10-2002

The effects of business-university alliances on innovative output and financial performance: A study of publicly traded biotechnology companies

Gerard GEORGE
Singapore Management University, ggeorge@smu.edu.sg

Shaker A. ZAHRA
University of Wisconsin-Madison

D. Robley WOOD
Virginia Commonwealth University

Citation

GEORGE, Gerard; ZAHRA, Shaker A.; and WOOD, D. Robley. The effects of business-university alliances on innovative output and financial performance: A study of publicly traded biotechnology companies. (2002). *Journal of Business Venturing*. 17, (6), 577-609. Research Collection Lee Kong Chian School Of Business.
Available at: https://ink.library.smu.edu.sg/lkcsb_research/4657

Published in Journal of Business Venturing, 2002, 17 (6), pp. 577-609
https://doi.org/10.1016/S0883-9026(01)00069-665

The effects of business–university alliances on innovative output and financial performance: a study of publicly traded biotechnology companies

Gerard George[a], Shaker A. Zahra[b,*], D. Robley Wood[c]

[a]*University of Wisconsin, Madison, WI, USA*
[b]*Babson College, MA, USA*
[c]*Virginia Commonwealth University, Richmond, VA, USA*

Abstract

Companies in the biotechnology industry face major challenges in developing and commercializing new products. Focusing on publicly traded biotechnology firms that are not members of university incubators or research parks, this paper argues that the links these companies develop with universities can have beneficial effects on a company's operations. Analysis of 2457 alliances undertaken by 147 biotechnology firms shows that companies with university linkages have lower research and development (R&D) expenses while having higher levels of innovative output. However, the results do not support the proposition that companies with university linkages achieve higher financial performance than similar firms without such linkages.

Keywords: Biotechnology; University-business alliances; Innovation; Knowledge

1. Introduction

Companies that compete in high-technology industries face major challenges in their quest for survival and profitability (Oliver and Liebeskind, 1998). In these industries, the

* Corresponding author. Tel.: +1-404-651-2894; fax: +1-404-651-2804.
E-mail address: szahra@gsu.edu (S.A. Zahra).

competitive landscape and the rules of competitive rivalry change constantly (D'Aveni, 1994), requiring firms to develop their absorptive capacity and the ability to continually reconfigure their competencies for value creation (Zahra and George, 2000). While opportunities for profitability and growth abound in these dynamic industries, the risks of failure are also high. Industries, such as biotechnology have been witness to some of the most gallant competitive efforts that nonetheless have ended in organizational defeat (Grant, 1998). To survive and achieve profitability, these companies need to act entrepreneurially to assemble and use their resources in ways that give them a competitive advantage (Barney 1991).

Companies in science-based industries, however, encounter serious challenges in gaining access to the resources needed to build strong capabilities (Zahra, 1996). Even though success requires a firm to utilize diverse technological capabilities, accumulating these capabilities is a time-consuming and an expensive process that is fraught with uncertainty (Teece et al., 1997). Firms, therefore, need to develop beneficial relationships with the suppliers of these scarce resources (Oliver and Liebeskind, 1998). These suppliers, in turn, are likely to respond favorably to the firm's needs if it is backed by a credible third party whom they trust (Pfeffer and Nowak, 1976; Powell et al., 1996). Relationships with established and reputable organizations such as leading research universities can enhance a company's legitimacy in the eyes of other powerful stakeholders (Mian, 1997). These relationships also give the firm access to diverse resources, sometimes at prices lower than the going market rates, which enables the firm to reduce its overall costs and achieve superior performance (Geisler, 1995; Matkin, 1990).

A widely used strategy in science-based industries is for firms to develop close linkages with universities (Bowie, 1994; Peters et al., 1998) that can give companies flexibility in conducting research and development (R&D) (MacLachlan, 1995; Sage, 1996). This is important because modern technology demands the mastery of multifaceted scientific disciplines that only few companies possess. Established research universities employ scientists who devote their time to conducting research in existing and emerging technologies. Usually leaders in their fields, these researchers also benefit from their universities' investments in R&D. Universities conduct about 60% of all basic research and a much smaller but still significant amount of applied research in the US (Lewis, 1990, p. 193). University research spending reached US$26.8 billion in 1999, up 10% over the previous year. With 12,324 invention discoveries reported in 1999 (up 5% over 1998) and the number of patents filed at 5545 (up 15% over 1998), universities can be a valuable source of knowledge and innovation (AUTM, 2000). In 1999 alone, 344 new ventures were formed from university-based inventions (AUTM, 2000).

Linkages with universities give the firm a window on emerging technologies and scientific discoveries (Lepkowski, 1996). University scientists typically view these links as providing fertile grounds for developing and testing theories, honing their skills, and training and placing their students (Cyert and Goodman, 1997). Links with business firms can also generate the funds needed to pursue important R&D projects and improve the quality of a university's research and teaching (Lee, 1996; Webster, 1994). Business–university alliances, therefore, can be a "win–win" situation, where the objectives of the firm and the university are achieved (Bolton, 1995; Bowie, 1994). A National Science Foundation report (NSF, 1998) concludes that there is an increasing trend in cooperation between universities and industry in basic research. This interaction becomes explicit with shared research agendas, industry research funding, and joint authorship on research papers that appear in the public research domain. For example, between 1990 and 1997, MIT faculty and graduates have founded more than 60 companies that have a combined market value of US$2.5 billion and created more than 2000 high-technology jobs. MIT, which receives about 100 patents each year, is illustrative of a positive trend in university–business relationships (Thayer, 1997). In order to tap the intellectual potential of its scientific community, universities such as the University of Wisconsin-Madison invest nearly US$500 million in research every year and have built their own research parks. Wisconsin's research park offers 23 buildings with more than 800,000 ft^2 of facility space.

Other research universities, such as Georgia Tech (Blau, 1999), Chicago (Melcher, 1998), Cornell (Thayer, 1997), Texas at Austin (Smilor et al., 1990), and Stanford (Thuemer, 1997) have entered into partnerships with businesses. These collaborations have been spurred by the active participation of the NSF (1998), through its Industry–University Cooperative Research Program. As of 1998, there were 18 such centers in the US, encompassing 700 partnerships with 550 companies (Hairston et al., 1998). Universities outside the US have also worked closely to foster the growth of science and technology-based new ventures (for a review, see Blau, 1999; Carayannis et al., 1998; Meyer-Krahmer and Schmoch, 1998).

In this article, we examine the potential effects of linkages with a university on firm innovation and performance outcomes among publicly traded biotechnology companies. The industry represents an important scientific paradigm shift that promises to alter the way science and its applications are made (Zahra and George, 1999). Universities have also played a key role in giving birth to this industry and supporting the creation of new companies to exploit its discoveries (Kuhlman, 1996). This has made the biotechnology industry an ideal setting to study collaborative relationships (Oliver and Liebeskind, 1998). Yet, little empirical research documents the positive effects of university linkages on firm innovation and performance.

As with other emerging industries, the biotechnology industry contains a wide range of organizations that vary in their ownership and missions (Zucker et al., 1998). This suggests that those biotechnology firms that seek linkages with universities are likely to emphasize different goals and priorities and exhibit different management styles in dealing with university researchers and scientists. Therefore, it should be noted that our analyses focus primarily on one, but crucial segment of the biotechnology industry: publicly traded firms. The study excludes firms that are privately held or lodged in university-based technology incubators (UBTIs) or research parks. Given that these firms may have access to different resources, generalizations of our results should be made with caution.

Section 2 reviews the literature on university–business alliances and presents the study's hypotheses on the differences in the innovative output and financial performance of biotechnology firms with linkages vs. without linkages to universities. This is followed by Section 3, a section on methodology and empirical analysis to test the hypotheses. Section 6 reviews the results and discusses their practical and theoretical implications.

2. Theoretical background and hypotheses

Understanding the linkages between universities and biotechnology firms requires an appreciation of the benefits and shortcomings of these relationships. A limitation of past research in this area is the absence of a unifying framework that clarifies the antecedents and consequences of these alliances (Mian, 1997). This has led researchers to follow different theoretical frameworks, generating contradictory and fragmented findings. Even though this research has been criticized as being descriptive and lacking in theory (Dahlstrand, 1997), we can gain some insights into the factors that may influence the outcomes biotechnology companies gain from joining alliances with universities. The literature on UBTIs and university–business alliances has addressed these issues and is, therefore, reviewed next.

2.1. University-based technology incubators

Collaborative relationships between US universities and industry are nearly a century old (Blumenthal, 1994; Bowie, 1994), reflecting the mutual needs of the two communities to join forces to achieve complex but varied goals (Bolton, 1995; Brannock and Denny, 1998; Cukor, 1992; Merrifield, 1987). These relationships are expected to increase because of the declining federal and state support for R&D in the US, the growing complexity of technology, and the ever-rising speed of technological change. These factors appear to underlie university faculties' growing acceptance of collaborative relationships with industry, as revealed by the results of a survey of 1000 faculty members (Lee, 1996). While the goals, nature, and structure of these collaborations differ (Nimtz et al., 1995), there is some anecdotal evidence that both universities and business firms can benefit from these relationships (Bowie, 1994; Brannock and Denny, 1998). The remainder of this section reviews the benefits publicly traded biotechnology firms can gain from their linkages with universities.

Oliver and Libeskind (1998) suggest that the birth and growth of the biotechnology industry have been made possible by the close, collaborative relationships between universities and business companies. The founders of many of these young companies have been professors and researchers, which have facilitated communication between managers and universities. New biotechnology firms have also found support from the incubators universities have established to capitalize on the growth of this industry. These incubators have had the support of public policymakers who are eager to attract and retain entrepreneurial companies in their home states. In Georgia, for example, there are a dozen such incubators, including a biotechnology incubator sponsored by Georgia Tech and Emory University.

Apart from biotech, UBTIs have been used in different industries as well. In fact, Mian (1997) suggests that there are over 50 such UBTIs in the US. Given their potential importance, UBTIs have received some attention in prior research (Merrifield, 1987; Udell, 1990). However, most past research on UBTIs is descriptive or anecdotal in nature (e.g., Bolton, 1995; Mian, 1997; Udell, 1990). Furthermore, few studies have documented the effect of UBTIs on firm performance (Mian, 1997). Consequently, credible evidence on the contributions of UBTIs is difficult to locate.

In one of the first published authoritative studies, Roberts (1968) examined the spin-offs and potential benefits of ties with universities, especially MIT. Roberts concluded that universities foster the creation of technology-based new ventures. Dorfman (1983), who studied the development of high-technology companies in the Boston area, concluded that MIT was the main contributing factor. Dorfman also found that the second most important factor was the presence of other high-technology firms, which is determined by the presence of research-oriented universities (Dahlstrand, 1997). Allen (1985), who examined 45 UBTIs, documented the different services these organizations offered their members. These varied services can sustain and foster the growth of young entrepreneurial companies. Who studied 117 incubators, concluded that UBTIs generate benefits, such as secretarial, administrative, counseling, and other services, that facilitate the growth of high-technology ventures. Geisler et al. (1990) studied 23 federally sponsored university–business centers and found that multiple factors (founders, organization, and administration) interact to determine these centers' success and net contributions. Udell (1990), who studied 71 UBTI, provided a comprehensive list of the services these organizations offered their members. These services can reduce the operating costs of fledgling firms' operations as they seek to establish their market positions.

Past UTBI research highlights several benefits that accrue to the business and university communities (e.g., Carayannis et al., 1998; Geisler, 1995; Etzkowitz, 1998). These benefits include job creation through new venture creation (Allen, 1985), wherein UBTIs can act as a source of cheaper specialized labor in the form of graduate students (Gluckv et al., 1987) and provide access to a steady stream of talented graduates and researchers (McGee, 1996; Smilor et al., 1990). UBTIs also spur technology-based entrepreneurship and innovation (Abetti and Stuart, 1985; Hisrich and Smilor, 1988; Mian, 1994). UBTIs, therefore, can act as a catalyst in regional development by providing an opportunity for new ventures to contribute to the local economy (Kuratko and LaFollette, 1987; Thayer, 1997). UBTIs also contribute to this goal through localized knowledge spillovers from university interactions and clustering of firms that generates a self-sustaining market for related services (Audretsch and Stephan, 1996; Ceccagnoli et al., 1998; Zucker et al., 1998).

Two conclusions can be drawn from prior research on UBTIs. First, UBTIs offer young companies several benefits that can nurture their growth and progress. Second, questions remain about the extent of the services offered by the incubators (Udell, 1990; Mian, 1997). While the present study does not look specifically into the role of UBTIs in improving a firm's performance, UBTIs are an example of positive outcomes some companies can gain by developing linkages with universities (Kuratko and LaFollette, 1987; Mian, 1997). This article explores the impact of university linkages (particularly alliances) on a firm's innovative outputs, though such firms do not necessarily belong to an UBTI.

Universities can contribute to the growth of an entrepreneurial culture in a region in other important ways (Carayannis et al., 1998; Dahlstrand, 1997; Thayer, 1997). For examples, some states (e.g., Georgia, Massachusetts, North Carolina, Virginia, and Wisconsin) have attempted to promote the creation and growth of high-technology companies by creating science parks that attract fledging companies and key service providers. There are over 140 such science parks in the US (Thuemer, 1997). Cabral and Dahab (1998), in their study of biotechnology firms, have concluded that the presence of the strong research-oriented universities close to these parks is a key requirement for success. Prevezer (1997) also suggests that the presence of strong research universities in a region is a major factor in biotechnology companies' location decision.

In spite of the positive outcomes, linkages between universities and business firms have been criticized on several grounds. Business–industry partnerships can be problematic in terms of quality control, coordination time, shared credit, and communication problems (Jasso, 1996). Slaughter (1990) notes that business leaders deal in both cooperation and cooptation with diverse institutions, and therefore may have multiple agendas when they form partnerships with universities. Powers et al. (1988) also warn that these partnerships may cause the faculty to spend less time working within their departments which in turn causes the departments to be less productive and cohesive. Incompatibilities between cultures, such as secrecy vs. free dissemination of knowledge, can be a stumbling block to university–industry alliances (Bower, 1992). University scientists often have priorities that conflict with strict industry schedules and may cause tension in collaborative activities (Bower, 1992; Eisenberg, 1996). Successful university–industry alliances can result in the formation of a university company where researchers become entrepreneurs and conflicts of interest may develop between their academic and corporate roles (Piercey, 1998). Close ties with the industry might also pressure faculty to pursue projects with strong applied orientations and are of immediate benefit to partner companies (Cukor, 1992), a practice which can weaken basic research (Lee, 1996). These drawbacks aside, research on 25 universities in Europe and the US over a 6-year period concluded that links with the universities are valued and important. They provide a ready source of external advice and frequently result in access to unique know-how and expertise (Blair and Hitchens, 1998).

The ever-growing number of linkages between business firms and universities highlights the potentially beneficial impact of institutional links on a company's performance (Geisler, 1995). A firm can benefit from these links in their credibility, legitimacy, resources, and costs (Lewis, 1990). Despite the *potential* benefits of firm–university links, however, empirical documentation of their *actual* contributions is limited (Cyert and Goodman, 1997), and findings on this issue have been inconsistent (Blair and Hitchens, 1998; Harmon et al., 1997). Past research does not provide answers to simple questions such as: Do these links reduce a firm's R&D costs? Do they enhance the firm's ability to innovate and improve a company's performance?

To address these fundamental issues through a study of biotechnology firms, this paper suggests that firm–university linkages can increase a company's access to knowledge (e.g., scientific advances) and other key resources (e.g., market information). Linkages with universities can also serve as a magnet that attracts technologically capable alliance partners to collaborate with the firm, which can improve the firm's knowledge base and its innovative outputs (e.g., patents). These linkages may also reduce a firm's costs, especially those relating to knowledge creation (e.g., R&D). These innovative outputs and cost reductions can give a firm a competitive advantage that can improve its financial performance (Grant, 1996). Currently, we know very little about the costs vs. the benefits that firms achieve from establishing links with universities, especially in their R&D operations. Given the expected growth of these alliances in the biotechnology industry, this study aims to fill this gap in the literature by exploring the effect of the firm's linkages with universities on innovation and performance.

Even though university–business alliances have been the topic of some research (Argyres and Liebeskind, 1998), rarely have they been examined from an entrepreneurial perspective. Entering these alliances represents an important entrepreneurial act, where managers take major risks in pursuit of competitive advantage. Alliances are also fraught with technological, administrative, and financial risks. Organizational-level entrepreneurial activities are usually characterized by such risks (Lumpkin and Dess, 1996). However, university alliances are an important way in which firms can obtain, combine, and leverage their resources in innovative ways that can lead to profitability and growth. These alliances can offset the weaknesses of a firm's resources and internal skills. Given that these alliances impact the boundaries of the firm and determine the sphere of its operations (Williamson, 1985), examining the activities that influence the domain of the firm is an issue of central interest in the field of entrepreneurship (Lumpkin and Dess, 1996). Finally, this study explores university–business alliances in the biotechnology industry. Researchers have noted the importance of this and other young industries in examining and understanding the entrepreneurial activities of firms (Zahra and George, 1999; Zucker et al., 1998).

Linkages with universities can enable the firm to gain and master different knowledge bases that can then be used in developing innovative products to obtain patents that strengthen its competitive position and financial performance. University–business links can improve the firm's innovative outputs and financial performance (Liebeskind et al., 1996; Peters et al., 1998). In the biotechnology industry, continuous innovation is a strategic priority in a firm's efforts to acquire and protect a competitive advantage (Lerner, 1994). Given the high costs of innovation (Grant, 1998), developing links with universities can be strategically advantageous for the firms by reducing R&D and other costs.

2.2. University–business linkages as catalyst for alliance formation

Success in new science-based industries requires firms to acquire or develop new and multifaceted competencies. Competencies are the skills a firm develops by effectively deploying its diverse assets and resources (Grant, 1998). To succeed, a firm should possess strong and diverse competencies throughout its operations. These competencies, especially technology-based, are hard to develop and may take years to assemble (Dodgson, 1992). Firms can assemble their technological competencies through internal R&D and by using internal sources that include outsourcing, licensing agreements, and linkages with universities (Link and Tassey, 1987). This study examines the linkages between biotechnology firms and universities. These linkages have not been thoroughly examined in prior research (Osborne and Hagedoorn, 1996).

University–business links are one type of interfirm alliances (Bowie, 1994). Potential benefits from these alliances include enhanced efficiency, increased profitability (Contractor and Lorange, 1988), reduced costs (Kogut, 1988), facilitating future technology partnering (Geisler, 1995; Hagedoorn, 1993), and improving organizational learning (Pennings et al., 1994). However, some alliances can erode the firm's competitive advantage and create complex administrative and coordination problems. They may also raise the firm's overhead and other costs, requiring careful management and control systems. Alliances may leak information about the firm's new technologies, allowing competitors to imitate these innovations quickly. Overall, little is known about the net contributions of university–business alliances to the firm's innovative outputs and financial performance.

One problem in studying university–business alliances is the diversity of their objectives and structures (Eisenberg, 1996), a factor that makes generalizations hazardous (Udell, 1990). While some alliances are broad-based and are comprehensive relationships that aim at discovering and commercializing new technologies, others center on licensing agreements that give a firm access to technology (Trune, 1996). Even when the relationship centers on licensing some learning occurs. Researchers observe that licensing agreements can give the firm a greater understanding of how different components interact and how to best assemble the required technologies. This basic understanding can foster learning that leads some firms to explore new avenues of research (Sage, 1996). Licensing-based alliances between business firms and universities, therefore, can improve a firm's new product development cycle (Hsu and Bernstein, 1997). Obviously, not all firms can engage in this learning, either because the licensed technologies fall beyond their areas of expertise or because of their limited ability to master the new technology. However, firms that learn from their alliances with universities are positioned to gain superior performance.

Links with established and leading universities can also help to further legitimize the firm's operations and increase its access to resources. These links connect the firm to a network of suppliers, financial institutions, and other companies; some leading universities (e.g., Stanford and MIT) typically maintain strong relationships with different firms and stakeholders (Bowie, 1994). As a firm establishes links with these universities, opportunities for more linkages (e.g., alliances) with companies in their network increase (Powell et al., 1996). Given their common link to the same university, these partners are more apt to share their expertise, knowledge, and resources with the firm, barring the possibility that firms compete in the same industry (Peters et al., 1998). Even when the firms are competitors, sometimes they exchange information that supports each other's growth. In today's environment, companies both collaborate and compete with each other (Hamel and Prahalad, 1994).

University–business linkages may also give the firm an opportunity to gain the experience needed to develop, organize, and manage more alliances (George et al., 2000; Lewis, 1990). University–business alliances, therefore, can bring together companies that build relationships that subsequently allow the company's access to the complementary skills they need to develop and introduce new products. This is especially important where firms do not have well-developed in-house functional skills, such as marketing and distribution (Zahra, 1996). Even though university alliances may not strengthen a firm's technical skills per se, they can give a company access to complementary skills that improve its performance.

A firm's absorptive capacity (Cohen and Levinthal, 1990), defined as the ability to evaluate and assimilate new projects, can determine the success of these alliances. Here too, linkages with a university can supplement and expand the firm's absorptive capacity through learning. As the company learns the skills needed to develop and organize alliances, its absorptive capacity increases (Zahra and George, 2000). In turn, the company becomes more proficient in attracting and identifying competent alliance partners, which improves the firm's capabilities in developing new products. As absorptive capacity increases, the firm can also successfully attract and retain more technology-based alliance partners. Coupled with its growing experience in evaluating and managing alliances, a firm with links to a university can attract more and better alliance technology-based partners (Leonard-Barton, 1995). These observations suggest the following hypothesis:

Hypothesis 1: Firms with university linkages will attract significantly more technology-based alliances than firms without these linkages.

2.3. University–business linkages and innovative outputs

To succeed in science-based industries, a firm must innovate (Link and Tassey, 1987) and protect its innovations from imitation by rivals (Grant, 1998). Business–university alliances can enhance a firm's innovative outputs, measured by the number of the products created (Deeds and Hill, 1996; Leonard-Barton, 1995) and the patents achieved (Austin, 1993; Liebeskind et al., 1996). As noted earlier, linkages with a university can give the firm an opportunity to enter into alliances with other firms, exposing a company to diverse management, marketing, managerial, and innovation systems (Leonard-Barton, 1995), a factor that can increase the firm's innovativeness (Deeds and Hill, 1996). A weakness of prior research is that it does not tell us much about the learning that might occur within business–university alliances (Oliver and Liebeskind, 1998; Peters et al., 1998). However, frequent interactions with diverse sources of knowledge also give the firm an opportunity to learn new skills (Dodgson, 1992). If this is true, then learning from and through alliances and networks can improve a firm's ability to develop new products, as found in other studies (Bartmess and Cerny, 1993; Gulati, 1998). However, the studies just cited have focused on alliances other than those developed between universities and business firms and used data from established companies. This study, therefore, seeks to establish if business–university alliances would yield the same types of results (e.g., higher new products). Confirmation of this effect is important because we know little about the nature of business–university alliances and how they may differ in their operations from business-to-business alliances. Yet, differences between these alliances might arise from the unique cultures of partner academic institutions, a factor that can affect the management and success of these alliances (Eisenberg, 1996; Jasso, 1996; Lewis, 1990).

In examining the relationship between university links and new products, however, one should separate products under development from those that have already been introduced to the market. Products under development often require a bundle of skills that differ significantly from those needed for successful commercialization (Afuah, 1998). Biotechnology firms usually have several products under development at any point in time, but only a few of these products eventually reach the market. The arguments presented above would apply more specifically to products under development. However, empirical evidence is lacking on the effect of the links companies establish with universities on the number of new products developed. This study seeks to empirically clarify this relationship.

One way links with universities can increase a firm's innovative outputs is by giving it access to valuable resources (Bowie, 1994; Sage, 1996; NSF, 1998). These resources include financial, marketing skills or information about market conditions, future partners, and emerging technological trends. This can help the firm reduce its expenditures and, therefore, devote more of its funds to support multiple R&D and new product development projects. Links with universities can also overcome some of the firm's internal weaknesses in R&D, while increasing the number of its new products under development (Morris and Hergert, 1987). These observations suggest the following hypothesis:

> *Hypothesis 2a:* Firms with university linkages will have more products under development than those firms without these linkages.

The process of new product commercialization is usually fraught with risk (Grant, 1998; Liebeskind et al., 1996), with only a small percentage of products achieving market or financial success. The greater the number and quality of products under development, the greater the chances of commercialization. Links to a university can increase the number of new products that a biotechnology firm eventually introduces to the market and improve the odds of successful commercialization by providing access to other network members (Peters et al., 1998). Access to other network members also facilitates the free flow of market-related and product-related information (George et al., 2000). This enhances the successful commercialization of new products or technologies (Teece et al., 1997) and increases a firm's market share (Bell, 1993) and financial performance (Fryxell, 1990). Given the strategic benefits associated with new product commercialization, a company can capitalize on the learning it has achieved and the resources it has gained from its links with a university by introducing more new products to the market. These observations suggest the following hypothesis:

> *Hypothesis 2b:* Firms with university linkages will have significantly more new products introduced to the market than those firms without such linkages.

Currently, we do not know whether firm–university linkages actually lead to higher rates of new product development and introductions or not. When a firm succeeds in developing new product ideas, it is likely to proceed to shield its products from imitation (Zahra, 1996). Biotechnology companies recognize that competitors have an incentive to quickly copy their products (Liebeskind et al., 1996). Patents delay imitation (Grant, 1998; Liebeskind et al., 1996) and serve other strategic purposes such as defending the firm's market position. Patents are useful in generating cash flows that support a firm's R&D and other ongoing operations through licensing agreements (Afuah, 1998). A firm can also swap its patents to gain access to other firms' marketing, distribution, or manufacturing skills. Patents can also help to preempt rivals' efforts to flank the firm, protecting the company's market position and enhancing its reputation. Investors, customers, and alliance partners also consider patents when examining their relationships with the firm. Patents are not only a repository of significant knowledge but they are also an important asset (Zahra, 1996). A firm that owns significant patents can also determine the speed and direction of the evolution of the industry (Teece et al., 1997). In the biotechnology industry, where successful product commercialization has been rare, companies have sought to protect their innovations through patents.

Thus, a biotechnology firm that joins a university alliance has an incentive to patent its innovations. As the firm becomes more proficient in its innovation and patenting, it can also learn how to conduct these activities quickly and efficiently, which would increase the total number of patents the firm obtains. These observations suggest the following hypothesis:

Hypothesis 3: Firms with university linkages will obtain more patents than those firms without such linkages.

2.4. University–business linkages and cost of R&D

Potential cost reductions are an important reason for a biotechnology firm to forge links with universities (Geisler, 1995; Kogut, 1988). These links can lower a firm's overhead costs by sharing the equipment required for R&D (Lewis, 1990), which is important for those biotechnology firms that do not have the required funds to maintain extensive R&D facilities (Geisler et al., 1990). The mutual sharing of information and R&D personnel can also reduce the firm's need to invest in R&D. The firm, therefore, can draw heavily on the expertise of the university's faculty and graduate students, rather than retaining a large full-time team of researchers (Geisler, 1995; Lewis, 1990). Universities active in business alliances also provide several services (e.g., market surveys, prototyping preparation for clinical trials, and market pretests) that can reduce a firm's R&D costs. These benefits have been documented in several UBTI studies (e.g., Allen, 1985; Udell, 1990). For example, the Virginia Biotechnology Park is closely linked (shared faculty and research resources) to the Medical College of Virginia, which provides access to experienced medical personnel and low cost patient testing during trials for the FDA approval process. The center also offers state-subsidized R&D facilities at lower than market price per square footage, apart from free consulting and legal advisory services. Finally, Oliver and Liebsekind (1998) observe that university–business alliances have allowed biotechnology companies to access scientific knowledge and complementary assets, which would help augment internal R&D.

Sometimes, participation in an alliance with a university can raise the firm's administrative overhead. Even though the need to coordinate R&D efforts with those of the university can increase a firm's costs, the direct and indirect benefits usually surpass the incremental costs of coordination, which can lower the firm's overall R&D costs. Still, despite the potential benefits and costs associated with university–business links, empirical evidence is lacking. This paper seeks to establish whether these links in fact reduce R&D costs by testing the following hypothesis:

Hypothesis 4: Firms with university linkages have lower R&D expenses than those firms without these linkages.

2.5. University–business linkages and company financial performance

The relationship between university linkages and company performance has been the subject of some research that has yielded contradictory results (Geisler, 1995). As Udell's

(1990) review of past UBTI research would suggest, evidence about these contributions is inconclusive. UBTI research, however, suggests several reasons why these linkages can influence a company's performance adversely. For instance, conflicts between the university and business cultures can sometimes depress company performance (Cyert and Goodman, 1997). Slow academic bureaucracies may also stifle technology commercialization and depress the firm's performance. Links with universities also increase costs because of the need for coordination, leading to lower performance.

However, business–university linkages can make important contributions to a company's financial performance. As noted earlier, universities offer multiple benefits to partner companies (Mian, 1994, 1997). These benefits can reduce biotechnology companies' operating costs and improve their performance. These linkages can also facilitate alliances with other firms, reduce R&D spending, and give the firm access to a pipeline of additional new products and patents. These products can also build a firm's reputation, increase its ability to gain market share, ensure growth, and improve profitability (Buzzell and Gale, 1987; Fryxell, 1990). Patents also give the firm control over its intellectual property and improve its market standing and reputation (Zahra, 1996). If university links increase the firm's ability to obtain patents, then they can improve the firm's market and financial position relative to companies without such links.

University–business alliances can also transfer valuable knowledge and technologies that can spawn innovative products (Burnham, 1997). They also increase a firm's access to different knowledge bases that can add to the production of innovative products (Grant, 1996; Kodama, 1995). As alliances multiply, a firm's absorptive capacity and competence also rise, allowing the firm to further exploit its knowledge by introducing new products, gain higher market share (Buzzell and Gale, 1987), and achieve superior value creation (Zahra and George, 2000). Given these potential benefits, the net contributions of university–business linkages on a company's financial performance are expected to be positive.[1] Therefore:

Hypothesis 5: The financial performance of firms with links to universities is significantly higher than that of firms without such links.

3. Method

To test the above hypotheses, data were collected from the biotechnology industry. This rapidly growing industry has a strong science-based basic research thrust that requires inputs from different streams of specialized knowledge (Hamilton, 1996). In 1996, there were 1308 US biotechnology companies producing a wide range of products with applications in human therapeutics, diagnostics, biomaterials, engineering processes, food preservation, environ-

[1] Benefits from alliances, however, may have upper limits. As alliances multiply, companies may reach the point of diminishing returns because of rising costs of administration and coordination (Deeds and Hill, 1996).

mental clean up, and veterinary sciences (Biotechnology Industry Organization (BIO), 1996). The knowledge-intensive nature of the industry has made it an attractive setting for examining new product development processes (Shan et al. 1994), strategic alliances (Kotabe and Swan, 1995; Liebeskind et al., 1996; Powell et al., 1996), R&D outsourcing decisions (Pisano, 1990), innovative output (Austin, 1993), and organizational competence (Henderson and Cockburn, 1994).

Today, biotechnology is being commercialized in several industries that include pharmaceuticals, plant and animal agriculture, chemicals, and others (Deeds and Hill, 1998; Shan, 1990). The "biotechnology industry" refers to the manipulation of genetic material through recombinant DNA technology, cell fusion, and monoclonal antibodies (Liebeskind et al., 1996). Under this definition, the industry only covers the human diagnostics and therapeutics segment that is involved in the R&D of drugs or diagnostics that will be placed in human beings (Deeds and Hill, 1996; Lerner, 1994; Powell et al., 1996).

Another way to define biotechnology firms is through the system adopted by the US Patent and Trademark Office (USPTO). Accordingly, Austin (1993) defines a biotechnology patent as one that has been given the classification number of 930 or 935 by USPTO, which corresponds to "peptide or protein sequence" and "genetic engineering: rDNA technology etc." [CASSIS/ASSIST, 1991 (USPTO index to classification numbers)]. This definition of biotechnology (patent class no. 930 or 935), which is used in this study, is consistent with other studies (Deeds and Hill, 1996; Shan, 1990).

3.1. Sample

Two steps were used to identify firms in the sample. In the first, classification through SIC codes yielded 504 firms — 104 firms in Human Diagnostics (SIC no. 2835), 96 firms in biological products excluding diagnostics (SIC no. 2836), and 304 in pharmaceutical preparations (SIC no. 2384). This classification included human therapeutics from biotechnology, as well as bulk pharmaceuticals and other specialty drugs. The second step involved elimination based on a firm's business focus, as provided in The 1997 GEN Guides to Biotechnology Companies. Only firms involved in gene therapy, human diagnostics, and therapeutics were included in the analysis. This process yielded 147 publicly traded firms with a primary business focus in human gene therapy, diagnostics, and therapeutics. The number of firms compared favorably with the 474 firms (both public and private firms) reported by the BIO (1996), and other studies using biotechnology data, including the Shan et al. (1994) study that used 85 firms and the Deeds and Hill (1996) study that used 132 firms.

3.2. Measures

Data were collected from secondary sources to construct four primary measures: (1) university linkages, (2) alliance characteristics, (3) R&D investment, and (4) performance. Alliance characteristics and performance had four submeasures each, as explained below.

(a) University linkages had the following three submeasures that were included in this study to highlight the importance of number and quality of these linkages:

1. The *sum total of university linkages*, a measure previously used in the literature (Arora and Gambardella, 1994; Deeds and Hill, 1996).
2. The *number of Research–I university linkages* (Carnegie Foundation, 1996). This measure was derived from the Carnegie Classification of universities. Accordingly, Research-I universities were those institutions that are committed to graduate education and placed a high priority on research. These universities awarded 50 or more doctoral degrees each year and received US$40 million or more in federal support. It was reasoned that the number of Research-I linkages that a firm possessed would be indicative of the number of high-quality research universities with whom the firm interacted.
3. *Total federal R&D funding*. This measure was used because of its wide acceptance in academia as an indicator of the quality of ongoing research programs due to the demanding and prestigious peer-review process of federal funding allocation decisions (NSF, 1996). Federal funding data for the universities was obtained from the NSF (1996). The measure was the sum total of federal R&D funding for all the university linkages of an individual firm.

(b) Alliance characteristics. Consistent with prior research on biotechnology firms, this study defined an alliance as any cooperative relationship between firms to develop or commercialize a new product (Deeds and Hill, 1996; Pisano, 1990; Shan et al., 1994). Data on alliances were obtained from *Recombinant Capital*, a comprehensive database on biotechnology firm alliances (Lerner, 1994) recommended by the BIO. The database listed all the alliances each biotechnology firm had joined since its formation. Thus, all figures for alliance characteristics are cumulative over the life span of the firm. The database also had notations on the type (licensing, joint venture, etc.), purpose (business focus), period (number of years), and size (value in million dollars) of each alliance.

The data collected for the study included all alliances (formal agreements) that the firm has entered into through the end of 1995. This yielded a total of 2457 alliances (cumulative count) that were completed by the 147 firms in the sample. Next, these 2457 alliances were coded to create the following four different submeasures: (a) number of links, (b) type of linkage, (c) content of the linkage, and (d) knowledge flow, as done previously by Hagedoorn and Schakenraad (1994). Two coders with graduate academic training in the life sciences were used to ensure accurate classifications. Coders agreed on their classification of 96.3% of the alliances. For the remaining 3.7%, a third coder (with a PhD degree in pharmacy) cast the deciding vote. Data were then used to develop the following four submeasures:

(1) The *number of linkages* was measured as the total number of alliances, as done previously in the literature (Arora and Gambardella, 1994; Powell et al., 1996).

(2) The *type of linkage* was measured by the ratio of the total number of horizontal linkages to the total number of vertical linkages (Kotabe and Swan, 1995). The log10 value of the ratio revealed a disposition of the firm to enter different types of alliances. Horizontal linkages included joint R&D, patent swaps, technology transfers, and joint ventures that

supplemented a firm's technology base, whereas vertical links included outsourcing and distribution links.

Research suggests that the distinction between horizontal and vertical alliances was necessary because firms gained different benefits from different types of alliances. Horizontal alliances usually give the firm access to resources (Kotabe and Swan, 1995), especially knowledge (Bowie, 1994; Lewis, 1990), that expedited new product development, enhanced the innovativeness of these products, and reduced their development costs (Burnham, 1997). Vertical alliances also reduced the firm's costs through efficient outsourcing. However, they may decrease a company's expertise in the outsourced applications over time. We acknowledge, therefore, that despite their conceptual distinctiveness, sometimes vertical and horizontal linkages may give a firm more or less the same benefits, depending on the organization and management of the alliance. One weakness of our study and prior research in this area, therefore, is that it did not consider how these alliances are organized and managed.

(3) *Content of the linkage* was measured by the technology-to-market alliance ratio. It was defined as the log10 of the ratio between the number of R&D-related linkages and the number of its market-related linkages (Hagedoorn and Schakenraad, 1994). This measure reflected a firm's level of technology inclination and attraction, relative to its interest in marketing skills. By taking the log10 form, equal weights for technology and market links were assumed. A neutral or zero score, therefore, indicated an equal weight for technology and market links, whereas a positive score showed an inclination for a technology-oriented link.

Technological and marketing alliances usually give the firm access to different but complementary types of knowledge (Contractor and Lorange, 1988). While the value of marketing skills and knowledge for success cannot be overstated, the knowledge embedded in a firm's technology (products) is important (Grant, 1998; Teece et al., 1997), especially in science-based industries, where companies need diverse skills and technologies to achieve success. While technology alliances are critical for generating new products or supporting R&D, marketing alliances enable the firm to successfully commercialize such technological advances (Hagedoorn and Schakenraad, 1994). A successful portfolio of technology and marketing-based alliances would therefore have important implications for the success of biotechnology ventures.

(4) *Knowledge flow*, which was measured by the log10 value of the ratio between the number of "generative" linkages and the number of "attractive" linkages, indicated the direction of the knowledge flow (Hagedoorn and Schakenraad, 1994). Generative linkages were collaborative in nature, involving joint R&D with other firms or universities. Attractive alliances involved purchasing and licensing agreements. Generative linkages, which supplied new technology to the firm, were useful in shortening the learning cycle, expediting product development, and reducing R&D costs. These variables can improve company performance (Heuss and Jolly, 1991). These linkages also deepen the firm's mastery of multiple technologies, which is conducive to developing and introducing highly innovative products that are marketed at premium prices and, therefore, can improve company performance.

Attractive alliance linkages, which usually conjoin the technological developments started by several firms, can also enhance a company's performance. A firm can use these linkages to change its products attributes and offer radically new products that are hard for competitors to copy. These innovative products improve the firm's profit margins and overall performance (Buzzell and Gale, 1987). Alternatively, a firm can leapfrog the competition using the knowledge gained from these linkages. Firms that succeed in applying this strategy are usually well positioned to set the rules of competitive rivalry and enjoy superior performance (D'Aveni, 1994). A firm can also exploit its learning by "fusing" different technologies (Kodama, 1995), combining them in a way that serves new segments where the company can maintain its technological and market leadership and achieve high performance[2] (Link and Tassey, 1987).

(c) R&D investment was measured in two ways. The first was absolute value of R&D spending in millions. The second measure was the ratio of a company's total spending on R&D (in million dollars) to the total number of full-time employees, thereby adjusting the R&D spending by company size.

(d) Company performance. The measurement of company performance and the outcomes of firm–university linkages have been the subject of considerable debate (Burnham, 1997; Cyert and Goodman, 1997; Harmon et al., 1997; MacLachlan, 1995). Given the complexity of this construct, four different measures were used in this study. Three of these measures covered the firm's innovative outputs, whereas the fourth captured financial performance, as described below:

(a) The *number of patents* issued to the firm under USPTO Class 930 or 935 was used as a key indicator of an innovative output (Austin, 1993). Despite their shortcomings as a measure of innovation (Grant and Baden-Fuller, 1995), patents captured some of a firm's technological knowledge (Almeida, 1996; Liebeskind et al., 1996). Patents were also highly valued by some of the firm's stakeholders (e.g., suppliers and venture capitalists), because they showed progress in a firm's effort to create new knowledge that one day might result in new goods (or products). Even though not all the knowledge contained in patents yielded new products, some of these patents became a source of revenue when other firms licensed or purchased them. Patents also signalled technological progress by the firm (Grant, 1996).

(b) The *number of products in the market* gauged the success of firms in developing and introducing new products. This measure was among the most widely used indicators of the firm's innovative outputs (Cyert and Goodman, 1997; Deeds and Hill, 1996; Harmon et al., 1997; MacLachlan, 1995).

(c) The *number of products under development* (in preclinical, clinical, FDA approval stages) was used as a third indicator of innovative output and, in general, company performance. It reflected the stock of knowledge-in-progress, which showed a firm's ability to sustain its innovative efforts (Lewis, 1990). These products were viewed as the

---

[2] Firms pursue generative and attractive alliances at the same time. Cohen and Levinthal (1990) point out that a firm cannot generate new knowledge unless it understands the domain of existing knowledge. However, in this study we use a ratio of generative-to-attractive linkages, which helps us avoid the problems resulting from the overlapping between the two measures.

forerunners of a company's future market offerings, and key stakeholders were likely to weigh this variable heavily in determining the company's viability. This measure, which corresponded to Cyert and Goodman's (1997) "intermediate outcomes" of firm–university linkages, was used in evaluating the contributions of these linkages (MacLachlan, 1995).

(d) *Net sales to total assets* was employed as a measure of a company's financial performance. This measure, which showed the firm's ability to generate sales with existing assets, accounted for the sales relative to company size (Wu and Ho, 1997). This ratio was especially important given a firm's need to generate the cash flow to support future R&D. Obviously, this measure has limitations because it can artificially inflate the rate of sales to assets; many young companies would have limited assets. However, since all firms in the sample are publicly traded firms, there were no anomalies with regard to either numerator or denominator being very low thereby skewing the data.

The data for net sales to total assets and R&D spending were collected from Compact Disclosure and were for 1996 only. The figures for the number of products on the market and under development, which came from The 1997 Guides to Biotechnology Companies, were cumulative over the firm's life span and up to the end of 1995.

4. Analysis

Table 1 presents the means, standard deviations, and interrelations for the study's variables. The correlations indicated that as the number of university alliances increased, firms with these links were able to attract more technology-based alliances with other business firms. As the number of university alliances increased, firms pursued more "attractive," rather than "generative," alliances. Firms also entered into more technology-based alliances than marketing alliances. Furthermore, there was a modest positive association ($P < .10$) between the number of university links and the number of products under development. The association between the number of university links and patents was not significant. However, the quality of universities (Carnegie Research-I ties and Federal R&D funding for the university) with which the firms interacted was significantly correlated with company performance, products on the market and products under development.

Multivariate analysis of covariance (MANCOVA) was used to test the study's hypotheses. In this analysis, the university link was treated as the independent variable. MANCOVA made it possible to simultaneously consider multiple dependent variables, thereby accounting for their intercorrelations. Two analyses of covariance (ANCOVAs) were also performed. In the first analysis, the dependent variables included the four performance measures, R&D spending, and total number of links. Firm age and size were entered as covariates.

The second ANCOVA included alliance type, content, and knowledge flow along with the performance measures. This test also attempted to control for university and firm internal competencies. This analysis included firm R&D spending, the number of Research-I linkages, total Federal R&D funding for the universities with which the firm has linkages, and the

Table 1
Descriptive statistics and correlations ($N = 147$)

Variables	Mean(S.D.)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
(1) Net sales/assets	0.40(0.61)	1													
(2) Products in market	1.17(2.19)	.34**	1												
(3) Products under development	3.43(2.35)	−.16†	.15†	1											
(4) Number of university linkages	1.94 (2.35)	−.18*	−.12	.16†	1										
(5) Number of links (alliances)	17.06 (20.21)	.32**	.32**	.38**	.25**	1									
(6) Type of linkage, log (horizontal/vertical)	−0.24 (0.37)	−.14	−.32**	−.03	.01	−.10	1								
(7) Content of linkage, log (technology/marketing)	0.52 (0.37)	−.26**	−.21*	.12	.38**	.07	.13	1							
(8) Knowledge flow, log (generative/attractive)	0.03 (0.35)	−.02	−.15†	−.06	−.18*	−.15†	.36**	.01	1						
(9) Patents (Class 930 and 935)	3.21 (10.49)	.09	.31**	.43**	.12	.51**	.01	−.02	−.03	1					
(10) R&D spending per employee (million dollars)	146.91 (205.68)	−.23**	−.15†	−.02	−.05	−.19*	.02	.05	.06	0	1				
(11) Assets (million dollars)	987.26 (3499.4)	.18*	.57***	.18†	−.06	.78***	−.03	−.14	.15†	.43**	−.17†	1			
(12) Age (years)	9.63 (3.27)	.14†	.34**	.25**	−.02	.20*	−.28**	−.24**	0	.35**	−.11	.03	1		
(13) No. of Research-I links	1.31 (1.83)	−.20*	−.18†	.16†	.93***	.16†	.00	.36***	−.14†	.04	−.04	−.16†	−.03	1	
(14) Federal R&D fund (million dollars)	235.3 (351.7)	−.17*	−.15†	.20*	.87***	.16†	−.06	.36**	−.12	.11	−.06	−.15†	.00	.94*	1

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

Table 2

Presence of university linkages and its effects on firm performance and alliance attributes

(a) ANCOVA and MANCOVA results of university linkages effects on performance (with total number of alliances as dependent variable, $N = 147$)

Dependent variables						
Variables	Net sales/ assets	Patents	Products (market)	Products (development)	Total alliances	R&D spending
Covariates						
Age (years)	0.02**	1.14***	0.16**	0.16**	1.01***	1.65**
Size (assets)	0.00009**	0.003***	0.001**	0.0004**	0.004***	0.12***
Factor						
University link (*absent* = 0, *present* = 1)	– 0.06	– 3.6 *	0.69†	– 0.22	9.19***	– 7.92†
Adjusted R^2 (overall effect)	0.12***	0.31***	0.41***	0.10 *	0.38***	0.96***
Net effects of test variable	Hotelling's trace	Wilk's λ	Pillai's trace	F statistic		
University linkage	0.26	0.80	0.20	4.14***		

(b) ANCOVA and MANCOVA results of university linkage effects on performance (with alliance characteristics as dependent variables, $N = 147$)

Dependent variables							
Variables	Net sales/ assets	Patents	Products (market)	Products (development)	Type	Content	Flow
Covariates							
Age (years)	0.02 *	0.47**	0.15***	0.09	– 0.02 *	– 0.04***	– 0.001
Size (assets)	0.001	0.002***	0.003***	0.003 *	– 0.0006**	– 0.0002	– 0.0001
R&D spending (million dollars)	0.004	0.19***	– 1.69†	0.03**	0.005**	0.0007	0.0006
No. Research-I universities	– 0.09 *	– 2.28 *	– 0.28	0.08	0.11†	– 0.03	– 0.09
Total Federal R&D funding (million dollars)	0.003	0.01 *	0.0005	0.0007	0.0006 *	0.0002	0.0002
Total number of links (alliances)	0.002	0.29***	0.04	0.02	– 0.008†	0.01**	– 0.002
Factor							
University link (*absent* = 0, *present* = 1)	– 0.17 *	– 0.57	0.45	0.81	– 0.19 *	– 0.14†	– 0.19 *
Adjusted R^2 (overall effect)	0.17***	0.70***	0.47***	0.26***	0.23***	0.32***	0.10
Net effects of test variable	Hotelling's trace	Wilk's λ	Pillai's trace	F statistic			
University linkage	0.19	0.84	0.16	2.41 *			

* $P < .05$.

** $P < .01$.

*** $P < .001$

† $P < .10$.

total number of alliances along with age and size as covariates. By doing so, we were able to identify the significance of university linkages after controlling for the firm's as well as the university's competence. Once it was determined that overall MANCOVA was statistically significant, *t* tests were used to test 1 Hypotheses 2a Hypotheses 2b Hypotheses 3 Hypotheses 4 Hypotheses 5 by comparing firms with and without university ties (*presence of linkage* = 1, *absent* = 0) in alliance characteristics, R&D spending, number of new products, patents, and financial performance.

5. Results

5.1. MANCOVA results

Treating university links as the independent variable with company age and size as covariates, MANCOVA was significant ($F = 4.14$, $P < .001$), with Wilks' lambda (λ) of 0.80, Pillai's trace of 0.20, and Hotelling's trace of 0.26. The results, displayed in Table 2a, also showed that company age and size were statistically significant across the dependent variables. The presence of university linkages was significant for the number of alliances and patents (at $P < .05$ or better) and marginally significant for two more dependent variables (products on the market and R&D spending) at $P < .10$.

A second MANCOVA test (Table 2b) indicated that the presence of university linkages had an overall effect across the multiple dependent variables examined. MANCOVA was significant ($F = 2.41$, $P < .05$), with Wilks' lambda (λ) of 0.84, Pillai's trace of 0.16, and Hotelling's trace of 0.19. When we controlled for firm and university internal competencies, the presence of university linkages was significant for three dependent variables (net sales/assets, type of linkage, and knowledge flow), at $P < .05$. The test was also marginally significant for alliance content ($P < .10$).

5.2. Hypothesis 1

As Table 3 shows, the results of the *t* tests support the study's first hypothesis. Firms with university linkages reported significantly more technology alliances than companies without such links. Also, firms with and without university links did not differ significantly in the ratios of horizontal to vertical or generative to attractive alliances. However, firms with university links had a marginally significantly ($P < .10$) higher number of alliances than firms without university links.

5.3. Hypothesis 2

This hypothesis suggested that firms with university linkages will have significantly more new products under development (Hypothesis 2a) and products on the markets (Hypothesis 2b) than firms without these links. Table 3 shows that there were no significant differences among firms with vs. without university links in products either under development or on the

Table 3
Differences in alliances, innovative outputs, and performance: companies with vs. companies without university links

Variables	Companies with links to universities	Companies without links to universities	Mean difference	t value
Total number of links	19.35[a] (18.27)[b]	12.69 (23.33)	6.66	1.87[†]
Log technology/marketing alliances	0.60 (0.37)	0.34 (0.32)	0.26	4.03***
Log horizontal/vertical alliances	– 0.22 (0.38)	– 0.28 (0.34)	0.06	0.88
Log generative/attractive alliances	0.04 (0.37)	0.02 (0.32)	0.02	0.24
Products under development	3.53 (2.31)	3.19 (2.55)	0.34	0.69
Products on the market	1.04 (2.14)	1.50 (2.37)	– 0.46	1.54
Patents	4.68 (12.84)	0.60 (1.32)	4.08	2.24*
R&D spending	131.24 (113.03)	180.48 (319.60)	– 49.24	7.53**
Net sales/total assets	0.32 (0.34)	0.44 (0.61)	– 0.12	– 1.52

[a] Means.
[b] Standard deviations.
* $P<.05$.
** $P<.01$.
*** $P<.001$.
[†] $P<.10$.

market. Though ANCOVA results (Table 2a) indicate some support at the $P<.10$ level, the results do not hold when the analysis controlled for firm and university competencies (Table 2b). However, correlations between number of Research-I linkages and Federal R&D funding to the dependent variables (Table 1) indicate that the quality of linkages could be more important to firm performance outcomes, rather than the mere presence or absence of a university link.

5.4. Hypothesis 3

Biotechnology firms with university linkages were expected to obtain more patents than firms without such linkages. The t test results supported Hypothesis 3, showing that firms with links to universities had significantly more patents than firms without these links ($P<.05$).

5.5. Hypothesis 4

Firms with university linkages were expected to have lower R&D expenses than firms without university linkages. The results supported Hypothesis 4, showing that firms with university linkages spent less (per employee) on R&D than firms without these linkages ($P<.01$).

5.6. Hypothesis 5

This hypothesis suggested that the financial performance of firms with university linkages will be higher than for those firms without such links. There was no statistically significant difference among the firms when the ratio of net sales-to-total assets was considered. However, ANCOVA results (Table 2b), when controlled for firm and university competence, indicated a statistically significant effect of university linkage on firm performance. Also, the number of high-quality university linkages measured by the number of Carnegie Research-I linkages has a significant effect on performance ($P < .05$).

6. Discussion

The benefits a business firm might gain from establishing links with universities have been the subject of interest in the literature (Cyert and Goodman, 1997; Eisenberg, 1996; Sage, 1996). Despite their growing popularity, the contributions of these linkages to the innovative outputs and performance of business companies have not been well documented. This study sought to fill this gap in the literature. The results of the study are summarized and discussed below.

6.1. Hypothesis 1

Results from Hypothesis 1 show that firms with university linkages enter into more business alliances than firms without such links. Perhaps these links serve as a magnet that draws technology alliance partners to join alliances with other firms. These technology alliances can improve the firm's knowledge base and competence, which can increase a firm's chances of survival. These alliances can give the firm access to emerging technologies that can be used to upgrade existing skills or venture into new fields, thus setting the stage for future growth and profitability (Teece et al., 1997).

But why do firms with university links develop more alliances than firms without these links? Given the nature of the data, we can only speculate that firms that develop these links may be more technologically proficient in their industry and, therefore, attract additional alliances. It is also possible that biotechnology firms continue to struggle with the accumulation of their technological competencies, and therefore may not pursue marketing alliances as vigorously. Of course, the results might reflect the current stage of the biotechnology industry's life cycle, where emphasis centers on creating products. As the industry becomes more established, attention will shift to gaining marketing competencies through alliances with other firms and universities. These possibilities should be examined in future empirical research.

6.2. Hypothesis 2

The number of university linkages is marginally associated (r=.16, $P < .10$) with products under development but not with products on the market. This suggests that university linkages can help some biotechnology firms emerge from an incubator stage by attracting technology and getting more products into development. However, the more powerful statistical tests performed on this hypothesis did not support these findings. Since ANCOVA considers the presence (or absence) of university linkages rather than the absolute number of university linkages, some of the university linkages may be critical to product development, while others may serve to bring in new knowledge that may not directly translate into products under development.

The results do not show a relationship between products on the market and number of university linkages, probably because the drug development process is lengthy, complex, and has several stages (Liebeskind et al., 1996), and the chances that any product that is in preliminary research will reach the market is about 1 in 1000 (BIO, 1996). With such a small product success rate, there is less chance of obtaining a statistically significant association between university linkages and the biotechnology products introduced to the market. Biotechnology firms, in general, have not been successful in commercializing their new products (BIO, 1996). Also, as firms come close to developing a product, they are likely to distance themselves from universities to increase appropriability and reduce royalty payments (Recombinant Capital, 1996). The results also highlight the importance of quality of the university with whom the firm interacts. There is a significant correlation between the university's Federal R&D funding and the products under development. But the correlation coefficient turns negative with products on the market (at $P < .10$), thereby supporting our earlier discussion of appropriability concerns.

6.3. Hypotheses 3 and 4

The hypothesized relationships with the number of patents or innovativeness (Hypothesis 3) and R&D cost savings (Hypothesis 4) are supported. The results show that firms with university ties have significantly more patents and spend a significantly lower amount on R&D spending than firms without these linkages. These combined efficiencies may arise from cost sharing in equipment (Lewis, 1990), pooling of scientific talent, and sharing of information through social networks (Bowie, 1994; Liebeskind et al., 1996; Oliver and Liebeskind, 1998), especially where knowledge is more likely to be tacit (Cohen and Levinthal, 1990). These variables can give a firm significant strategic advantage in cost efficiencies and competitive positioning. Noteworthy are the significant effects of the quality of university ties on innovative output (Table 2b). The number of research university ties and the Federal R&D funding are indicative of the quality of the firm's linkages in its ability to attract useful, innovative knowledge.

The above results support the strategic importance of developing links between business firms and universities. Firms that develop these links have significantly higher numbers of patents, which are a major source of market value in the industry (Zahra, 1996). Furthermore, given the youth of the biotechnology industry, patents represent a milestone in a firm's quest for building a technology-based alliance. Patents are also important indicators of the accumulation of knowledge, which is a prerequisite to future successful product development and commercialization (Almeida, 1996; Grant and Baden-Fuller, 1995).

The finding that firms with university links have lower R&D spending than firms without these links suggest multiple interpretations. For example, firms with such links have a lower base of R&D spending than firms without these links. Consequently, firms with lower R&D spending will be motivated to enter university alliances to defray overhead and other administrative costs. Alternatively, university links may offer advantages to participating firms, thereby lowering R&D costs. These rival explanations should be considered in future studies to determine the ways in which business–university alliances effectively reduce the firm's R&D spending. For the time being, however, the results show that biotechnology firms with university links report lower R&D spending than those without such links.

From a managerial perspective, the fact that there are significant differences in new products and patents between firms with linkages with universities and those without those linkages is interesting. If the firm's strategy centers on increasing innovation, then establishing linkages with universities is one approach to reach this goal. Product innovation is widely viewed as an important strategic priority in the biotechnology industry (Zahra, 1996). Another way a firm can leverage the benefits it gains from these linkages is to use patents to enter into other alliances with firms in the industry (Teece et al., 1997) or simply license its technologies. The firm may also use patents defensively and preempt competitors from entry. Finally, the finding that firms with links report lower R&D spending has some strategic implications. Given that the cost of R&D is one of the key components of the firm's pricing structure, lower R&D costs can be used to lower prices and build the firm's market share. Lower R&D costs can allow the firm to focus on supporting the development of other functional skills, such as operations and marketing.

6.4. Hypothesis 5

The data do not support the performance effects of university linkages. Contrary to expectations, the results show that firms with university ties do not have any significantly higher net sales-to-assets ratio than biotechnology companies without these links. However, given the nature of the secondary data used in this research, it is possible that companies with strong financial track records do not seek alliances with universities. Firms seeking such ties with universities may be offsprings of university-based scientific talent. Indeed, it is not uncommon to see scientists and professors leave university employment to start their own firms when a chemical compound or genetic strain has been isolated (Roberts, 1991). However, scientists prefer to maintain university ties to share ongoing research results as well as maintain access to the scientific knowledge pool (Audretsch and Stephan, 1996). These fledgling firms are likely to be located in research parks and have virtually no sales, other having a lower sales-to-assets ratio than independent ventures with established product lines. Our study did not distinguish between firms based on locational factors (Audretsch and Stephan, 1996) or participation in a research park or incubator (Mian, 1994, 1996), which should be examined in future research. Given that the study's performance measure was lagged by only 1 year, future researchers should consider a longer time frame in establishing the effect of university linkages on company financial performance. It is possible that university linkages improve company financial performance but these improvements might not have materialized in the current sample because of the study's short time frame.

One of the study's surprising findings is that the hypotheses for the performance variables (products under development, products on the market, and financial performance) were not supported, whereas the hypotheses on intermediate outcomes were supported. As we have just noted, the short time lag related to performance variables might account for this. Companies might have gained the skills to develop new products, but have not yet mastered the skills associated with marketing them and making a profit. As stated earlier, commercialization remains a major problem facing many biotechnology companies. It is also possible that firms are making sacrifices in the short term hoping to cash in on their discoveries later. Alternatively, companies in the sample are investing heavily in managing their alliances by devoting money for administrative overhead while investing less in their R&D, whereas their counterparts without university links may not have to make these tradeoffs. These explanations require further analysis in future research.

6.5. Limitations

The findings on increased innovative activity combined with a reduction in R&D costs are preliminary and should be interpreted with caution because of the study's shortcomings. The study's cross-sectional design makes it difficult to establish casual relationships among the variables. Further, although the Carnegie classification and Federal funding measured the quality of firm–university linkages, the study did not measure the quality and nature of interactions between the firm and the university. The quality of the linkages, however, can spell the difference between success and failure in knowledge transfer and utilization (Arora and Gambardella, 1994; Oliver and Liebeskind, 1998) or attaining competitive advantage (Harmon et al., 1997). Also, while there are several important benefits for single industry studies, the fact that this research was conducted in the biotechnology industry might limit the generalizability of findings to other industries or even other sectors of the industry.

Another limitation of this study is the exclusion of privately held firms and those firms that belong to a university incubator or research park system. By excluding these firms, we have narrowed the scope of the important payoffs of university linkages. Many high-technology spin-offs reside in these parks but remain privately held, a factor which makes access to alliance or performance data difficult. Mian (1997) identifies several potential problems in this regard, including selection bias, lack of control variables, and poor data sources. Though university incubators are an important source for technology-based entrepreneurship (Roberts, 1991), data availability clearly restricted the scope of our study. Also, given the dynamic evolution of the biotechnology industry, the results might capture relationships among variables of interest at only one point in time. The study did not explore the differences in firms' ability to manage their university alliances and how these differences might affect a company's innovative and financial performance. Companies need to develop those skills that will enable them to manage these alliances effectively, and the current study did not examine this issue. Finally, the study did not consider firms' motives for entering into linkages with universities; these goals can determine the outcomes of these linkages. The secondary data used did not allow us to distinguish different types of linkages. Still, the results have several implications for effective managerial practice and future research.

6.6. Implications for managerial practice

One key message from this study is that linkages with universities are positively associated with a firm's innovative outputs. Given the crucial value of innovation for survival in the biotechnology industry, these preliminary results suggest that some business firms can benefit from developing and effectively managing linkages with universities. While these relationships can be costly and challenging, they can be strategically valuable in terms of the firm's innovative outputs.

Though the number of high-quality university linkages influences innovative output, there are no guarantees that these benefits will materialize. Therefore, managers need to evaluate the risks and rewards of linkages with universities by examining the skills and capabilities they might bring to the alliance. This can be achieved by considering the composition and capabilities of the faculty and staff, institutional culture and bureaucracy, prior experiences with other business firms, available research space and equipment, and the importance the university attaches to its linkage with the company. Companies should also evaluate these variables as they determine whether or not to formalize these links. In evaluating the merits of these alliances, however, executives need to recognize their importance in connecting the firm with other companies in pursuit of innovation, as indicated by the increased number of patents the firm might obtain.

Managers should be aware that linkages with universities may not positively impact their companies' short-term performance. Indeed, these linkages are not significantly associated with short-term financial performance. The costs associated with managing these alliances and the possible tradeoffs between covering the costs of managing alliances, while reducing R&D costs, are potential explanations of the insignificant results observed here. These results highlight the need for managers to carefully evaluate the contributions of linkages with universities, realizing that they may not pay off in the short term.

6.7. Implications for future research

The results also suggest several issues to be considered in future studies. One area for future research is to examine biotechnology firms which are members of UBTIs or research parks and are not publicly traded. Future research should establish whether or not the results reported in the current paper apply to them. As stated earlier, publicly traded firms may pursue goals that differ from those achieved by firms that are not traded publicly.

There is a need to examine the nature, quality and duration of firm–university linkages in theorizing about their effect on a firm's innovative outputs and financial performance. Universities may structure their relationships differently with different firms (ranging from collaborative R&D to patent licensing), a factor which suggests that the attributes of this relationship can significantly impact its results. Accounting for, and incorporating, these attributes can therefore enrich future theory building and provide a solid empirical basis to assess the results of firm–university linkages.

Another issue is why some firm–university linkages are successful and others are not. The attributes, context, and management of these relationships can determine whether or not they succeed in improving a company's innovative outputs and financial performance (Cyert and Goodman, 1997). Researchers, therefore, need to study these key variables and establish their relative contributions to the results of firm–university relationships, measured by innovative outputs and financial performance.

The dynamic nature of the relationships between the variables examined in this paper should be explored in future studies. Absorptive capacity and new product development, for example, are path-dependent activities (Cohen and Levinthal, 1990; Zahra and George, 2000), where future success depends on the firm's past achievements. The dynamism of science-based industries, along with the path-dependent relationships just noted, suggests a need for longitudinal research designs that permit the application of causal modeling techniques to establish the direction and strength of the relationships among the study's variables.

As noted previously, our knowledge of the differences in scope, goals, operations, and management of university–business alliances is limited. Therefore, we were compelled to rely heavily on prior findings from research on business-to-business alliances. To move the literature forward, we need studies that compare these two different types of alliances and establish where they are different and where they are similar. These studies would help to clarify when and how university–business alliances create competitive advantages for participating firms. Toward this end, it would be useful to gauge the objectives of both firms and universities from developing these linkages.

Another area that deserves attention in future research is the effect of university–business alliances on a company's performance. Individual measures of financial performance have serious weaknesses, and the use of multiple measures can provide a more realistic view of the effect of alliances on the multiple indicators of company performance. Therefore, we would like to encourage future researchers to consider multiple financial measures to establish the efficacy of these alliances. Longitudinal designs would further improve our appreciation of the contributions of these alliances to companies' performance over time.

The formation and payoff from alliances, including those developed between universities and firms, can be explained using a variety of perspectives (Contractor and Lorange, 1988). In this paper, we relied heavily on the strategic choice perspective. To better explain the formation of these alliances, future researchers need to consider and integrate multiple perspectives (Osborne and Hagedoorn, 1996). Such integration can help to explain how alliances (particularly the linkages created by universities and business firms) enhance performance. For example, the use of the legitimacy and institutional perspectives can help to show why these linkages come into existence in the first place. The strategic perspective can clarify the reasons why linkages are structured differently and the conditions under which they can add value to the firm's innovative and financial performance. The learning perspective can explain the various types of knowledge to be gained from these linkages.

Business firms and universities are under considerable pressure to cooperate by joining forces and developing alliances beneficial to both parties. Universities are under pressure from the general public to become more involved in the lives of their communities. Students are also pressuring universities to provide them with opportunities to hone their skills. Businesses are under mounting pressure because of the intense competitive conditions in their industries. Competitors are becoming more and more agile and innovative. Customers are more demanding and products are growing in complexity. These pressures have served to bring more and more universities and business firms into collaborative linkages. This is especially the case in science-based industries, such as biotechnology, where technological change is rapid and the need to acquire multiple competencies is great. In an era of limited resources, these linkages can give universities revenues that allow the vigorous pursuit of cutting-edge research. Universities and companies can benefit from entering and supporting such mutually beneficial alliances.

7. Executive summary

In recent years high-technology companies have developed close links with universities. These links are important for developing and transferring new technology as well as the creation of new products and goods. Links with business firms are also an important source of revenues and new knowledge for some universities. Links with leading universities in particular serve other important purposes, such as improving a firm's reputation and increasing its access to key sources of innovation. These links can connect business firms to sources of information about new scientific discoveries. Though challenging, costly and time consuming, these links can give the firm important competitive advantages that improve their markets. Understandably, more and more companies have actively sought to establish links with universities.

The growing links between universities and businesses have attracted some scholarly attention. Researchers have examined the organizational and political challenges that companies and universities face in building mutually beneficial alliances. Researchers have also studied the obstacles to the effective transfer of technologies developed from these alliances. Even though this research has enriched our understanding of the contributions of business–university links, some basic questions remain unanswered. Do these links improve the business firm's performance? Do they enhance the firm's ability to develop and introduce new products to the market? Do they increase its ability to obtain patents? How do these links impact a business firm's spending on R&D? This study seeks to answer these questions.

Using data from publicly traded biotechnology companies in the US, this study finds that firms with established links to universities ($n=97$) surpass firms without such links ($n=50$) in the number of their patents and had significantly lower R&D spending than firms without these links. These results indicated that links with universities might serve as a substitute for expensive in-house R&D spending. While other causes of lower R&D spending are possible, this interpretation was reinforced by the finding that companies with university links were able to attract more technology alliance partners. These links can enhance the firm's technological innovations without the need for expensive in-house R&D.

The results also show that, as anticipated, links with universities can enhance product development and other key indicators of a company's innovative outputs such as patents. However, we did not find statistically significant differences in financial performance (measured by the ratio of net sales to assets) between firms with university linkages and those without these linkages. Results also indicated that the quality of university linkages (measured as Carnegie Research-I University and Federal R&D funding for universities) significantly influence the performance outcomes of these alliances. Given the complex organizational and operational issues that arise in the course of developing and managing university and business alliances, managers need to study the merits and limitations of these linkages. Managers should not simply follow other companies seeking these linkages; instead, they should evaluate potential partners and develop the structure that best suits their firm's situation. Linkages with universities are costly because they can raise administrative overhead. Success in these linkages requires the firm to develop specific managerial and administrative competencies, which is a time-consuming process. Companies that do not have these skills may not fully gain the benefits associated with these linkages. Indeed, companies can benefit from these links by gaining significant strategic advantages, especially in terms of innovative outputs. These results should be interpreted and used with caution because our analyses focused on publicly traded biotechnology companies that were not members of university incubators or research parks and, therefore, may not apply to privately held firms. Clearly, our results indicate that links with universities (especially those with a strong research mission) can be strategically beneficial to publicly traded biotechnology companies.

Acknowledgements

We acknowledge the constructive comments of two JBV reviewers, Anson Seers, William Dewey, Dennis Garvis, James C. Hayton, and Patricia H. Zahra. The first author was affiliated with Syracuse University when this article was written. He gratefully acknowledges the support of the Entrepreneurship and Emerging Enterprises Program at Syracuse University. The second author acknowledges with much appreciation the support of the College of Business Administration at Georgia State.

References

Abetti, P., Stuart, R., 1985. Entrepreneurship and technology transfer: key factors in the innovation process. In: Sexton, D., Smilor, R. (Eds.), The Art and Science of Entrepreneurship. Balliger, Cambridge, M.A. pp. 1181–1210.

Afuah, A., 1998. Innovation Management: Strategies, Implementation, and Profits. Oxford Univ. Press, New York, NY.

Allen, D., 1985. Creating Jobs by Creating New Businesses: The Role of Business Incubators. National Council for Urban Economic Development, Washington, DC.

Almeida, P., 1996. Knowledge sourcing by foreign multinationals: patent citation analysis in the US semiconductor industry. Strategic Manage. J. 17, 155–165 (Winter).
Argyres, N., Liebeskind, J., 1998. Privatizing the intellectual commons: universities and the commercialization of biotechnology. J. Econ. Behav. Organ. 35 (4), 427–454.
Arora, A., Gambardella, A., 1994. Evaluating technological information and using it. J. Econ. Behav. Organ. 24, 91–114.
Audretsch, D., Stephan, P., 1996. Company–scientist locational links: the case of biotechnology. Am. Econ. Rev. 86 (3), 641–652.
Austin, D.H., 1993. An event–study approach to measuring innovative output: the case of biotechnology. Am. Econ. Rev. 83 (2), 253–258.
Association of University Technology Managers (AUTM), 2000. Licensing Survey FY 1999. AUTM, Norwalk, CT.
Barney, J., 1991. Firm resources and sustained competitive advantage. J. Manage. 17, 771–792.
Bartmess, A., Cerny, K., 1993. Building competitive advantage through a global network of capabilities. Calif. Manage. Rev. 35 (2), 78–103.
Bell, E., 1993. Some current issues in technology transfer and academic industrial relations: a review. Technol. Anal. Strategic Manage. 5 (3), 307–321.
Biotechnology Industry Organization (BIO), 1996. The Editors and Reporters Guide to Biotechnology, second ed. Biotechnology Industry Organization, Washington, DC (http://www.bio.org.).
Blair, D., Hitchens, D., 1998. Campus Companies — UK and Ireland. Ispwich Book, Great Britain.
Blau, J., 1999. Telecom R&D binds French tech park to Georgia Tech. Res.-Technol. Manage. 42 (1), 5–7.
Blumenthal, D., 1994. Growing pains for new academic/industry relationships. Health Aff. 13 (3), 176–193.
Bolton, R., 1995. A broader view of university–industry relationships. SRA J. 26 (3,4), 45–47.
Bower, D., 1992. Company and Campus Partnership. Routledge, New York.
Bowie, N., 1994. University–Business Partnerships: An Assessment. Rowman and Littlefield, Lanham, MD.
Brannock, J.C., Denny, A.M., 1998. Basic guidelines for university–industry research relationships. SRA J. 30 (1/2), 57–62.
Burnham, J., 1997. Evaluating industry/university research linkages. Res.-Technol. Manage. 40 (1), 52–55.
Buzzell, R., Gale, B., 1987. The PIMS Principles: Linking Strategy to Performance. The Free Press, New York, NY.
Cabral, R., Dahab, S.S., 1998. Science parks in developing countries: the case of BIORIO in Brazil. Int. J. Technol. Manage. 16 (8), 726–739.
Carayannis, E., Rogers, E., Kurihara, K., Albritton, M., 1998. High-technology spin-offs from government R&D labs and research universities. Technovation 18, 1–11.
Carnegie Foundation, 1996. University and Higher Education Classification. Carnegie Foundation Press, New Jersey.
CASSIS/ASSIST, 1991. Index to patent classification. US Patent and Trademark Office. http://www.uspto.gov.
Ceccagnoli, M., Arora, A., Cohen, W., Vogt, W., 1998. R&D, knowledge spillovers, and competition among firms with asymmetric technological capabilities. Working Paper. Heinz School of Public Policy and Management, Carnegie Mellon University.
Cohen, W., Levinthal, D., 1990. Absorptive capacity: a new perspective on learning and innovation. Adm. Sci. Q. 35, 128–152.
Compact Disclosure. SEC Filings and Company Information. http://www.disclosure.com/.
Contractor, F., Lorange, P., 1988. Competition vs. Cooperation: A Benefit/Cost Framework for Choosing Fully-owned Investments and Cooperative Relationships. Manage. Int. Rev. 28, 5–18 (Special issue).
Cukor, P., 1992. How GTE laboratories evaluates its university collaborations. Res.-Technol. Manage. 35 (2), 31–37.
Cyert, R.M., Goodman, P.S., 1997. Creating effective university–industry alliances: an organizational learning perspective. Organ. Dyn. 25 (4), 45–57.
Dahlstrand, A., 1997. Growth and innovativeness in technology-based spin-offs. Res. Policy 26, 331–344.

D'Aveni, R., 1994. Hypercompetition: The Dynamics of Strategic Maneuvering. Basic Books, New York, NY.
Deeds, D.L., Hill, C.W., 1996. Strategic alliances and the rate of new product development: an empirical study of entrepreneurial biotechnology firms. J. Bus. Venturing 11, 41–55.
Deeds, D.L., Hill, C.W.L., 1998. An examination of opportunistic action within research alliances: evidence from the biotechnology industry. J. Bus. Venturing 14, 141–163.
Dodgson, M., 1992. Technological collaborations: problems and pitfalls. Technol. Anal. Strategic Manage. 4 (1), 83–88.
Dorfman, N.S., 1983. Route 128: the development of a regional high-technology economy. Res. Policy 12 (6), 299–316.
Eisenberg, R., 1996. Public research and private development: patents and technology transfer in government-sponsored research. Va. Law Rev. 82, 1663–1727.
Etzkowitz, H., 1998. The norms of entrepreneurial science: cognitive effects of the new university–industry linkages. Res. Policy 27 (8), 823–833.
Fryxell, G., 1990. Multiple outcomes of product R&D: profitability under different strategic orientations. J. Manage. 16 (3), 633–646.
Geisler, E., 1995. Industry–university technology cooperation: a theory of inter-organizational relationships. Technol. Anal. Strategic Manage. 7 (2), 217–229.
Geisler, E., Furino, A., Kiresuk, T.J., 1990. Factors in the success or failure of industry–university cooperative research centers. Interfaces 20 (6), 99–109.
George, G., Zahra, S., Wheatley, K., Khan, R., 2000. The effects of alliance portfolio characteristics and absorptive capacity on performance: a study of biotechnology firms. Presentation at the Academy of Management National Meeting, Toronto.
Gluck, M., Blumenthal, D., Stoto, M., 1987. University–industry relationships in the life sciences: implications for students and post-doctoral fellows. Res. Policy 16, 327–336.
Grant, R.M., 1996. Prospering in dynamically-competitive environments: organizational capability as knowledge integration. Organ. Sci. 7 (4), 375–387.
Grant, R.M., 1998. Contemporary Strategy Analysis, third ed. Blackwell, New York, NY.
Grant, R.M., Baden-Fuller, C., 1995. A knowledge-based theory of inter-firm collaboration. Academy of Management. Best Papers, Proceedings, 17–21.
Gulati, R., 1998. Alliances and networks. Strategic Manage. J. 19 (4), 293–317.
Hagedoorn, J., 1993. Understanding the rationale of strategic technology partnering: interorganizational modes of cooperation and sectoral differences. Strategic Manage. J. 14 (5), 371–385.
Hagedoorn, J., Schakenraad, J., 1994. The effects of strategic technology alliances on company performance. Strategic Manage. J. 15, 291–309.
Hairston, D., Crabb, C., Cooper, C., Kamiya, T., 1998. Sticky issues for corporate–university R&D alliances. Chem. Eng. 105 (6), 39–43.
Hamel, G., Prahalad, C., 1994. Competing for the future. Harv. Bus. Rev. 721 (4), 122–128.
Hamilton, J.O., 1996. Commentary: measuring biotech by patents is patently absurd. Bus. Week 22, p. 47 (April 22).
Harmon, B., Ardishvili, A., Cardozo, R., Elder, T., Leuthold, J., Parshall, J., Raghian, M., Smith, D., 1997. Mapping the university technology transfer process. J. Bus. Venturing 12, 423–434.
Henderson, R., Cockburn, I., 1994. Measuring competence: exploring firm-effects in pharmaceutical research. Strategic Manage. J. 15, 63–84.
Heuss, V., Jolly, V.K., 1991. Commercializing multi-faceted technology through partnerships. Int. J. Technol. Manage. 6 (1), 59–74.
Hisrich, R., Smilor, R., 1988. The university and business incubation: technology transfer through entrepreneurial development. J. Technol. Transfer 13 (1), 14–19.
Hsu, D., Bernstein, T., 1997. Managing the university technology licensing process: findings from case studies. J. Assoc. Univ. Technol. Managers 8, 1–14.

Jasso, G., 1996. Finding Corporate Resources. Corwin Press, Thousand Oaks, CA.
Kodama, F., 1995. Emerging Patterns of Innovation: Sources of Technology Licensing in the Development of Global Product Strategy: Conceptual Framework and Research Propositions. Harvard Business School Press, Boston, MA.
Kogut, B., 1988. Joint ventures: theoretical and empirical perspectives. Strategic Manage. J. 9, 319–332.
Kotabe, M., Swan, K.S., 1995. The role of strategic alliances in high-technology new product development. Strategic Manage. J. 16, 621–636.
Kuhlman, G.A., 1996. Alliances for the future: cultivating a cooperative environment for biotech success. Berkeley Technol. Law J. 11 (2), 311–362.
Kuratko, D., LaFollette, W., 1987. Small business incubators for local economic development. Econ. Dev. Rev. 59 (2), 44–55.
Lee, Y.S., 1996. "Technology transfer" and the research university: a search or the boundaries of university–industry collaboration. Res. Policy 25 (6), 843–863.
Leonard-Barton, D., 1995. Wellsprings of Knowledge. Harvard Business School Press, Boston, MA.
Lepkowski, W., 1996. US R&D vulnerable: needs more federal, industry, university alliances. Chem. Eng. News 74 (17), 30–33.
Lerner, J., 1994. The importance of patent scope: an empirical analysis. Rand J. Econ. 25 (2), 319–333.
Lewis, G., 1990. Partnerships for Profit: Structuring and Managing Strategic Alliances. The Free Press, New York, NY.
Liebeskind, J.P., Oliver, A.L., Zucker, L., Brewer, M., 1996. Social networks, learning and flexibility: sourcing scientific knowledge in new biotechnology firms. Organ. Sci. 7 (4), 428–443.
Link, A., Tassey, G., 1987. Strategies for Technology-Based Competition. Lexington Books, Lexington, MA.
Lumpkin, G., Dess, G., 1996. Clarifying the entrepreneurial orientation and linking it to performance. Acad. Manage. Rev. 21, 135–172.
MacLachlan, A., 1995. Trusting outsiders to do your research: how does industry learn to do it? Res.-Technol. Manage. 38 (6), 48–53.
Matkin, G., 1990. Technology Transfer and the University. McMillan, New York, NY, pp. 240–274.
McGee, M.K., 1996. IS creates 'farm teams' — University–business alliances ensure ready pool of talented recruits. Inf. Week, p. 120 (September 30).
Melcher, R., 1998. An old university hits the high-tech road. Bus. Week 3593, 94–96.
Merrifield, B., 1987. New business incubators. J. Bus. Venturing 2 (4), 277–284.
Meyer-Krahmer, F., Schmoch, U., 1998. Science-based technologies: university–industry interactions in four fields. Res. Policy 27 (8), 835–851.
Mian, S.A., 1994. US university sponsored technology incubators: an overview of management, policies, and performance. Technovation 14 (8), 515–528.
Mian, S.A., 1996. Assessing value-added contributions of university technology business incubators to tenant firms. Res. Policy 25 (3), 325–336.
Mian, S.A., 1997. Assessing and managing the university technology business incubator: an integrative framework. J. Bus. Venturing 2, 251–285.
Morris, D., Hergert, M., 1987. Trends in international collaborative arrangements. Columbia J. World Trade 22 (2), 15–21.
Nimtz, L.E., Coscarelli, W.C., Blair, D., 1995. University–industry partnerships: meeting the challenge with a high tech partner. SRA J. 27 (2), 9–17.
NSF, 1996. Academic Science: R&D Funds, Scientists and Engineers, Graduate Enrollment and Support. National Science Foundation Press, Arlington, VA (NSF 84-322).
NSF, 1998. Industry Trends in Research Support and Links to Public Research. National Science Foundation Press, Arlington, VA.
Oliver, A., Liebeskind, J., 1998. Three levels of networking for sourcing intellectual capital in biotechnology: implications for studying interorganizational networks. Int. Stud. Manage. Organ. 27 (4), 76–103.
Osborne, R., Hagedoorn, J., 1996. The institutionalization and evolutionary dynamics of interorganizational alliances and networks. Acad. Manage. J. 40 (2), 261–278.

Pennings, J., Barkema, H., Douma, S., 1994. Organizational learning and diversification. Acad. Manage. J. 37 (3), 608–640.

Peters, L., Groenewegen, P., Fiebelkorn, N., 1998. A comparison of networks between industry and public sector research in materials technology and biotechnology. Res. Policy 27, 255–271.

Pfeffer, J., Nowak, P., 1976. Joint ventures and interorganizational interdependence. Adm. Sci. Q. 21, 398–418.

Piercey, L., 1998. Go team, Go! University licensing and technology transfer. Signals: The online magazine for biotechnology industry analysis. June 23. http://www.signalsmag.com/.

Pisano, G.P., 1990. The R&D boundaries of the firm: an empirical analysis. Adm. Sci. Q. 35, 153–176.

Powell, W.W., Koput, K.W., Smith-Doerr, L., 1996. Interorganizational collaboration and the locus of innovation: networks of learning in biotechnology. Adm. Sci. Q. 41, 116–145.

Powers, D., Powers, M., Betz, F., Aslanian, C., 1988. Higher Education in Partnership with Industry. Jossey-Bass Publishers, San Francisco.

Prevezer, M., 1997. The dynamics of industrial clustering in biotechnology. Small Bus. Econ. 9 (3), 255–271.

Recombinant Capital, 1996. Targeting university technology. Edwards, M. (Ed). http://www.recap.com/.

Roberts, E., 1968. A basic study of innovators: how to keep and capitalize upon their talents. Res. Manage. 11 (4), 249–266.

Roberts, E., 1991. Entrepreneurs in High Technology — Lessons from MIT and Beyond. Oxford University Press, New York, NY.

Sage, W., 1996. Funding fairness, public investment, proprietary rights, and access to healthcare technology. Va. Law Rev. 82, 1737–1752.

Shan, W., 1990. An empirical analysis of organizational strategies by entrepreneurial high-technology firms. Strategic Manage. J. 11, 129–139.

Shan, W., Walker, G., Kogut, B., 1994. Interfirm cooperation and startup innovation in the biotechnology industry. Strategic Manage. J. 15, 387–394.

Slaughter, S., 1990. The High Learning and High Technology. State University of New York Press, Albany, NY.

Smilor, R., Gibson, D., Dietrich, G., 1990. University spin-out companies: technology start-ups at UT-Austin. J. Bus. Venturing 5, 63–76.

Teece, D.J., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Strategic Manage. J. 18 (7), 509–553.

Thayer, A., 1997. Universities join economic growth. Chem. Eng. News, pp. 21–24 (June 30).

The 1997 GEN Guides to Biotechnology Companies. Mary Ann Liebert, Larchmont, NY. http://www.genengnews.com/.

Thuemer, K.E., 1997. Maximum R&D. World Trade 10 (4), 70–78.

Trune, D., 1996. Comparative measures of university licensing activities. J. Assoc. Univ. Technol. Managers 7, 1–13.

Udell, G., 1990. Are business incubators really creating new jobs by creating new business and new products? J. Prod. Innovation Manage. 7 (2), 108–122.

Webster, A., 1994. University–corporate ties and the construction of research agendas. Sociol.: J. Br. Sociol. Assoc. 28 (1), 123–142.

Williamson, O., 1985. The Economic Institution of Capitalism. The Free Press, New York, NY.

Wu, C., Ho, S.K., 1997. Financial ratio adjustment: industry-wide effects or strategic management? Rev. Quant. Finance Account. 9, 71–88.

Zahra, S., 1996. Technology strategy and performance: a study of corporate-sponsored and independent biotechnology ventures. J. Bus. Venturing 11 (4), 289–321.

Zahra, S., George, G., 1999. Manufacturing strategy and new venture performance: a comparison of independent and corporate ventures in the biotechnology industry. J. High Technol. Manage. Res. 10 (2), 313–345.

Zahra, S., George, G., 2000. Absorptive capacity: a review and reconceptualization. Best Paper Proceedings of the Academy of Management National Meeting, Toronto.

Zucker, L., Darby, M., Armstrong, J., 1998. Geographically localized knowledge: spillovers or markets. Econ. Inq. 36, 65–86.