technological innovation in industry: evidence from engineering research centers. *Research Policy* 31, 457–474.
- Gassman, O., von Zedtwitz, M., 1999. New concepts and trends in international R&D organization. *Research Policy* 28, 231–250.
- Geuna, A., 1999. *The economics of knowledge production: funding and the structure of university research*. Edward Elgar, Northampton, MA.
- Graff, G., Heiman, A., Zilberman, D., 2002. University research and offices of technology transfer. *California Management Review* 45 (1), 88.
- Greve, H.R., Taylor, A., 2000. Innovations as catalysts for organizational change: shifts in organizational cognition and search. *Administrative Science Quarterly* 45, 54–80.
- Helfat, C.E., 1994. Firm specificity in corporate applied R&D. *Organization Science* 5, 173–184.
- Helfat, C.E., 1997. Know-how and asset complementarity and dynamic capability accumulation: the case of R&D. *Strategic Management Journal* 18 (5), 339–360.
- Henderson, R.M., Clark, K.B., 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly* 35, 9–30.
- Holmqvist, M., 2004. Experiential learning processes of exploitation and exploration within and between organizations: an empirical study of product development. *Organization Science* 15 (1), 70–81.
- Industrial Research and Institute, 1995. *Industrial R&D Organization and Funding Charts*. Washington, DC, IRI.
- Jensen, M., Meckling, W., 1992. Specific and general knowledge, and organization structure. In: Werin, W., Wijkander, H. (Eds.), *Contract Economics*. Blackwell, Oxford, pp. 251–274.
- Kay, N., 1988. The R&D function: corporate strategy and structure. In: Dosi, G., Freeman, G., Nelson, R., Silverberg, G., Soete, L. (Eds.), *Technical Change and Economic Theory*. Pinter, London, pp. 283–294.
- Klevorick, A., Levin, R., Nelson, R., Winter, S., 1995. On the sources and significance of interindustry differences in technological opportunities. *Research Policy* 24 (2), 195–205.
- Kogut, B., 1988. Joint ventures: theoretical and empirical perspectives. *Strategic Management Journal* 10, 319–332.
- Koza, M.P., Lewin, A.Y., 1998. The co-evolution of strategic alliances. *Organizational Science* 9, 255–264.
- Lane, P.J., Lubatkin, M., 1998. Relative absorptive capacity and interorganizational learning. *Strategic Management Journal* 19 (5), 461–477.
- Laurson, K., Slater, A., 2005. My precious: the role of appropriability in shaping innovative performance. DRUID Working Paper No 5-02.
- Leonard-Barton, D., 1995. *Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation*. Harvard Business School Press, Boston, MA.
- Levin, R.C., Klevorick, A.K., Nelson, R.R., Winter, S.G., 1987. Appropriating the returns to industrial R&D. *Brookings Papers on Economic Activity* 1987 (3), 783–831, Special Issue On Microeconomics.
- Levinthal, D., March, J., 1993. The myopia of learning. *Strategic Management Journal* 14, 95–112.
- Link, A.N., 1996. Research joint ventures: patterns from federal register filings. *Review of Industrial Organization* 11, 617–628.
- Mansfield, E., 1998. Academic research and industrial innovation: an update of empirical findings. *Research Policy* 26, 773–776.
- March, J., 1991. Exploration and exploitation in organizational learning. *Organization Science* 2 (1), 71–87.
- Milmo, S., 2003. BASF opens R&D lab at European university. *Chemical Market Reporter* 263 (4), 6.
- Mowery, D., Rosenberg, N., 1989. *Technology and the Pursuit of Economic Growth*. Cambridge University Press, Cambridge, UK.
- Mowery, D.C., Oxley, J.E., Silverman, B.S., 1996. Strategic alliances and interfirm knowledge transfer. *Strategic Management Journal* 17 (1), 77–91.
- Mowery, D., Nelson, R., Sampat, B., Ziedonis, A., 2001. The growth of patenting and licensing by U.S. universities: an assessment of the effects of the Bayh-Dole Act of 1980. *Research Policy* 30, 99–119.
- Nagarajan, A., Mitchell, W., 1998. Evolutionary diffusion: internal and external methods used to acquire encompassing, complementary,

- and incremental technological changes in the lithotripsy industry. *Strategic Management Journal* 19 (11), 1063–1077.
- National Science Foundation, Division of Science Resources Studies, 2001. *Strategic Research Partnerships: Proceedings from an NSF Workshop*, NSF 01-336 [Project Officers, John E. Jankowski, Albert N. Link, Nicholas S. Vonortas, Arlington, VA, 2001].
- Pisano, G.P., 1991. The governance of innovation: vertical integration and collaborative arrangements in the biotechnology industry. *Research Policy* 20 (3), 237–249.
- Powell, W.W., Koput, K., Smith-Doerr, L., 1996. Inter-organizational collaboration and the locus of innovation: networks of learning in biotechnology. *Administrative Science Quarterly* 41, 116–145.
- O'Reilly III, C.A., Tushman, M.L., 2004. The ambidextrous organization. *Harvard Business Review* 82 (4), 74–81.
- Rosenberg, N., Nelson, R., 1994. American universities and technical advance in industry. *Research Policy* 23, 323–348.
- Rosenfeld, S.A., 1996. Does cooperation enhance competitiveness? Assessing the impacts of inter-firm collaboration. *Research Policy* 25 (2), 247–263.
- Rosenkopf, A., Nerkar, 2001. Beyond local search: boundary-spanning exploration, and impact in the optical disk industry. *Strategic Management Journal* 22, 287–306.
- Rothaermel, F., Deeds, D., 2004. Exploration and exploitation alliances in biotechnology: a system of new product development. *Strategic Management Journal* 25 (3), 201–221.
- Shane, S., 2002. Selling university technology: patterns from MIT. *Management Science* 48 (1), 122–137.
- Shane, S., 2004. Encouraging university entrepreneurship? The effect of the Bayh-Dole Act on university patenting in the United States. *Journal of Business Venturing* 19, 127–151.
- Stokes, D., 1997. *Pasteur's quadrant: basic science and technological innovation*. Brookings Institution Press, Washington, DC.
- Teece, D., 1985. Multinational enterprise, internal governance and industrial organization. *American Economic Review* 75, 233–238.
- Thursby, J., Thursby, M., 2004. Are faculty critical? Their role in university–industry licensing. *Contemporary Economic Policy* 22 (2), 162–178.
- Tripsas, M., Gavetti, G., 2000. Capabilities cognition and inertia: evidence from digital imaging. *Strategic Management Journal* 21, 1147–1161.
- Tushman, M., O'Reilly, C., 1996. Ambidextrous organizations: managing evolutionary and revolutionary change. *California Management Review* 38 (4), 8–30.
- Von Hippel, E., 1988. *The Sources of Innovation*. Oxford University Press, New York.
- Williamson, O., 1991. Comparative economic organization: the analysis of discrete structural alternatives. *Administrative Science Quarterly* 36, 269–296.
- Zucker, L., Darby, M., Armstrong, J., 2002. Commercializing knowledge: university science, knowledge capture, and firm performance in biotechnology. *Management Science* 48 (1), 138–153.
- Association of University Technology Managers, 2002. *AUTM Licensing Survey: FY 2000, Survey Summary*. Association of University Technology Managers, Norwalk, CT.
- Arrow, K., 1962. Economic welfare and the allocation of resources of invention. In: National Bureau of Economic Research (Ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors*. Princeton University Press, Princeton, NJ, pp. 609–625.
- Bercovitz, J., Feldman, M., Feller, I., Burton, R., 2001. Organizational structure as a determinant of academic patent and licensing behavior: an exploratory study of Duke, Johns Hopkins, and Pennsylvania State Universities. *Journal of Technology Transfer* 26, 21–35.
- Cohen, W., Walsh, J., 2001. Public research, patents and implications for industrial R&D in the drug, biotechnology, semiconductor and computer industries. In: Wessner, C.W. (Ed.), *Capitalizing on New Needs and New Opportunities: Government–Industry Partnerships in Biotechnology and Information Technologies*. National Academy Press, Washington, DC, pp. 223–243.
- David, P., Mowery, D., Steinmueller, E., 1997. University–industry research collaborations: managing missions in conflict. In: David, P., Steinmueller, E. (Eds.), *A Productive Tension: University–Industry Research Collaborations in the Era of Knowledge-Based Economic Development*. Stanford University Press, Stanford, CA.
- Feldman, M., Feller, I., Bercovitz, J., Burton, R., 2002. Equity and the technology transfer strategies of American research universities. *Management Science* 48 (1), 105–121.
- Gulati, R., 1995. Does familiarity breed trust? The implications of repeated ties for contractual choice in alliances. *Academy of Management Journal* 38 (1), 85–112.
- Hagedoorn, J., 1993. Understanding the rationale of strategic technology partnering: inter-organizational modes of cooperation and sectoral differences. *Strategic Management Journal* 14, 371–385.
- Hagedoorn, J., 2002. Inter-firm R&D partnerships: an overview of major trends and patterns since 1960. *Research Policy* 31, 477–492.
- Hagedoorn, J., Link, A.N., Vonortas, N.S., 2000. Research partnerships. *Research Policy* 29 (4–5), 567–586.
- Henderson, R., Cockburn, I., 1994. Measuring competence? Exploring firm effects in pharmaceutical research. *Strategic Management Journal* 15, 63–84.
- Henderson, R., Jaffe, A., Trajtenberg, M., 1998. Universities as a source of commercial technology: a detailed analysis of university patenting, 1965–1988. *The Review of Economics and Statistics* 80 (1), 119–127.
- Industrial Research Institute, 2002. Industrial institute's R&D trends forecast for 2002. *Research Technology Management*, January–February, 16–20.
- Jensen, R., Thursby, M., 2001. Proofs and prototypes for sale: the licensing of university inventions. *The American Economic Review* 91 (1), 240–259.
- Koestler, A., 1990. *The Act of Creation*. Viking, New York.
- Lam, A., 2003. Organizational learning in multinationals: R&D networks of Japanese and US MNEs in the UK. *Journal of Management Studies* 40 (3), 673–703.
- Lerner, J., Merges, R.P., 1998. The control of technology alliances: an empirical analysis of the biotechnology industry. *Journal of Industrial Economics* 46 (2), 125–156.
- Link, A.E., Vonortas, N., 2001. Strategic research partnerships: results of the workshop. In: J.E. Jankowski, A.N. Link, N.S. Vonortas (Eds.), *Proceedings from an NSF Workshop on Strategic Research Partnerships*, NSF 01-336, Project Officers, Arlington, VA.

## Further reading

- Argyres, N., Julia Porter, L., 1998. Privatizing the intellectual commons: universities and the commercialization of biotechnology. *Journal of Economic Behavior and Organization* 35, 427–454.

- Magun, S., 1996. The development of strategic alliances in Canadian industries: a micro analysis. *Applied International Economics Working Paper*.
- Mowery, D.C., Teece, D.J., 1996. Strategic alliances and industrial research. In: Rosenbloom, R., Spencer, W. (Eds.), *Engines of Innovation: U.S. Industrial Research at the End of an Era*. Harvard Business School Press, Boston, pp. 111–129.
- Mowery, D., Ziedonis, A., 2002. Academic patent quality and quantity before and after the Bayh-Dole Act in the United States. *Research Policy* 31 (3), 399–418.
- National Science and Board, 2002. *Science and Engineering Indicators 2002*. U.S. Government Printing Office, Washington, DC.
- National Science and Board, 2004. *Science and Engineering Indicators 2003*. U.S. Government Printing Office, Washington, DC.
- National Science Foundation and the United States Department of Commerce, U.S. Corporate R&D: Vol. I. Top 500 Firms in R&D by Industry Category, NSF 00-301 [Carl Shepherd, Department of Commerce/Office of Technology Policy, and Steven Payson, National Science Foundation/Division of Science Resources Studies, Arlington, VA, 1999].
- Nelson, R., 1959. The simple economics of scientific research. *Journal of Political Economy* 67, 297–306.
- OECD., 2002. *Main Science and Technology Indicators*. OECD, Paris.
- Oxley, J., 1997. Appropriability hazards and governance in strategic alliances: a transaction cost approach. *Journal of Law, Economics, and Organization* 13 (2), 387–409.
- Sakakibara, M., 1997. Heterogeneity of firm capabilities and cooperative research and development: an empirical examination. *Strategic Management Journal* 18 (S1), 143–164.
- Sampson, R.C., 2003. R&D alliances & firm performance: the impact of technological diversity and alliance organization on innovation (September).
- Shane, S., Stuart, T., 2002. Organizational endowments and the performance of university start-ups. *Management Science* 48 (1), 154–170.
- Siegel, D., Waldman, D., Link, A., 2002. Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: an exploratory study. *Research Policy*.
- Teece, D.J., 1996. Firm organization, industrial structure, and technological innovation. *Journal of Economic & Behavioral Organization* 31, 193–224.
- Thursby, J., Kemp, S., 2002. Growth and productive efficiency of university intellectual property licensing. *Research Policy* 31 (1), 109–124.
- Thursby, J.C., Thursby, M.C., 2000. Industry perspectives on licensing university technologies: sources and problems. *The Journal of the Association of University Technology Managers* 12, 9–22.
- Thursby, J., Thursby, M., 2002. Who is selling the ivory tower? Sources of growth in university licensing. *Management Science* 48 (1), 90–104.
- Thursby, J., Jensen, R., Thursby, M., 2001. Objectives, characteristics, and outcomes of university licensing. *Journal of Technology Transfer* 26, 59–72.
- Zucker, L.G., Darby, M.R., 1996. Star scientists and institutional transformation: patterns of invention and innovation in the formation of the biotechnology industry. *Proceedings of the National Academy of Science of the United States of America* 93, 12709–12716.