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The Affordable Resources strategy and the Milieux Embeddedness strategy as alternative approaches to facilitating innovation in a knowledge-intensive industry

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Abstract

The paper reports the results of an original empirical field study of firms in a knowledge-intensive technology industry, the biotechnology industry. Data on the firms are compared with data on firms in related fields, including medical devices, pharmaceuticals, and other sectors of bioscience technology. The relative roles of interorganizational relationships, locational attractiveness, and research and development (R&D) intensity, as determinants of performance, are examined. It is found that firms whose people engage in high levels of informal interorganizational communication perform better than other firms but only when they also exhibit high levels of R&D intensity. The paper concludes that a Milieux Embeddedness strategy will be superior to an Affordable Resources strategy as a basis for managing innovation in knowledge-intensive technology firms.

Keywords: Innovation; Industry; Knowledge; Affordable Resources strategy; Milieux Embeddedness strategy

1. Introduction

In this paper, I examine two alternative types of strategies by which innovation may be managed in knowledge-intensive technology enterprises. The first type of strategy—which I call the Affordable Resources strategy—emphasizes the idea that a technological enterprise may grow more successfully by choosing to locate in a region that enables the enterprise to reduce its cost of doing business and to operate without the burden of an onerous regulatory regime. The second type of strategy—which I call

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the Milieux Embeddedness strategy—instead emphasizes the idea that a technological enterprise may better thrive by immersing itself in a healthy local technological milieu characterized by rich interpersonal and interorganizational communication and collaboration. I also examine whether the relative power of these two types of strategies may vary according to the intensity with which the enterprise engages in research and development (R&D) activities. In this paper, R&D intensity is treated as a proxy for knowledge intensity. Because of its widely touted status as a preeminently R&D-intensive industry, dominated by knowledge-intensive enterprises, the biotechnology industry is employed in this paper as an empirical context for comparing the two types of strategies.

2. Themes in strategy and technological innovation

The academic literature on the theme of managing technological innovation that has appeared during the last two decades contains at least several subthemes of discourse: the role of technological competitiveness, the importance of place, the importance of interorganizational relationships, and the importance of knowledge intensity as a dimension of business.

2.1. Technological competitiveness

The concern of business scholars during the 1980s with the theme of competitiveness—stimulated by the publication of Porter's extremely influential books on "competitive strategy" (Porter, 1980) and "competitive advantage" (Porter, 1985)—was, and continues to be, nurtured by a growing awareness that technological innovation is a significant factor affecting the relative competitiveness of firms (e.g., Clark, Hayes, & Lorenz, 1985; Dermer,1986; Dosi, 1984; Furino, 1988; Leonard-Barton, 1995; Link & Tassey, 1987; Swann, 1993; Utterback, 1994). Much of the research was focused on entrepreneurial technology firms and entrepreneurial technology strategy (see Roberts 1991; Romanelli 1987; Teece, 1987).

During the 1990s, business research related to competitive entrepreneurial technology strategy has continued rather than waned (e.g., Dougherty & Hardy, 1996; Jelinek, 1996; Jelinek & Schoonhoven, 1993; Koberg, Sarason, & Rosse, 1996; Lawless & Anderson, 1996; Nelson, 1992a, 1992b, 1993; Pitt & Clarke, 1997; Powell & Dent-Micallef, 1997; Rhyne et al., 1997; Sherman & Olsen, 1996; Teece, 1996), strengthening even further the nexus between research concerned with strategic management and research on technology-intensive industries.

Research on the relationships among strategy, technological change, and competitive advantage has more recently matured in its level of analytical precision, methodological finesse, and theoretical complexity (e.g., Afuah, 2001, 2002; Garud & Karnøe, 2003; McEvily & Chakravarthy, 2002; Rogers, 2001; Shane, 2001a, 2001b; Zahra, Ireland, & Hitt, 2000). Much of the new post-1990s wave of research in this general domain explores subtle associations among such factors as organizational structure, organizational culture, technological capabilities, product market linkages, market entry modes, and internationalization strategies. Long gone are the days when providing evidence for technology being an endogenous variable in business and the economy could be treated as a distinctive contribution to scholarship. In short, over the last two decades, research by management scholars on the nature and role of technology in business has shifted from being a specialized field of inquiry on the margins of orthodoxy to being firmly entrenched as a legitimate and mainstream field of scholarship.

2.2. The importance of "place"

Interest in technological entrepreneurship has not been restricted to scholars in business schools. A second group of scholars, often working out of departments of regional planning or geography (e.g., Blakely, 1994; Brotchie et al., 1995; Flynn & Forrant, 1997; Garnsey & Cannon-Brookes, 1993; Kenney & Florida, 1994; Lomi & Larsen, 1996; Markusen, 1994; Noponen, Graham, & Markusen, 1993; Quinn & Dickson, 1995; Rondinelli & Vastag, 1997; Sassen, 1991; Saxenian, 1990, 1994; Scott & Paul, 1990; Segers, 1992; Willoughby, 1998b) have made a significant contribution to the literature through their inquiries into the impact of technological entrepreneurship on the economic and industrial structure of regions.

Much of this literature has been concerned with seeking to understand the emergence of regions with economies based on "high-technology" industry complexes, the most prominent of which (e.g., "Silicon Valley") are in the United States. In addition to scholarly research, there has been significant number of practical initiatives on this topic during recent decades, such as numerous efforts by national, regional, and local governments throughout the world to develop strategy to emulate such complexes in the hope of attaining regional economic development (e.g., Castells & Hall, 1994; Preer, 1992).

More recently, business scholars have began to express a deeper appreciation of the spatial dimensions of competitive strategy (e.g., Kogut, 1993; Porter, 1990, 1995, 1997, 1998; Rosenberg, Landau, & Mowery, 1992). By the end of the 1990s, a nascent theme has emerged in the literature that geographically specific processes play an important role in technological entrepreneurship (see Bolland & Hofer, 1998; Swann, Prevezer, & Stout, 1998). Parallel and complementary research on such themes is now commonplace among scholars of both business and regional studies often with an emphasis on determining what actions may be taken to build up local high-technology industry clusters (Bathelt, 2001; Beneito, 2002; Holmén, 2002; Steinle & Schiele, 2002; Thierstein & Wilhelm, 2001; Wintjes, 2002).

2.3. Complex interorganizational relationships

Another theme, which has emerged in the strategy literature related to technology or R&D-intensive business, has been a recognition of the critical role played by interorganizational relationships and the network form of organization (e.g., Freeman & Barley, 1990; Harpaz & Meshoulam, 1997; Millar, Demaid, & Quintas, 1997; Sakakibara, 1997a, 1997b; Senker, 1995; Willoughby, 1993a). Similarly, some management scholars have also published work that attempts to take a holistic view of technological innovation, linking together community, population, and organization considerations (e.g., Drazin & Schoonhoven, 1996; Henderson & Mitchell, 1997; Teece, Pisano, & Shuen, 1997; Wade, 1995, 1996). Recent research places emphasis on empirical investigations of the impact of interorganizational cooperation on the performance of technology enterprises (Neill, Pfeiffer, & Young-Ybarra, 2001; Park, Chen, & Gallagher, 2002; Steensma & Corley, 2000) and on the role of organizations other than firms, such as universities, in such relationships (Santoro, 2000; Spencer, 2001).

In short, during the 1990s, research by business scholars about competitive strategies in technological entrepreneurship has moved progressively from a relatively narrow focus on the firm situated within its environment through a broader perspective of firms embedded in diadic interorganizational relationships (Bouty, 2000; Davenport & Miller, 2000; Hagedoorn, 2002; Steensma & Corley, 2001; Steier, 2001) toward recognizing that competitive firms tend to be embedded in complex interorganizational networks (Deroïan 2001, 2002; Lechner & Dowling, 2003; Olk & Young, 1997; Schilling, 2002).

2.4. Knowledge intensity

In the literature on strategy for technology-intensive industries, an emphasis has emerged on the themes of "knowledge" and "knowledge management" (e.g., Boland et al., 2001; Breschi, Lissoni, & Malerba, 2003; Firestone, 1999; McMillan & Hamilton, 2000; Rynes, Bartunek, & Daft, 2001; Schulz, 2001; Schulz & Jobe, 2001; von Krogh & Roos, 1996). Much of its attention is directed toward the themes of cooperation and collaboration, which are also associated with the interorganizational literature noted above (e.g., Chen, 1997; Fleck, 1997; Helfat, 1997; Leonard-Barton, 1995; Nonaka & Takeuchi, 1995; Quinn, 1992; Ranft & Lord, 2000). Some of this literature on the role of knowledge in strategy steps explicitly beyond the conceptual boundary of the firm by pointing to the importance of interorganizational relationships for technological learning and knowledge generation (Almeida, Dokko, & Rosenkopf, 2003; Ernst & Kim, 2002; Meeus, Oerlemans, & Hage, 2001; Schilling, 2002) or the competitive performance of firms (Autio, Sapienza, & Almeida, 2000; Coff, 2003; Hipp, 2002; Santoro, 2000; Tsai, 2001).

2.5. Convergence of themes?...“innovative milieux”

Finally, there is an emerging group of scholars whose work appears to integrate insights from each of the above four themes...under the rubrics of "dynamic networks" (Saxenian, 1994) and "innovative milieux." Useful summaries of this literature may be found in the conceptual syntheses of Cooke and Morgan (1994), Hall (1990), Maillat (1991), and Willoughby (1998b). Some scholars have combined insights from the dynamic networks perspective and the innovative milieux perspective in search of a more comprehensive approach to regional technological innovation and development. Examples may be found in publications by Bergman, Maier, and Tödtling (1991), Boekholt et al. (1998), Camagni (1991), Marceau (1991, 1993, 1994), and Willoughby (2000).

The essence of the innovative milieux idea is that success in technological innovation may not be adequately explained by the strategies of individual firms or even by the combined strategies of groups of firms acting in alliances or networks. Rather, technological innovation is nurtured through the complex interplay of intangible factors within complex local milieux within which firms and individuals are embedded.

The empirical research to be described in this paper was designed to identify what insights for firm-level technological innovation may be gained by using the innovative milieux perspective in the assessment of strategy. Before describing this research, however, the paper will briefly introduce the empirical domain of the research: strategic management in the biotechnology industry.

3. Biotechnology, innovation, and entrepreneurship

During the second half of the 1980s, several exploratory studies appeared concerning strategy, innovation, and entrepreneurship in the emerging biotechnology industry, including Blakely and Willoughby (1990), Chakrabarti and Weisenfeld (1989), Oakey et al. (1990), Orsenigo (1989), Pisano (1990a, 1990b), Roberts and Ryosuke (1988), Shan (1990), Teece, Pisano, and Shan (1987), and

Willoughby and Blakely (1989, 1990). The connections among technological innovation, entrepreneurship, and competitive advantage—combined with the movement away from context-free views of the firm toward viewing firms as embedded within complex organizational and geographical milieux, which have appeared in the wider business literature—have been even more pronounced within the biotechnology industry literature.

Since its emergence as a commercial activity during the 1970s (with the United States being the lead nation), biotechnology has evolved from being an experimental outgrowth of modern biological science into a new industry. While at one level biotechnology is a collection of techniques (e.g., for recombinant DNA, cell culture, monoclonal antibody production, or microbial fermentation of enzymes) for application in existing industries (such as the pharmaceutical, chemical, agricultural, and food processing industries), the collection of firms and other organizations involved with these techniques constitutes an industry in its own right, which many communities have been seeking to cultivate as a regional economic asset (Cohen et al., 1991; Moses & Cape, 1991).

In the wake of this trend, almost every federal and provincial government in the industrialized world has established some kind of agency or program to facilitate entrepreneurial development of biotechnology (Blakely & Nishikawa, 1989; Shamel & Keogh, 1994). Competitiveness in biotechnology entrepreneurship is seen as a key to future economic competitiveness (Bureau of National Affairs, 1989). While it is not clear exactly how the economic benefits of biotechnology innovation might be realized and how they might be appropriated by investors, most industrialized countries (and a significant number of less industrialized countries) are competing with each other to develop a strong national biotechnology industry. While the United States has been the leader in this industry (Bullock & Dibner, 1995; Bureau of National Affairs, 1989; Sharp, 1990a, 1990b), massive public sector investment and growing private sector support for biotechnology entrepreneurship in other countries has made biotechnology an arena for international competition in technological innovation (Arundel, 2001; Lipparini & Lomi, 1999; Ramani, 2002; Senker, 1998; Swann et al., 1998).

Throughout the 1990s and onwards, scholarly interest in the biotechnology industry, with much of the research focused on issues in innovation strategy and development, has continued apace. Examples include Appiah-Adu and Ranchhod (1998), Arora and Gambardella (1994), Austin (1993), Carlsson (1993), Coombs and Deeds (2000), Deeds (1994), Deeds and Hill (1996), Delaney (1993), della Valle (1993), Folta and Ferrier (2000), Forrest and Martin (1992), George, Zahra, Wheatley, and Khan (2001), Hamilton (1993), Just and Hueth (1993), Kenney and Florida (1994), Kreiner and Schultz (1993), Liebeskind et al. (1995), Murray (2002), Pisano and Mang (1993), Powell (1996), Powell, Koput, and Smith-Doerr (1996), Senker (1995), Senker and Sharp (1997), Weisenfeld-Schenk (1994), Willoughby (1993b, 1998b), Woiceshyn (1993), Zahra and George (2000), and Zucker et al. (1995). The majority of these works address issues related to the interorganizational relationships of biotechnology firms, with most adopting a network approach rather than just a diadic approach in their research and some (e.g., the studies of Zucker, Darby, and Brewer, Kenney and Florida, and Willoughby) pay serious attention to the geographical context of biotechnology innovation. Recent empirical research on the causes of geographical clustering in the biotechnology industry has demonstrated the importance of social networks and access to intangible resources associated with knowledge-intensive entrepreneurial activities as significant explanatory factors (Stuart & Sorenson, 2003).

One of the reasons why biotechnology has remained an interesting domain for research into technological innovation is that the biotechnology industry is a *knowledge-based* industry par excellence (Liebeskind et al., 1995; Saracevic & Kesselman, 1993; Saviotti, 1998; Zucker, Darby, & Brewer, 1994).

Because much of the debate over competitive innovation strategy relates to the knowledge intensity of new industry, studies of biotechnology industry are germane to research on the difference that knowledge intensity makes to regional industry dynamics (Darby & Zucker, 1996).

Knowledge intensity and strong capability in the management of knowledge are now widely seen to be keys to the creation of competitive advantage (Hansen, Nohria, & Tierney, 1999; Leonard-Barton, 1995; von Krogh & Roos, 1996). The unusually high knowledge intensity of biotechnology, exemplified by its unusually high scientific content, makes the biotechnology industry a superb laboratory for the analysis of entrepreneurial technological strategy.

Finally, the vast majority of enterprises in the biotechnology industry are entrepreneurial firms (Daly, 1985; Kenney, 1986; Orsenigo, 1989; Willoughby, 1993b, 1998a, 1998b). This fact creates an additional reason why the industry is eminently appropriate for research associated with strategy for technology-related entrepreneurship.

4. Generic innovation strategies: the Affordable Resources strategy and the Milieux Embeddedness strategy

Drawing on the above material, at least two different generic strategies may be identified for innovative firms in knowledge-intensive industries: the Affordable Resources strategy and the Milieux Embeddedness strategy. The concepts for each of these *firm-level* generic strategies were derived from a prior basic conceptual framework I developed for technology-based *regional-level* economic development strategy (for a more elaborate conceptual review, see Willoughby, 2000). This framework was developed while I was studying the biotechnology industry in California during the late 1980s (Willoughby & Blakely, 1989, 1990, 1991; Willoughby, Blakely, & Nishikawa, 1993) and was further refined through a study of the biotechnology industry in New York during 1991 (Willoughby, 1993b) and applied later in Utah during 1998 (Willoughby, 1998a). For the sake of convenience, we could refer to the firm-level strategies as "microorganizational strategies" and to the region-level strategies as "mesoorganizational strategies" ("meso" being halfway between "micro" and "macro"). The correspondence between the different levels of generic strategy is illustrated in Table 1.

4.1. Mesoorganizational generic strategy 1: the Industrial Location Factors approach

The first generic mesoorganizational strategy, the Industrial Location Factors approach, is a strategy for building up local technology-based industry by seeking to attract "desirable" (high-technology) firms to relocate to "our place" through making resources (tangible resources, typically) in the local environment more accessible and less expensive. This strategy will be recognized by most informed readers as an orthodox approach followed by the vast majority of economic development agencies and industry development organizations, at least until relatively recently. There is probably no formal, theoretical advocacy of this approach in the literature; rather, it is the dominant guiding principle that is tacitly assumed by the proponents of countless economic development programs.

Typically, local authorities or industry promoters adopting this strategy will seek to put in place such "attractive" resources as subsidized land, roads/railways, waste disposal, energy supply, water supply, or other kinds of physical facilities; subsidized training facilities (e.g., technical schools) near the site; supplies of cheap labor (through industrial relations policies); taxation exemptions; and relief from

Table 1
Generic strategies for local technological innovation

	Industrial Location Factors approach	Local Technological Milieux approach
Mesoorganizational generic strategy	Defining theme • Attract firms to relocate through reducing the cost of doing business locally Other themes • Focus on external/tangible aspects of regional environment • Single "ultimate factor" for industrial/technological competitiveness • Assumption of direct linear causality in industrial dynamics	Defining theme • Build up local technological milieux by facilitating interorganizational communication locally and globally Other themes • Focus on internal/intangible aspects of regional milieux • Self-renewing process, which has no single cause other than the process by which it renews itself • Assumption of indirect nonlinear causality in industrial dynamics
	Affordable Resources strategy	Milieux Embeddedness strategy
Microorganizational generic strategy	Defining theme • Build competitiveness by locating the activities of a firm in places that are attractive vis-á-vis the cost of resources and the regulatory environment	Defining theme • Build competitiveness by deeply embedding the firm and its people in informal communication networks of a web of local technological milieux

regulations (such as environmental regulations or labor/employment regulations). The ultimate aim is to make it easier for firms to reduce their cost of doing business locally by reducing their cost of access to resources. Strategies based on this perspective also tend to be based on the assumption that a policy action (e.g., a tax break or the provision of subsidized space in a technology park) will bring about the desired result (improved locally based global technological competitiveness) in a simple, direct cause-and-effect manner. Reviews of programs based on this approach may be found in Blair and Premus (1987), Bridges (1965), and Rubin and Zorn (1985).

4.2. Mesoorganizational generic strategy 2: the Local Technological Milieux approach

A local technological milieu may be defined as a coherent space (expressed along sociocultural, organizational/institutional, and knowledge/informational dimensions) within an environment, centered around a particular domain of technology practice (Willoughby, 1995, p. 131). The second mesoorganizational generic strategy, the Local Technological Milieux approach, is a strategy for building up local technology-based industry by facilitating the emergence of new technology-based entrepreneurial business activity from within the existing community (rather than by attracting firms to relocate from elsewhere). Instead of emphasizing making business resources accessible and affordable for firms, promoters of this approach would seek to nurture new entrepreneurial activity from networks of relationships between people and organizations already grounded in the local community. In other words, they would seek, indirectly, to generate a local technological milieu.

Proponents of such a strategy would focus on intangible factors in the local milieu such as people and their knowledge, the culture and history of the place, the richness and complexity of symbolic experience and communication between people and organizations, and the vigor and diversity of pertinent local institutions (such as industry associations). The Local Technological Milieux concept draws heavily on the innovative milieux concept; however, it is focused on a particular technological/scientific domain and stresses that technological innovation and technology-based industry development tend to grow, not so much from the input of resources from the local environment and the combination of factors from the local environment but as a self-renewing process that has no single cause other than the process by which it sustains itself.

Proponents of the Local Technological Milieux approach tend to eschew presumptions that a desired result may be simply brought about (“caused”) as a result of a specific policy action (e.g., establishing a technology park or setting up a state-subsidized venture capital scheme). In contrast to the Industrial Location Factors approach, the Local Technological Milieux approach assumes that there is an indirect, multifaceted, nonlinear, and unpredictable relationship between means and ends. Rich patterns of informal communication locally and globally by significant actors within the local milieu and between them and those in other milieux are the hallmark of a healthy local technological milieu.

4.3. Microorganizational generic strategy 1: the Affordable Resources strategy

At the microlevel of organization (the firm), the analogue of the Industrial Location Factors approach is the Affordable Resources strategy. The essence of this strategy is that the managers of an innovative technology firm would seek to build and maintain competitiveness by locating the activities of their enterprise in environments that are attractive from the point of view of the resources to which they need access to conduct their business. In particular, the approach emphasizes the minimization of cost and regulatory obstacles to resource access. This strategy, although rarely (if ever) discussed by business people with this kind of terminology, is widely seen as “common sense” business practice.

4.4. Microorganizational generic strategy 2: the Milieux Embeddedness strategy

At the microlevel of organization (the firm), the analogue of the Local Technological Milieux approach is the Milieux Embeddedness strategy. The essence of this strategy is that the leaders of an innovative technology venture would ensure that they and the other people in their enterprise were deeply embedded in the informal communication networks of a local technological milieu and of other associated technological milieux. In short, they would seek to embed their enterprise in a web of local technological milieux even if such a strategy was incompatible with minimizing the cost and ease of access to resources.

4.5. Comparing the two microorganizational generic strategies

My previous research on the biotechnology industry provided evidence that communities following the Local Technological Milieux approach were more likely to succeed in gaining significant economic development benefits from biotechnology than were communities following the Industrial Location Factors approach (Willoughby, 1993b). The research found that, while certain basic resources for the biotechnology industry (such as a supply of high-quality scientific knowledge and personnel from universities) were essential to its survival, the mere existence of such resources appeared to be insufficient to ensure the development of the industry. The propensity of biotechnology firms to facilitate informal communication between their personnel and people in other organizations and for those firms to form relationships with other organizations in complementary fields of activity, both locally and globally, was found to be the probable key to unlocking innovative potential. That research led to the conclusion that biotechnology firms, which pursued a strategy of simultaneous "local embeddedness" and "global connectedness," were more likely than otherwise to exhibit superior performance and to stimulate local economic development.

These results from research on mesoorganizational strategy suggest that a parallel phenomenon might be observable in microorganizational strategy. In other words, they raise the possibility that technological firms following the Milieux Embeddedness strategy might build and maintain competitiveness more successfully than firms following the Affordable Resources strategy.

5. Hypotheses, variables, and procedures for empirical research

To verify the power of the ideas described above and of the results found in my previous research, I formulated several formal hypotheses, listed below, to be tested through a field-based empirical study of the "bioscience technology" industries in New York State during 1996 and 1997. The study covered not only dedicated biotechnology firms (narrowly defined) but also firms active in medical devices technology, pharmaceuticals technology, and other fields of technology related to the life sciences. This group of firms, including dedicated biotechnology firms, was labeled collectively as "bioscience technology" firms. Biotechnology firms tend to be significantly more knowledge intensive (defined, operationally, as R&D intensive) than other bioscience technology firms; their comparison with other bioscience technology firms was therefore intended to facilitate investigation of the relative significance of knowledge intensity for strategies in innovative technology firms. Full details of the field study procedures and descriptive statistics may be found in a published technical report (Willoughby, 1997).

5.1. Hypotheses

Hypothesis 1. That the performance of bioscience technology firms, as indicated by relative revenue growth rates, will be enhanced through the adoption of relatively high levels of *informal communication* between people in those firms and people in other organizations in a range of complementary industries.

Hypothesis 2. That the performance of bioscience technology firms, as indicated by relative revenue growth rates, will be enhanced through the adoption of relatively high levels of *formal collaboration* with other organizations in a range of complementary industries.

Hypothesis 3. That the performance of bioscience technology firms, as indicated by relative revenue growth rates, will be enhanced through being physically situated in a region that is perceived by managers to be *locationally advantageous* from the point of view of the regulatory environment or the cost of doing business.

Hypotheses 1 and 2 were designed as vehicles for testing of the power of the Milieux Embeddedness strategy to account for the relative performance of bioscience technology firms, while Hypothesis 3 was designed as a vehicle for testing the power of the Affordable Resources strategy to account for the relative performance of bioscience technology firms.

Hypothesis 4. That the performance of bioscience technology firms, as indicated by relative revenue growth rates, will be enhanced through the adoption of relatively high levels of both *informal communication* between people in those firms and people in other organizations in a range of complementary industries and relatively high levels of *formal collaboration* with those organizations.

Hypothesis 4 was also designed as a vehicle for testing the power of the Milieux Embeddedness strategy to account for the relative performance of bioscience technology firms. While Hypotheses 1 and 2 each separately address the importance of informal communication and formal collaboration, respectively, Hypothesis 4 addresses the importance of the two different forms of interorganizational relationships combined.

Hypothesis 5. That the performance of bioscience technology firms, as indicated by relative revenue growth rates, will be enhanced through a combination of the adoption of relatively high levels of interorganizational *informal communication*, together with *formal collaboration*, and through being physically situated in a region that is perceived by managers to be *locationally advantageous* from the point of view of the regulatory environment or the cost of doing business.

Hypothesis 5 was designed as a vehicle for testing the combined power of the Milieux Embeddedness strategy and the Affordable Resources strategy to account for the relative performance of bioscience technology firms.

Hypothesis 6. That improvements to the performance of bioscience technology firms through the adoption of relatively high levels of interorganizational *informal communication* will accrue most strongly to those firms which also exhibit relatively high levels of engagement in R&D activities.

Hypothesis 6 was designed as a vehicle for testing whether the advantages of high interorganizational communication appear to benefit biotechnology firms more than other kinds of firms due to the relatively high knowledge intensity of biotechnology firms (indicated by their relatively high emphasis on R&D activity).

5.2. Variables

For a list of variables employed in the statistical analyses below, see Table 2. The main construct used here as a measure of the performance of individual firms is a revenue growth index (REVIND) derived from the annual rate of revenue growth of firms (ANNREV) but modified to compensate for the fact that entrepreneurial start-ups tend to have extraordinarily high rates of revenue growth until they mature. In this paper, a logarithm of REVIND (LNREVIND) is employed as the dependent variable. The ANNREV figures and the employment size figures used here were produced from data collected directly from the firms interviewed in the study. Revenue growth data were selected for reasons of logical relevance, wide scope of applicability, and feasibility of data collection. The majority of bioscience technology firms are under private ownership and a higher proportion of the population is more prepared to reveal revenue

Table 2
Description of variables

Variable	Label	Definition/description
Informal communication index	IIC	Total number of organizations (in 24 different organizational and geographical categories), which have people with whom the CEO of the firm engaged in significant informal communication during the previous year.
Formal collaboration index	IFC	Total number of organizations (in 24 different organizational and geographical categories) with which the firm formally collaborated during the previous year.
Locational advantage index	ILARC	Index of the perceived relative advantageousness of the local region of the firm for conducting R&D and manufacturing activities ILARC= (LARDREG + LARDCOST + LAMFREG + LAMFCOST) × 25
	LARDREG	Locational advantage score for R&D vis-á-vis the regulatory environment (advantageous = 1, no difference = 0.5, disadvantageous = 0)
	LARDCOST	Locational advantage score for R&D vis-á-vis cost of doing business (advantageous = 1, no difference = 0.5, disadvantageous = 0)
	LAMFREG	Locational advantage score for manufacturing vis-á-vis regulatory environment (advantageous = 1, no difference = 0.5, disadvantageous = 0)
	LAMFCOST	Locational advantage score for manufacturing vis-á-vis cost of doing business (advantageous = 1, no difference = 0.5, disadvantageous = 0)
Log of revenue growth index	LNREVIND	Logarithm of REVIND (weighted index of ANNREV)
	REVIND	REVIND = ANNREV (INDEMP/MEANEMP)
	ANNREV	Annual rate of revenue growth of the individual firm
	INDEMP	Worldwide FTE employment levels of individual firm
	MEANEMP	Mean worldwide FTE employment levels for the industry sample
Percentage of spending devoted to R&D	moneyR&D	Proportion of the firms total spending in all its facilities combined, which is allocated to R&D functions
Percentage of FTE employees devoted to R&D	workR&D	Proportion of the firm's FTE employment (total person years per year) devoted to R&D activities

growth data than is prepared to reveal profitability data. In any case, the nature of the biotechnology industry is such that "profitability" is arguably a poor measure of comparative performance because even the best firms may take many years before their bottom line is in the black.

The exact formula for the REVIND for each firm is as follows: REVIND = ANNREV(INDEMP/MEANEMP), where INDEMP is worldwide employment level (number of full-time-equivalent [FTE] persons employed) of the individual firm and MEANEMP is the mean worldwide employment level for the industry sample.

The indicators of interorganizational relationships were derived from a series of questions about the firms' informal communication and formal collaboration during the previous year with various types of organizations: universities and research laboratories, hospitals and health-care institutions, bioscience technology firms (including pharmaceutical companies), all other types of firms (i.e., commercial/industrial businesses), financial service organizations, regulatory agencies, public sector support agencies, and "other" organizations. Data in response to these questions were collected for organizations in three geographical categories: the same local region within New York as the firm, elsewhere in the United States (including nonlocal parts of New York), and in foreign countries.

5.3. Data collection procedures

The data collection process involved two main phases both administered through the Office of the Center for Biotechnology at the State University of New York at Stony Brook. The first phase, which was conducted from July to December 1996, consisted of an exhaustive census of all firms in New York State active in bioscience technology. To be included in the study, a firm had to pass through several analytical filters: (i) the firm had to be an identifiable bona fide New York business, with its core operations located within New York State; (ii) its dominant activity needed to be centered on at least one of the four subfields of bioscience technology defined above; (iii) it needed to possess a significant internal technical capability of its own within bioscience technology; (iv) it needed to conduct R&D in bioscience technology, produce bioscience technology, employ bioscience technology in its business, or produce specialized technical supplies for bioscience technology; and (v) it needed to devote the majority of its efforts to the above activities.

A master list of several thousand candidate organizations in bioscience technology was assembled from multiple sources. Each organization on this list was subjected to two rounds of inquiries: (i) an initial check for information consistency, plausibility, and verification as to whether the organization was still in business or was actually in New York State (this process reduced the candidate list to less than 1000 organizations) and (ii) a second inquiry, conducted mostly by telephone, to identify whether the firm could successfully pass through all the analytical filters indicated above (this process, which was completed by October 1996, reduced the candidate list to about 300 firms). An additional (fine-tuned) analysis of all firms, which made it through the above two inquiry processes, was completed by December 1996 and revealed the verifiable industry population in New York State to be 273 bioscience technology firms.

The second phase consisted primarily of a detailed structured questionnaire survey of the population of firms identified in the census. This work involved three subphases: (i) sending introductory letters (from the Director of the Center for Biotechnology and the Executive Director of the New York Biotechnology Association) to every bioscience technology firm in the population to introduce the study and its purposes, (ii) completing the first half of the questionnaire through a structured telephone interview with the CEO (or CEO equivalent) of each firm, and (iii) completing the balance of the questionnaire by obtaining completed responses by fax or mail to a set of printed interview sheets. Data were provided by each of the firms under a promise of confidentiality. It was not uncommon for this process to involve more than a dozen points of contact (by telephone, fax, or letter) between myself or my research assistants and each of the firms being studied. Data were also collected on other matters for which there is insufficient space in this paper to report.

At the completion of the data collection process, during May 1997, telephone interviews had been completed for 125 firms, and completed interview sheets had been received from 96 firms. Comprehensive data sets (both the telephone interview and the written fax/interview sheets, combined) were completed for 94 firms. Thus, substantial data (covering between 50% and 100% of the items) were assembled for 46% of the population; comprehensive data sets (covering close to 100% of the data

Table 3
Description of formal models

Model	General form of the model
Model 1	$Y = b_0 + b_1\text{IIC} + \text{error}$
Model 2	$Y = b_0 + b_1\text{IFC} + \text{error}$
Model 3	$Y = b_0 + b_1\text{ILARC} + \text{error}$
Model 4	$Y = b_0 + b_1\text{IIC} + b_2\text{IFC} + \text{error}$
Model 5	$Y = b_0 + b_1\text{IIC} + b_2\text{IFC} + b_3\text{ILARC} + \text{error}$
Model 6	$Y = b_0 + b_1\text{IIC} + b_2\text{moneyR\&D} + b_3\text{workR\&D} + \text{error}$
Dependent variable	LNREVIND

items) were assembled for 34% of the population. Basic identifying data were assembled for 100% of the population (273 firms).

The formal models used to help test these hypotheses are described in Table 3. Each model is expressed as a linear regression equation. All statistical tests were performed on a microcomputer using StatView II data analysis software (produced by Abacus Concepts).

6. Results of empirical inquiry

6.1. Dedicated biotechnology firms only

Tables 4a and 4b summarize the results of statistical tests designed to evaluate the relative merits of the Milieux Embeddedness strategy and the Affordable Resources strategy using only the biotechnology firms from the survey sample.

The correlation matrix in Table 4a was produced to identify any possible problems with multicollinearity in the data. According to Tabachnick and Fidell (1989, p. 87), multicollinearity is a problem when predictors are highly correlated (with correlation coefficients greater than .90). As the ranges in Table 4a indicate, where the Pearson correlation coefficients are quite low, there does not appear to be any problem with multicollinearity in these data. Table 4b also shows that the distribution of residuals around the mean is quite balanced, giving us confidence about the validity of the statistics.

The analysis of variance calculations summarized in Table 4b reveal that only in Model 1 are there sufficient grounds for rejecting the null hypothesis. These results therefore provide support for Hypothesis 1 but do not provide support for Hypothesis 2, 3, 4, or 5. In other words, the data provide grounds for believing that the performance of *biotechnology firms*, as indicated by relative revenue

Table 4a
Descriptive statistics and Pearson correlation coefficients: biotechnology firms, New York, 1996 ($n = 66$)

Variable	Mean	S.D.	n	1	2	3	4
1 IIC	67.24	89.27	51	1			
2 IFC	31.66	62.74	47	.17	1		
3 ILARC	37.26	24.44	52	−.04	.38	1	
4 LNREVIND	0.195	0.77	23	.42	−.10	−.41	1

Table 4b
Regression table for financial performance of bioscience technology firms: biotechnology firms, New York, 1996

Variables		Model 1	Model 2	Model 3	Model 4	Model 5
df	Degrees of freedom	23	21	23	21	21
R	Coefficient of multiple correlation	.45	.10	.39	.45	.58
R^2	Coefficient of multiple determination	.20	.01	.16	.21	.33
Adjusted R^2	Population-squared *R*, unbiased estimate	.17	− .04	.12	.12	.21
F	*F*-test statistic	5.33	0.19	3.87	2.32	2.82
P	Probability	.03	.67	.06	.13	.07
S.E.	RMS residual (S.E.)	0.70	0.75	0.73	0.70	0.66
$e>0$, $e<0$	Positive residuals, negative residuals	12, 11	10, 11	11, 12	11, 10	9, 12
Critical *F*	Critical *F* at 95% confidence interval	4.32	4.38	4.32	3.55	3.2
a	Constant	− 0.07	0.33	0.64	0.10	0.46
IIC		.45 (2.31)*			.45 (2.10)*	.41 (2.01)
IFC			− .10 (0.44)		− .17 (0.82)	− .02 (0.10)
ILARC				− .39 (1.97)		− .39 (1.80)

Standard coefficient of correlation and *t* values (*t* values in parentheses).
Dependent variable: LNREVIND.
* $P<.05$, significance level for *t* tests.

growth rates, will be enhanced through the adoption of relatively high levels of informal communication between people in those firms and people in other organizations in a range of complementary industries.

6.2. Bioscience technology firms other than biotechnology firms

Tables 5a and 5b summarize the results of statistical tests designed to evaluate the relative merits of the Milieux Embeddedness strategy and the Affordable Resources strategy using only those firms from the sample that *did not engage in biotechnology*.

The correlation matrix in Table 5a indicates that there does not appear to be any problem with multicollinearity in these data, and the residual data in Table 5b also affirm the validity of the statistics. The analysis of variance calculations summarized in Table 5b reveal that there are no grounds for rejecting the null hypothesis in any of the five models. These results (from the "nonbiotechnology"

Table 5a
Descriptive statistics and Pearson correlation coefficients: bioscience technology firms other than biotechnology firms, New York, 1996 ($n=61$)

Variable	Mean	S.D.	*n*	1	2	3	4
1 IIC	181.03	372.11	38	1			
2 IFC	48.18	85	34	.26	1		
3 ILARC	30.45	23.96	39	− .18	− .21	1	
4 LNREVIND	0.55	0.81	25	.24	.06	− .11	1

Table 5b
Regression table for financial performance of bioscience technology firms: bioscience technology firms other than biotechnology firms, New York, 1996

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
df	24	22	25	22	22
R	.23	.06	.04	.24	.25
R^2	.05	.00	.00	.06	.06
Adjusted R^2	.01	− .05	− .04	− .04	− .09
F	1.25	0.07	0.04	0.60	0.41
P	.28	.80	.84	.56	.75
S.E.	0.79	0.82	0.83	0.82	0.84
$e>0$, $e<0$	11, 13	11, 11	12, 13	10, 12	11, 11
Critical *F*	4.3	4.35	4.28	3.52	3.16
a	0.47	0.57	0.59	0.46	0.54
IIC	.23 (1.12)			.25 (1.06)	.24 (0.99)
IFC		.06 (0.26)		− .01 (0.03)	− .02 (0.08)
ILARC			− .04 (0.20)		− .07 (0.31)

Standard coefficient of correlation and *t* values (*t* values in parentheses).
$P<.05$, significance level for *t* tests.
Dependent variable: LNREVIND.

firms) do not provide support for Hypothesis 1, 2, 3, 4, or 5. In other words, when taken together with the results from Table 4b, the data provide grounds for believing that the performance of biotechnology firms only, and not other kinds of bioscience technology firms, may be expected to be enhanced (as indicated by relative revenue growth rates) through the adoption of relatively high levels of informal communication between people in those firms and people in other organizations in a range of complementary industries.

6.3. Influence of R&D intensity on the performance of bioscience technology firms

Tables 6a and 6b summarize the results of statistical tests designed to evaluate the impact of R&D intensity on the performance of bioscience technology firms (including both biotechnology firms and all other kinds of bioscience technology firms). There do not appear to be any multicollinearity problems in the data, and the residuals are balanced about the mean.

Table 6a
Descriptive statistics and Pearson correlation coefficients: all bioscience technology firms, New York, 1996 ($n=127$)

Variable	Mean	S.D.	*n*	1	2	3	4	5	6
1 IIC	115.82	256.81	89	1					
2 IFC	38.59	72.88	81	.24	1				
3 ILARC	34.34	24.34	91	− .15	.06	1			
4 LNREVIND	0.38	0.8	49	.31	.02	− .31	1		
5 Percentage of spending devoted to R&D	34.28	33.77	83	− .01	− .05	− .05	.10	1	
6 Percentage of FTE employees devoted to R&D	32.6	28.3	124	− .09	− .15	− .02	− .10	.63	1

Table 6b
Regression table for financial performance of bioscience technology firms: all bioscience technology firms, New York, 1996

Variables	Model 6
df	45
R	.33
R^2	.11
Adjusted R^2	.05
F	1.69
P	.18
S.E.	0.79
$e>0$, $e<0$	22, 23
Critical *F*	2.84
a	0.34
IIC	.30 (2.04)*
moneyR&D	.05 (0.26)
workR&D	− .14 (0.74)

Standard coefficient of correlation and *t* values (*t* values in parentheses).
Dependent variable: LNREVIND.
*$P<.05$, significance level for *t* tests.

The model, Model 6, explores the combined effect of two different measures of R&D intensity (one money-based and the other people-based), and the measure of informal communication behavior, on performance (LNREVIND). The analysis of variance results do not provide sufficient grounds for rejecting the null hypothesis. The *t* tests for the individual variables in the regression equation do provide some support for the proposition that informal communication index (IIC) has a significant effect on performance; this result, however, does not add anything to the results gained from the analyses summarized in Table 4b.

In short, the results in Table 6b do not provide support for the idea that a bioscience technology firm would increase its performance (as defined above) by devoting an unusually high proportion of either its personnel or its spending to R&D activities. Nevertheless, some data collected in the questionnaire survey provide some clues as to the moderating influence that R&D intensity is likely to exert on the phenomena with which we are concerned in this paper. Comparisons of the functional distribution of employment of each subfield of bioscience technology revealed that biotechnology firms, on average, devote a higher proportion of their personnel to R&D activities than do other kinds of bioscience technology firms (52% for biotechnology vs. 24% for all "nonbiotechnology" firms within the larger bioscience technology sample). These data suggest that the reason why biotechnology firms tend to benefit more than other firms from a heavy emphasis on interorganizational

Table 7a
Descriptive statistics and Pearson correlation coefficients: bioscience technology firms with above average percentage of personnel devoted to R&D, New York, 1996 ($n=53$)

Variable	Mean	S.D.	*n*	1	2	3	4
1 IIC	70.12	100.98	42	1			
2 IFC	32.03	45.13	38	.17	1		
3 ILARC	31.1	22.9	41	.66	.38	1	
4 LNREVIND	0.18	0.831	22	.48	.47	− .40	1

Table 7b
Regression table for financial performance of bioscience technology firms: bioscience technology firms with above average percentage of personnel devoted to R&D, New York, 1996

Variables	Model 1	Model 2	Model 3	Model 5
df	22	20	22	20
R	.51	.47	.39	.55
R^2	.26	.22	.15	.30
Adjusted R^2	.22	.18	.11	.17
F	6.87	5.14	3.60	2.27
P	.02	.04	.07	.12
S.E.	0.74	0.75	0.78	0.76
$e>0$, $e<0$	12, 10	10, 10	12, 10	10, 10
Critical *F*	4.35	4.32	4.26	3.13
a	− 0.17	− 0.07	0.71	0.16
IIC	.51 (2.62)*			.24 (0.83)
IFC		.47 (2.27)*		.24 (0.83)
ILARC			− .39 (1.90)	− .19 (0.78)

Standard coefficient of correlation and *t* values (*t* values in parentheses).
Dependent variable: LNREVIND.
* $P<.05$, significance level for *t* tests.

communication and collaboration is that they tend to be more R&D intensive than the other firms. A series of statistical tests were conducted (summarized in Tables 7a, 7b, 8a, and 8b) to explore this idea (embodied in Hypothesis 6).

6.4. Moderating influence of R&D intensity on benefits of informal communication

Tables 7a and 7b are based entirely on data drawn from those bioscience technology firms, which devote a greater than average proportion of their personnel to R&D activities. Tables 8a and 8b are based entirely on data drawn from those bioscience technology firms that devote a smaller than average proportion of their personnel to R&D activities. The correlation matrices for the two data sets both reveal that there do not appear to be any problems with multicollinearity with either of the data sets. There do appear to be some minor imbalances in the distribution of residuals about the mean for the regression equations in Table 8b (the firms with below average R&D intensity), which means that any "statistically significant" results would have to be treated with caution for that sample. The regression equations in Table 7b, however, do not suffer from this problem.

Table 8a
Descriptive statistics and Pearson correlation coefficients: bioscience technology firms with below average percentage of personnel devoted to R&D, New York, 1996 ($n=74$)

Variable	Mean	S.D.	*n*	1	2	3	4
1 IIC	156.66	336.85	47	1			
2 IFC	44.4	90.83	43	.16	1		
3 ILARC	37	25.38	50	− .07	.21	1	
4 LNREVIND	0.54	0.76	26	.23	− .24	− .20	1

Table 8b
Regression table for financial performance of bioscience technology firms: bioscience technology firms with below average percentage of personnel devoted to R&D, New York, 1996

Variables	Model 1	Model 2	Model 3	Model 5
df	25	23	26	23
R	.23	.24	.13	.38
R^2	.05	.06	.02	.15
Adjusted R^2	.01	.01	− .02	.01
F	1.23	1.28	0.41	1.08
P	.28	.27	.53	.38
S.E.	0.73	0.70	0.77	0.70
$e>0$, $e<0$	15, 10	13, 10	14, 12	10, 13
Critical *F*	4.28	4.32	4.26	3.13
a	0.51	0.70	0.65	0.70
IIC	.23 (1.11)			.26 (1.21)
IFC		− .24 (1.13)		− .26 (1.15)
ILARC			− .13 (0.64)	− .12 (0.56)

Standard coefficient of correlation and *t* values (*t* values in parentheses).
$P<.05$, significance level for *t* tests.
Dependent variable: LNREVIND.

The analysis of variance calculations in Table 8b do not provide support for rejecting the null hypothesis for any of the four models tested. Neither were any significant *t* test scores found for any of the individual variables in the equations. There is no significant support in Table 8b for Hypothesis 6 in the sample with below average R&D intensity. The analysis of variance calculations in Table 7b do provide statistically significant results, at the 95% confidence interval, for rejecting the null hypothesis for both Models 1 and 2. The strongest result was found for Model 1 (IIC as the independent variable). These results provide significant support for Hypothesis 6 but only in firms that exhibit above average R&D intensity.

6.5. Summary of results of regression analyses

The statistical analyses summarized in the preceding pages provide support for the following conclusions.

6.5.1. Accept Hypothesis 1 but only for biotechnology firms and not for other bioscience technology firms

In other words, the data support the proposition that the association between relatively high levels of informal communication between people in biotechnology firms and people in other organizations (in a range of complementary industries) and relatively high performance (measured by revenue growth rates) cannot be explained by chance. These results provide grounds for confidence in the proposition that relatively high levels of interorganizational informal communication by people in biotechnology firms lead to relatively high levels of performance. The data do not provide statistically significant evidence of such a relationship in nonbiotechnology firms in the sample.

6.5.2. Reject Hypothesis 2 for most kinds of bioscience technology firms but recognize that there is some support for the hypothesis for those firms that devote an above average proportion of their personnel to R&D activities

In other words, the data do not provide statistically significant grounds for having confidence that relatively high levels of performance (measured by revenue growth rates) will be associated with relatively high levels of formal collaboration between bioscience technology firms and other organizations in a range of complementary industries. The data do provide some support for such a relationship only in bioscience technology firms with high levels of R&D activity.

6.5.3. Reject Hypothesis 3 for all categories of bioscience technology firms

In other words, the data provide no support for the proposition that bioscience technology firms, of any kind, will experience higher levels of performance (measured by revenue growth rates) through being physically situated in a region that is perceived by managers to be locationally advantageous from the point of view of the regulatory environment or the cost of doing business.

6.5.4. Tentatively and provisionally accept Hypothesis 4 only for those bioscience technology firms with an above average proportion of personnel devoted to R&D activities

In other words, there is only very weak support in the data for the proposition that the performance of bioscience technology firms (as indicated by relative revenue growth rates) will be enhanced through the adoption of relatively high levels of *both* informal communication *and* formal collaboration with other organizations; even then, the relationship (weak as it is) holds only for those firms with high levels of R&D activity.

6.5.5. Reject Hypothesis 5

In other words, there is no support in the data for the proposition that the performance of bioscience technology firms (as indicated by relative revenue growth rates) will be enhanced through a combination of the adoption of relatively high levels of interorganizational informal communication, together with formal collaboration, and through being physically situated in a region that is perceived by managers to be locationally advantageous from the point of view of the regulatory environment or the cost of doing business. In short, locational advantage factors do not appear to play a significant role, vis-à-vis firm performance, even when they are combined with high levels of communication and collaboration. This conclusion holds for all types of bioscience technology firms.

6.6.6. Accept Hypothesis 6

In other words, the data provide statistically significant support for the proposition that improvements to the performance of bioscience technology firms through the adoption of relatively high levels of interorganizational informal communication will accrue most strongly to those firms that also exhibit relatively high levels of engagement in R&D activities. As biotechnology firms tend, on the whole, to be more R&D intensive than other kinds of bioscience technology firms, and given that the data supported Hypothesis 1 for biotechnology firms only, we would expect the data to also support Hypothesis 6. The data also show that bioscience technology firms other than those engaged in biotechnology may also experience the performance benefits of high levels of interorganizational informal communication if they also engage in relatively high levels of R&D activity.

7. Discussion and conclusions

7.1. Main conclusions from the empirical research

The foregoing statistical analyses support the proposition that the Milieux Embeddedness strategy is a superior strategy for building competitiveness among biotechnology firms than is the Affordable Resources strategy.

Bioscience technology firms with high levels of informal communication between their people and people in other bioscience technology firms, and in a range of categories of complementary organizations, tend to outperform those that exhibit lower levels of such informal communication behaviors. In contrast, firms with locational behaviors driven by the goal of lowering their cost of access to resources or by the goal of avoiding stringent regulatory regimes do not perform any better than their competitors.

The knowledge intensity of firms' activities is an important moderating variable. The data provide strong support for the idea that the benefits to a firm of engaging in relatively high levels of interorganizational behavior are more likely to be realized if the firm is a R&D-intensive organization—in other words, if the firm is a knowledge-intensive organization. The practical relevance of the Milieux Embeddedness strategy appears to vary according to the degree to which a firm devotes its resources to R&D activities.

Of the two types of interorganizational relationships investigated in this study—informal communication and formal collaboration—the former has the greatest impact on the performance of bioscience technology firms. Some positive (although limited) impacts of high levels of formal collaboration on the performance of firms are observable only when high levels of knowledge intensity are also observable, and a high level of formal collaboration appears to be efficacious mainly only as an adjunct to a high level of informal communication.

The data revealed no significant relationship between locational behavior and performance (at least, that is, locational behaviors driven by consideration of resource costs and regulations). The intangible interorganizational behaviors of innovative technology firms appear to exert a much greater influence on their performance than do their locational behaviors. In short, how a firm's people behave appears to be more important than where a firm is located. Of course, this begs the question of "What if a firm's location affects the ability of its people to engage in rich communicative behaviors?" We can only infer an answer to that question from the data. The data suggest that a firm choosing a location on the basis of its people, knowledge, and institutional resources is more likely to thrive than one choosing its location on the basis of the regulatory regime, the cost of doing business, or the cost of access to resources.

7.2. Implications for theory

The first theoretical implication of this research is that knowledge-intensive technology enterprises (in other words, "high-technology firms") do appear to exhibit distinctive qualities that, in turn, create the need for distinctive approaches to strategy. Theoretical approaches to strategy derived from generic studies of various types of industries (undifferentiated according to their technological characteristics or degree of knowledge intensity) may be of little relevance in high-technology contexts. The emergence of specialized management and policy journals devoted to scholarship in technology management appears to be justified, because some strategies and some theoretical perspectives are more applicable to high-technology contexts than to other contexts. Conventional concepts of competitive advantage may be less applicable in the domain of technology-related strategy than in other domains.

The second theoretical implication of this research is that the recent growth of interest among management scholars in the "knowledge-based" theory of the firm appears to be warranted. The fact that variations in knowledge intensity appear to have a notable effect on the impact of the interorganizational behavior of bioscience technology firms (as identified in this study) suggests that there may be theoretical value in management scholars developing deeper characterizations of the nature of knowledge and its relationships to other organizational phenomena. In particular, the study of epistemology may provide a fruitful source of insight to guide future theorizing in management research. The immense impact of the pioneering work of Nonaka on contemporary management thought, exemplified by his concept of "knowledge creation," is an instructive case (Nonaka 1994; Nonaka & Takeuchi, 1995). While much of Nonaka's work has been grounded in case study research of well-known Japanese technology-intensive corporations, his ideas and his subsequent research have in fact been framed by his early readings in epistemology, especially the writings of the philosopher Polanyi (1966).

The third theoretical implication of this research lies in the area of organization studies. As indicated earlier in this paper, a huge body of business literature has been produced in the area of interorganizational relationships, dealing with such topics as joint ventures, alliances, interfirm cooperation, market transactions, business networks, and the dynamic factors that determine the boundaries of firms. The data analyzed above reveal that interorganizational factors can indeed play a big role in determining the relative performance of technology-intensive enterprises. Much of the literature to date has been concerned with developing theories that explain why certain organizational configurations emerge as a basis for predicting under what conditions they will dominate. The research documented in this paper suggests that there is a need for normative theory dealing with the impact on performance of high-technology firms of various types of interorganizational behaviors. More particularly, my data have revealed the relative importance of *informal* interorganizational relationships over *formal* interorganizational relationships. The majority of theoretical developments within the last decade of management research on interorganizational relationships have focused on the formal dimensions rather than on the informal dimensions. A stronger emphasis on informal interactions rather than formal ties between organizations in future theory development is indicated. Notable examples of research that points the way include the studies of Bouty (2000), Kogut and Zander (1992), Kreiner and Schultz (1993), Schrader (1991, 1995), Spender (1996), and Von Hippel (1987).

The fourth theoretical implication of the research documented in this paper is suggested by the concept itself of the local technological milieu. The intellectual seeds, which eventually budded in to the conceptual flower of the local technological milieu, came from the academic seed beds of a wide variety of disciplines, including geography, city and regional planning, economic development studies, public policy analysis, philosophy, and technology studies. The implication of this is that the future development of management theory in the domain of technology may be aided by prudent yet open-minded interdisciplinary theoretical inquiry.

7.3. Implications for future research

The empirical research reported in this paper was based on one particular set of related industries: biotechnology and other bioscience technology industries (medical devices technology, pharmaceuticals technology, and other fields of technology related to the life sciences). Compared with the majority of industries that make up the American economy, all subsectors of the bioscience technology sector are quite knowledge intensive. However, the fact that positive local technological milieux effects on firm performance are observable (at statistically significant levels) mainly only for the biotechnology firms raises some interesting questions. Just how knowledge intensive does a firm need to be to benefit from being embedded in a rich local technological milieu?

It would be valuable to conduct similar research for other industry sets to see how broadly applicable these results would be across a range of technological fields. The multivariate statistics reported here suggest that it is knowledge intensity that makes the difference to a firm rather than the fact that it is part of the biotechnology industry per se. Apparently, strong "milieu effects" are observable in the biotechnology industry primarily because biotechnology firms tend, by their very nature, to be knowledge intensive in their activities. However, similar research in other technology fields would serve to test the robustness of the results.

Similarly, the data in this study came from firms in one particular region within the United States, New York State. New York is a superb field laboratory for research in to technology-based industries because it is both big enough to contain a substantial population of firms and small enough that it is feasible to conduct an original study. In addition, New York State contains a full repertoire of industrial and economic settings, including metropolitan New York City, Long Island, Westchester County, and the whole upstate region, which includes small scientifically rich (yet somewhat isolated) towns such as Ithaca, medium-sized cities such as Syracuse and Rochester (that have been homes to technology-based industries for many years), and many rustic small towns that often form congenial homes for technology-based enterprises. New York has a rich diversity of economic, demographic, geographic, industrial, and institutional conditions that make it ideal for technology-related industry research. Nevertheless, the universal applicability of the results of this research needs to be tested by conducting similar studies in other geographic regions, including regions outside the United States.

The prominence in this study of informal and intangible factors as determinants of the performance of high-technology firms (as opposed to formal factors such as the appearance of joint ventures and interfirm alliances) has significant implications for research methodology. The vast majority of studies by management researchers during the last two decades—on the interorganizational relationships of firms—have been based on secondary data, mostly drawn from publicly available sources. There are good reasons for this: it is cheaper and more efficient to test theories based on data already collected than it is to build fresh data sets from the ground up, especially if researchers wish to work with large data sets (and even more so when the time-constrained pressures of "publish or perish" may apply).

However, publicly available data sets tend to be biased almost exclusively toward *formal* organizational phenomena (such as recorded transactions, joint venture arrangements, and legally structured interfirm agreements). Furthermore, publicly available industry data sets are heavily biased toward publicly traded firms (because it is, by definition, much easier to collect data from public firms than it is to collect data from private firms). In contrast—notwithstanding the fact that the majority of articles on technology enterprises in both scholarly journals and the popular business press feature publicly traded firms—the vast majority of technology firms are privately owned (in the population that was the focus for this study, less than 10% of firms were publicly traded). Hence, the results of the majority of the quantitative multivariate interorganizational studies that have been conducted by management scholars during the last two decades are biased toward the somewhat distinctive conditions of public firms (hence, toward formal rather than informal interorganizational phenomena).

The implication of these matters is that scholars in the field of technology management need to conduct more original studies, from the ground up, based on direct data collection from representative samples of the whole population of technology enterprises in a particular industry, giving appropriate weight to private firms as well as public firms. The *informal* interorganizational factors that appear to play such an important role in building competitiveness for high-technology enterprises may not be properly addressed without serious efforts along these lines, although such research may take more time to complete. This study has demonstrated the potential fruitfulness of such research methods.

7.4. Implications for managerial practice

The primary implication of the research described in this paper for managers of high-technology enterprises is that they are more likely to achieve business success associated with technological innovation if their actions conform to the requirements of a Milieux Embeddedness strategy rather than an Affordable Resources strategy. In practice, that means several things. First of all, it means that the managers themselves need to spend a great deal of time engaging in conversation with managers of other firms in their own industry and with leaders in a range of complementary industries and organizations. Informal communication—that is, talking (whether face to face, by telephone, or by other means)—is likely to yield greater results than might be expected in areas such as attraction of additional capital, identification of attractive pathways for R&D projects, obtaining critical information about technological options and trajectories, attracting scarce talent to the enterprise, identification of new markets and applications for existing technologies, and generation of new knowledge.

Secondly, it means that managers should encourage their employees and other key people associated with their firms to engage actively in communication with their counterparts in other companies both locally (in the same city or region as the firm's home base) and elsewhere in the world. Informal communication should be extended to wherever key people (in touch with pertinent knowledge) are located, no matter whereabouts in the world that may be. High levels of spending on national and international travel, telecommunications, or entertainment should be seen as potentially valuable investments rather than as questionable perquisites to be avoided. The allocation of employees' time to "keeping in touch" with what is going on in their industry and related industries—locally and globally—should be seen as an essential part of the core activities of the enterprise rather than as a distraction from "real work." This principle is particularly important when the firm is in a relatively isolated place.

Thirdly, it means that the firm should not place undue emphasis on secrecy and parsimony in the sharing of information with potential competitors. While care should of course be taken with basic legal aspects of intellectual property protection, managers of technology enterprises should realize that the dark side of technological and business secrecy is isolation from other people's knowledge—knowledge that could be critically important to the development of one's own enterprise. A company with a culture that militates against its people sharing information with their counterparts in other organizations, under the guise of intellectual property protection and confidential business information, will consequently also be excluded from important informal information networks. Knowledge generation requires a certain amount of reciprocity in information sharing outside the boundaries of the firm.

Fourthly, it means that high-technology managers should see their firms and the people associated with their firms as belonging to a loose knit community of individuals and organizations and a web of nodes of knowledge and expertise rather than as being discrete islands of technological enterprise.

Fifthly, the results of this study suggest that proportionally increasing spending on R&D is unlikely to yield competitive advantage or significant business results for a firm, unless such investments are matched by a concomitant increase in informal engagement by that firm's people in vibrant technological milieux both locally and elsewhere. In other words, allocating resources to support informal participation in professional networks and other pertinent social and business networks is an important complementary "asset" to direct investment in R&D.

Finally, this study suggests that managers of technology-based enterprises need to be aware that the more knowledge intensive their businesses become the more important it is that they and their employees engage locally and connect globally with other people in their own industry and in related or complementary fields.

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