ELSEVIER

DYNAMIC CAPABILITIES AND NEW PRODUCT DEVELOPMENT IN HIGH TECHNOLOGY VENTURES: AN EMPIRICAL ANALYSIS OF NEW BIOTECHNOLOGY FIRMS

DAVID L. DEEDS, Ph.D.
Weatherhead School of Management
Case Western Reserve University

DONA DeCAROLIS, Ph.D.
College of Business Administration
Drexel University

JOSEPH COOMBS
School of Business & Management
James Madison University

EXECUTIVE SUMMARY

In industries populated by entrepreneurial high technology firms, the rapid development of new products is viewed as a key determinant of success. Developing a portfolio of new products is necessary to gain early cash flows, external visibility and legitimacy, early market share, and increase the likelihood of survival (Schoonhoven, Eisenhardt, and Lyman 1990). In addition, recent research has shown that new product development improves a firm's ability to raise money through an initial public offering (Deeds, DeCarolis, and Coombs 1997).

This paper develops a model of new product development which is tested on a sample of 94 pharmaceutical biotechnology companies. We hypothesize that new product development capabilities are a function of a firm's scientific, technological, and managerial skills. To test this relationship, we develop several

Address correspondence to David L. Deeds at Weatherhead School of Management, Case Western Reserve University, 10900 Euclid Ave., Enterprise Hall, Cleveland, Ohio 44106; (216) 368-6008; E-mail: entprof@aol.com

Journal of Business Venturing **15**, 211–229

655 Avenue of the Americas, New York, NY 10010
0883-9026/00/$–see front matter
PII S0883-9026(98)00013-5

firm specific measures in an attempt to triangulate in on the core construct of firm specific new product development capabilities.

Some important implications for entrepreneurs/managers of high technology firms flow from our results. First, entrepreneur/managers need to view the choice of geographic location as an important strategic decision which will impact their firm's access to the skilled technical personnel and the streams of knowledge. Our results indicate that a choice location has a significant concentration of similar firms, but the level has not yet reached a point where competition for resources in the local environment offsets any advantages of the location. In the case of biotechnology, this would seem to indicate that the prime locations would be expanding areas such as San Diego, Seattle, and Philadelphia rather then the established locations of Silicon Valley and Boston.

Second, as scientific knowledge plays an ever more important role in a firm's success the quality of the firm's scientific team is a critical ingredient in a firm's new product development capability. But how do you evaluate the quality of scientific personnel? Our results indicate that there is a strong positive relationship between the impact—as measured by citations—of a team's prior research in the academic community and the productivity of that team in a commercial research laboratory. Therefore, the judgement of a scientific field, captured by citations or perhaps expert judgement, should prove to be a useful tool when evaluating personnel for a firm's research team.

Third, the results from our measures of CEO experience and the percentage of the top management team with a Ph.D. are interesting. As expected the prior experience of CEO in managing a commercial research facility enhances a firm's new product development capabilities. However, results for our top management team variable appears to indicate that the over reliance on technical personnel in the management of the organization detracts from the product development process. Taken together these results seem to imply that it is important that the leadership of the organization have knowledge of and experience in managing the new product development process, but that diverting the firm's scientific personnel's energies away from the laboratory and into the management of the organization maybe counter-productive. Therefore, what a high technology venture appears to need is leadership that understands and has experience in the new product development process, but which is separate and distinct from the scientific team. This type of leadership keeps the scientific team focused on research and development, and out of the boardroom.

INTRODUCTION

In industries populated by entrepreneurial high technology firms, the rapid development of new products is a key determinant of success. Companies in industries such as biotechnology, computers, and electronics face an environment characterized by incessantly changing technologies and intense global competition. These dynamic environments demand that firms be innovative with respect to their product offerings. Thus, to compete and survive, these firms must rely on a steady stream of innovative products.

Developing a portfolio of new products is necessary to gain early cash flows, to enhance external visibility and legitimacy, to attain early market share, and to increase the likelihood of survival (Schoonhoven, Eisenhardt, and Lyman 1990). In addition, recent research has shown that new product development improves a firm's ability to raise money through an initial public offering (Deeds, DeCarolis, and Coombs 1997).

The ability to consistently generate new products is dependent on a firm's scientific and technological capabilities. These capabilities must be as dynamic as the environment in which they exist. Capabilities are embedded in the firm's knowledge base and in high technology industries. This knowledge base is continually advancing.

For capabilities to be relevant to managers and researchers, measures of these capabilities need to be developed at the firm level, and as such, identifying and measuring organizational capabilities has become an integral part of recent research efforts. (Hen-

derson and Cockburn 1994; Pisano 1994; Leonard-Barton 1992; Hall 1993). What we have learned from this empirical research is that those organizational capabilities or competencies which give rise to competitive advantage are not "simple" assets, but compound asset structures which are built over time and are path dependent (Dierckx and Cool 1989; Schendel 1994; Teece, Pisano, and Schuen 1992).

Several studies have provided empirical support for the proposition that firm specific capabilities may lead to persistent performance differences among firms (Henderson and Cockburn 1994; Rumelt 1991). Recent research (Henderson and Cockburn 1994; Pisano 1994) indicates that firm specific differences will also lead to differences in research productivity among firms. Another study has also indicated that a firm's research and development skills are important in the creation of shareholder value (Kelm, Narayanan, and Pinches 1995).

This study focuses on the biotechnology industry and the firm variables which lead to new product development in this industry. Our model is based on the premises established in the dynamic capabilities theory (Teece, Pisano, and Shuen 1992) as our independent variables reflect the accumulated and evolving capabilities of firms which lead to new product development. We suggest that new product development is a function of a firm's location, scientific capabilities, external contacts, and the functional and educational background of top managers. The next section of the paper provides the theoretical background and the development of the hypotheses. The second and third sections present the methodology and the results of the statistical analysis, respectively. We conclude with a discussion of the implications of this research and suggestions for future research.

THEORY AND HYPOTHESES

The resource based view of the firm, initially developed by Penrose (1959), proposes that a firm's competitive advantage is in large part determined by its unique resources and capabilities. A basic premise in this theory is that those firm capabilities which are rare, inimitable, and difficult to trade form the basis for sustainable competitive advantage (Barney 1991). Subsequent researchers have highlighted the importance of intangible resources, such as knowledge and scientific capabilities, to competitive advantage (Henderson and Cockburn 1994; Kogut and Zander 1992; Petraff 1993). These resources are tacit, complex, and firm specific, rendering them inimitable to rivals (Reed and DeFillippi 1990).

The dynamic capabilities approach to understanding the business enterprise builds upon the basic assumptions of resource-based theory through its assertion that these unique firm capabilities develop over time. This accumulation of capabilities is driven by organizational learning and molded by path dependencies, complementary assets, and industry opportunities (Teece, Pisano, and Schuen 1992). This approach emphasizes that it is not only the bundle of resources which matters but also the mechanisms through which firms accumulate these skills and the contingencies which constrain their direction.

According to dynamic capabilities theory, firms accumulate knowledge, expertise, and skills through organizational learning. Learning enables firms to perform their activities in improved ways. Organizational learning occurs as individuals interact with each other and develop common codes of communication and coordinated search proce-

dures. Moreover, organizational learning is not limited to internal activity but also results from assimilating and utilizing knowledge generated outside the firm.

The accumulated knowledge generated by organizational learning is, of course, not static but dynamic as organizations continue to learn. This firm knowledge is not boundless, however, as the firm is constrained in its knowledge development by path dependencies. "History matters" and as such, firms learn in areas which are related to previous activities. (Hill and Deeds 1997; Teece, Pisano, and Schuen 1992)

The path of firm knowledge is also constrained by a firm's complementary assets. Firms have an established asset base from prior activities. Any new products or processes which require radically different complementary assets, particularly in terms of manufacturing and downstream activities, can enhance or destroy the value of previously established assets (Leonard-Barton 1992). Consequently, because of path dependencies and complementary assets, organizational capabilities, though dynamic, are constrained in their direction.

In the context of the biotechnology industry, dynamic capabilities theory is a particularly useful lens through which we can view and appreciate the knowledge-building which leads to new product development. The knowledge base of this industry is in its infancy stage (Pisano 1994) thus providing a broad and rich springboard for future advancements. Therefore, a firm's product development capabilities in the biotechnology industry must keep pace with the advances in basic scientific research in such areas as molecular biology and genetics.

In light of this, assessment of present and future research capabilities is more uncertain in small biotechnology firms than in the pharmaceutical industry. Specifically, this is due to the fact that the industry is based on highly complex and specific knowledge which is still emerging, unlike the mature knowledge structure of the traditional pharmaceutical companies (Pisano 1994). These companies are generating not only new products but new methods to discover new drugs and new types of medical instruments and diagnostic tools. Much of their knowledge is based not only on molecular biology and organic chemistry but also on such diverse fields as computer technology and software development. Their knowledge bases represent a confluence of disciplines very unlike traditional pharmaceutical companies

Being dependent on emerging new knowledge, biotechnology companies cannot rely solely on internal knowledge development. They need to absorb relevant knowledge from external sources. Their absorptive capacity (Cohen and Levinthal 1990) is critical to their ultimate success.

In an atmosphere where new knowledge generation is occurring at such a rapid pace, biotechnology companies must be continually tapping flows of knowledge (both internal and external) and using these to refine their product development capabilities. Competitive advantage in this industry depends upon the continual accumulation of relevant knowledge. In the following section, we outline our model of stocks and flows of organizational knowledge in the biotechnology industry and their relationship to a firm's ability to develop new products.

Geographic Location and New Product Development

Organizations develop their capabilities not only through internal learning but also through the absorption of knowledge from external sources such as competitors, trade associations, suppliers, customers, and formal and informal meetings (Cohen and Levin-

thal 1990; Pouder and St. John 1996). There is much evidence throughout history of "hot spots"—clusters of firms in one industry located in close geographic proximity (Pouder and St. John 1996).

External sources of knowledge are critical to innovation. (Brock 1975; Mansfield 1988; Peck 1962; Rosenberg and Steinmuller 1988; Saxenian 1990). March and Simon (1958) have suggested that "borrowing" is the catalyst for innovation, not "invention." Innovation then, to a large extent, is dependent on a firm's ability to absorb information from the external environment. This "borrowing" frequently forms the basis for the development of capabilities (Teece, Pisano, and Shuen 1992) which evolve over time as new knowledge is learned and integrated into any organization.

Organizations have an 'absorptive capacity' which is the ability of an organization to evaluate and assimilate external knowledge and is a function of the level of a firm's prior related knowledge (Cohen and Levinthal 1990). Absorptive capacity enables a firm to recognize valuable new information, assimilate it, and apply it to the development and refinement of dynamic capabilities. Interfacing with the external environment is critical to an organization's dynamic capabilities. The structure of communication between the external environment and the organization enhances the learning capacity of individual firms. Consequently, the physical location of a firm may serve to enhance dynamic capabilities through communication flows. Close proximity of organizations with similar interests promotes the natural exchange of ideas through both formal and informal networks established among the organizations.

Knowledge spillovers leading to interorganizational learning occur through formal and informal channels of communications among employees. There are many mechanisms of knowledge diffusion. Formal mechanisms among firms include licensing, technology partnerships, strategic alliances, and acquisitions. Informal channels of knowledge may be found in the inter-firm mobility of scientists and engineers (Rogers and Larsen 1984). These informal mechanisms also include such events as social meetings and trade meetings (Almeida and Kogut 1994; Saxenian 1990).

Recent empirical work on knowledge spillovers also attests to the fact that knowledge tends to be localized. Jaffe, Trajtenberg, and Henderson (1993) investigated the extent to which knowledge spillovers are geographically localized by comparing the geographic location of patent citations to that of cited patents. They found strong evidence of localization of knowledge spillovers on three geographic levels—country, state, and Metropolitan Statistical Area (MSA). Almeida and Kogut (1994) examined the relationship between geographic location and patent holders in the semiconductor industry. Their fine-grained analysis examined the movement of inventors of major patents from 1974–1994. They found significant intra-regional mobility, particularly in the Silicon Valley.

Therefore, a firm located in a geographic area with a high concentration of similar firms will have access to knowledge which is unavailable to firms which are geographically isolated. Because of this increased access to scientific and technological knowledge, a firm's dynamic capabilities are enhanced by its geographic location. Thus, the location of a firm is an indicator of its propensity to absorb new knowledge and to develop and refine the dynamic capabilities required to create new products. Thus, these location advantages should increase the speed with which new products are developed by the firm.

H1: The concentration of biotechnology firms located in a firm's geographic area will have a positive relationship with the number of new products developed by the firm.

However, the relationship between geographic concentration and the development of new products may not be as simple as the proposed linear relationship. Organizational ecology argues that at low and moderate levels of density the legitimation dynamic predominates, improving performance, but at high density the competitive dynamic predominates and performance will be decreased (Hannan and Freeman 1989). Thus the rate of failures decreases until it reaches an inflection point at which the rate begins to increase. The converse occurs for founding rates. This model has been empirically tested on organizational populations such as museums (Blau 1991), newspapers (Carroll and Hannan 1989), breweries (Carroll and Wade 1991), and several other industries. When accessing resources required for new product development at low and moderate levels of concentration, the positive effects discussed above are likely to predominate and improve the productivity of a firm's product development. However, at higher levels of concentration, the competition for resources will have a negative impact on a firm's ability to develop new products. Therefore, the relationship between new product development and geographic concentration is likely to be an inverse U-shaped relationship with new product development increasing initially until some point at which the increasing competition for resources decreases a firm's ability to create new products (Figure 1):

> *H1A:* There will be an inverted U-shaped relationship between the concentration of biotechnology firms located in a firm's geographic and the number of new products developed by the firm.

Research Team Capabilities and New Product Development

Many researchers have suggested that locally embedded competencies found within the scientific team contribute to new product development (Henderson and Cockburn 1994; Leonard-Barton 1992). In high technology environments product development is increasingly being driven by basic scientific research (Dasgupta and David 1994). Biotechnology in particular is highly dependent upon scientific research capabilities, due to the highly complex and evolving nature of the knowledge base of the industry (Pisano 1994). Therefore, the quality of a firm's scientific team will be critical to the product development process.

Consistent with the dynamic capabilities theory, the skills and expertise of a firm's research scientists may be viewed as a bundle of intangible and valuable resources which accumulate over time. Not only are research capabilities critical to the internal creation of new knowledge, but the capabilities of the scientific team are also critical to the firm's ability to absorb, evaluate, and act upon research being carried out beyond the boundaries of the firm.

In the 'science club' membership is dependent upon the creation and dissemination of new knowledge (Dasgupta and David 1994, McMillan, Klavans, and Hamilton 1995). The informal exchange of information that occurs at conferences and seminars, and access to working papers are very valuable to new product development, but access to these information sources is limited to 'scientific club' members (della Valle and Gambardella 1993). It is the publication record of individuals, labs, and firms that are used to determine membership into the 'club' (McMillan, Klavans, and Hamilton 1995). In fact, publication record has been found to be highly correlated with the desirability of a pharmaceutical firm as an employer by Ph.D. students and Post-docs (McMillan

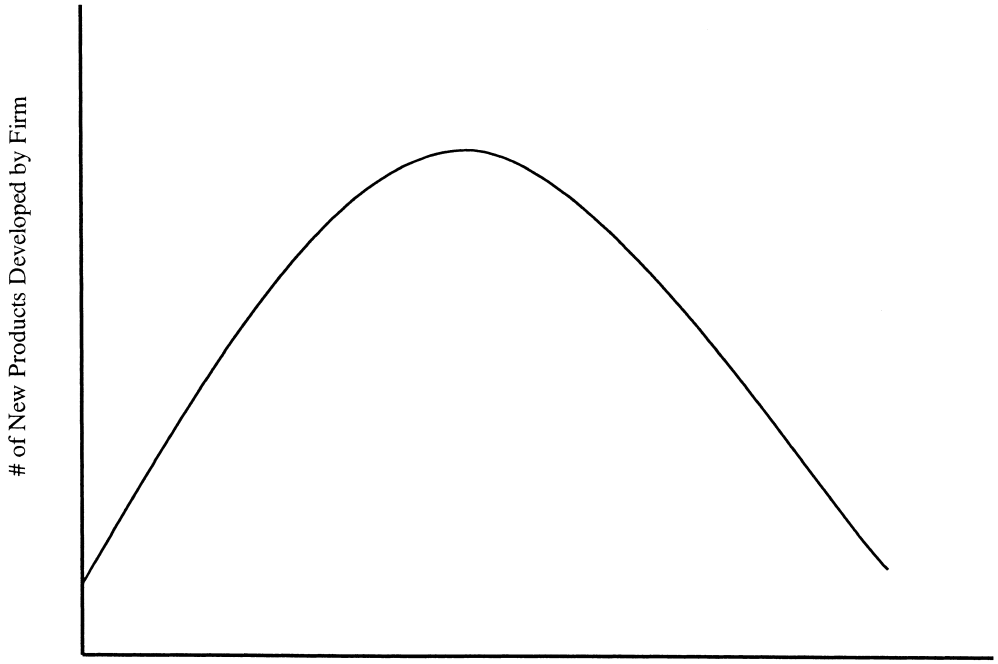

FIGURE 1 The relationship between geographic location and new product development.

and Deeds 1997) and with patenting activity by pharmaceutical companies (McMillan 1995). Therefore, not only will a firm with a strong group of scientists be more likely to internally generate new knowledge, but it will also have superior access to critical new developments and be able to rapidly incorporate leading edge research from beyond the firm's boundaries into the firm's product development efforts. In the context of the biotechnology industry where the knowledge base is immature and evolving rapidly (Pisano 1994), access to external knowledge is essential. Thus, we hypothesize:

> *H2:* The quality of the firm's research team will have a positive relationship with the number of new products developed by the firm.

Strategic Alliances and New Product Development

As we argued previously, the accumulated knowledge generated by organizational learning is not boundless and firms are constrained in their knowledge development by path dependencies created by their prior investment in their knowledge base, capabilities, and complementary assets (Hill and Deeds 1996; Leonard-Barton 1992; Teece, Pisano, and Schuen 1992). Consequently, because of path dependencies and complementary assets, organizational capabilities, though dynamic, are constrained in their direction. In addition, given the complexity and multi-disciplinarity of new product development, new ventures are unlikely to have the broad range of skills, assets, and capabilities necessary to fully exploit the capabilities they have developed (Deeds and Hill 1996; Teece 1986).

However, there is a solution to this problem. High technology ventures can reach beyond their boundaries to access the complementary capabilities the new product de-

velopment process requires (Teece 1986). In addition to providing access to the complementary assets necessary to leverage existing capabilities, information from these external linkages can increase a firm's openness to its environment and stimulate internal innovativeness (Haagedorn 1993; Terpstra and Simonin 1993). In fact, Teece has argued that "to be successful, innovating organizations must form linkages upstream and downstream, lateral and horizontal" (1992: 22). Consistent with these arguments, Deeds and Hill (1996) and Shan et al. (1995) found a positive relationship between the number of a firm's strategic alliances and their new product development. This leads to our next hypothesis.

> *H3:* The total number of strategic alliance of a firm will have a positive relationship with the number of new products developed by the firm.

R&D Management Capabilities and New Product Development

How does an organization decide which capabilities to develop and which to drop? Which development projects to invest in and which to pass? Theoretical and empirical research has shown that decisions to initiate strategic change or undertake new strategic initiatives are the responsibility of the top management team of the organization (Child 1972; Hambrick 1994). Research in this stream has shown that the demographics of the top management team and the CEO play an important role in determining organizational strategies and culture (Bantel and Jackson 1989; Scherer and Huh 1992; Wiersema and Bantel 1992). The skills, knowledge, and background that executives bring with them play a critical role in determining the organization's strategic choices. In a technologically uncertain environment determining the capabilities in which the firm invests is critical to the productivity of the research process and the future of the firm.

As argued previously, the knowledge base of the biotechnology industry is in its infancy stage (Pisano 1994), and a firm's product development capabilities must keep pace with the advances in basic scientific research in such areas as molecular biology and genetics. Under these circumstances the assessment of present and future research capabilities is uncertain and highly dependent upon specific technical knowledge. These companies are generating not only new products but also new methods to discover new drugs and new types of medical instruments and diagnostic tools. Much of their knowledge is based not only in molecular biology and organic chemistry but also on such diverse fields as computer technology and software development.

In this research intensive environment a top management team which has a high degree of technical knowledge, skills, and prior experience in managing the R&D organizations will be better equipped to judge the potential of competing research streams and better able to direct scarce research funds towards the development of more valuable capabilities. This leads to our final hypothesis.

> *H4:* A firm's R&D management capabilities will have a positive relationship with the number of new products developed by the firm.

METHODOLOGY

The Sample and Data

The biotechnology industry of 225 publicly held companies provides the population of firms for this investigation (Burrill and Lee 1993). These firms were contacted by phone

with a request for a copy of the prospectus from their IPO. A total of 106 companies, representing a response rate of 47%, were willing to provide a prospectus. However, twelve of these companies were excluded from the sample because of incomplete data. Thus, our final sample consisted of 94 firms.

To test for potential biases in this sample we compared the average total assets and average total liabilities of the firms in our sample in 1992 to the average total assets and liabilities reported by Burill and Lee (1993) for all 225 public firms. Our sample averaged $11,023,000 in total assets and $3,784,000 in total liabilities. Burill and Lee (1993) reported the average total assets and total liabilities of the 225 public biotechnology firms in 1992 as $11,377,000 and $3,313,000 respectively. Based on this comparison and the size of our sample, we believe we have a fairly representative sample of the publicly held biotechnology companies.

The data used in our analysis was gathered from (1) the prospectus for each of the initial public offerings by the firms in our sample; (2) Ernst and Young's industry annual reports on the biotechnology industry and (3) the Institute for Scientific Information's Science Citation Index.

Measures

New Product Development

The dependent variable in this study is new product development. We emphasize "development" to call attention to the fact that in the biotechnology industry, it is the development of new products—that is, products still in the pipeline—which is critical to success. Due to the early stage of development of the firms and the industry, very few products have actually reached the market.

The most unambiguous definition of new products is to only recognize products that have been cleared by the appropriate regulatory agency (FDA, EPA, or Dept. of Agriculture) and reached the market as "products". This seems reasonable since the ultimate aim of any biotechnology company is the final regulatory approval of their products. However, this does mean excluding those "products" currently undergoing trials that might reach the market at some future date—and one could argue that such "products" should be included in the total count since they represent the innovative output of a new biotechnology firm. In addition, the relative youth of the biotechnology industry and the 10-year development time that is now common for new drugs argues in favor of a broader definition of "products". Finally, as mentioned earlier recent work has related the number of products in a firm's pipeline to the ability of entrepreneurial firms to raise capital through an IPO (Deeds, DeCarolis, and Coombs 1997) and the creation of shareholder value (Kelm et al. 1995). Therefore, we defined total products as products on the market plus the number of products that a firm has in regulatory trials (field trials, pre-clinical, and clinical trials). This measure has been used in prior studies of the research productivity of biotechnology firms (Deeds and Hill 1996; Shan et al. 1994).

Product information was gathered from the business section of the prospectus for each of these firms' initial public offerings. Only products which had reached the preclinical stage of development or beyond were included. Multiple applications of the same product were counted as a single product.

Independent Variables

Location

Based on the location of the firm's headquarters, firms were coded into geographic territories according to zip code and MSA (Metropolitan Statistical Areas). These locations were then compared to the eight areas identified by Burill and Lee as concentrations of biotechnology activity. In order to capture the variance in the concentration of these eight areas, the location variable is the percentage of the nation's total biotechnology firms located in the firm's specific MSA. A "0" was recorded for firms not in one of the eight geographical areas.

Quality of the Scientific Team

In this study we are using citation analysis as an indication of the quality of the scientific personnel of the biotechnology firm. A widely accepted method of assessing research quality in the academic community is citation analysis. Citation analysis uses the number of times a paper or an author is cited as an indication of the importance of the work to the field. The more frequently the paper or an individual's body of work is cited, the more important and, hence, the higher the quality of the work. Those of us who have chased or are chasing tenure in academia are quite familiar with the importance citations are given during the tenure process.

Citation analysis has been used to map the development of fields of scientific inquiry (Small and Griffith 1974), to estimate the quality of the scientific capabilities of countries in specific fields (Healey, et al. 1986), the performance of academic departments (Wallmark et al. 1988), and as the basis for the assessment of scientific and technical research programs (Narin and Rozek 1988; Vinkler 1986). In addition, citation analysis has recently entered into the discussion of strategic planning. Van Der Eerden and Saelens (1991) discussed the use of citations as indicators of research group performance and the quality of the scientific research being undertaken by the group, as well as a tool to guide competitive assessment, merger and acquisition targeting, and research strategy. Therefore, it is our contention that the number of citations a firm's scientists have is an indication of the quality of a firm's scientific capabilities and a predictor of a firm's research productivity.

The names of the top scientists employed by each firm were gathered from the prospectus of the firm's initial public offering. Only full time employees were included in the list in order to control for biases created by firms attempting to increase their visibility/legitimacy by hiring a long list of scientific advisors or consultants. Names of all scientific personnel listed in the prospectus as well as top executives were compiled. We then used the Science Citation Index to gather the total number of citations for each scientist in the firm during his/her career. These citations were then totaled to create a measure of the quality of the scientific team employed by the biotechnology firm at the time of its initial public offering.

Number of Strategic Alliances

This variable is the total number of formal strategic alliances entered into by the firm. This data was reported in the prospectus of the firm's IPO. All contractual agreements

between the firm and both for-profit and non-profit organizations are described in the business section of the prospectus.

R&D Management Capabilities

This variable was measured in two ways. First, we measured the percentage of the management team with a Ph.D. or MD. This data was gathered from the firm's prospectus. The top management team was defined as the CEO and the next highest level as determined by the title. Vice presidents were included in the team if there was no designation of executive vice president.

The second measure for the quality of the research scientists was whether or not the CEO had prior research management experience. This variable is a dummy variable which is coded as "1" if the CEO's biography described him/her as having prior experience as the manager of an R&D laboratory or as a vice president of research and development at a for-profit organization. This variable was gathered from the firm's prospectus.

Control Variables

Age

The age of the firm was calculated from the date of inception of operations until the date of the initial public offering, as reported in the prospectus.

Number of Employees

In order to control for the effects of size on research productivity, the total number of employees of the firm was included in our regressions. This data was gathered from the firm's prospectus.

R&D Intensity

The intensity of a firm's expenditures on research and development has been used as an indicator of innovative activity in many industries (Scherer 1980). Several studies have looked at the relationship between R&D spending and productivity returns (Grabowski and Vernon 1990; Graves and Langowitz 1993; Pakes 1985; Vernon and Gusen 1974), and several studies have linked R&D expenditures to increases in market value (Chauvin and Hershey 1993; Doukas and Switzer 1992). R&D intensity was measured as the total R&D expenditure reported by the firm in the prior year, divided by the total expenditures of the firm. The traditional measure of R&D intensity has been R&D as a percentage of sales, but, given their early stage of development, most of these companies have little or no revenue, therefore, dividing through by total expenditures was the logical choice to measure the firm's focus on R&D.

TABLE 1 Descriptive Statistics

Variable	Mean	Standard Deviation
Log (total products)	0.53	0.36
Location	7.53	5.13
Firm citations	125.60	138.37
Alliances	4.75	3.51
CEO R&D experience	0.28	0.45
TMT % w/Ph.D.	0.47	0.21
Age	5.48	4.01
Log (# employees)	1.71	0.41
R&D intensity	0.59	0.24

Statistical Modeling Technique

You will recall that we have competing hypotheses 1 and 1A. Hypothesis 1 predicts an increasing linear relationship between geographic concentration and the number of new products developed by the firm. Hypothesis 1A predicts an inverted U shaped relationship with the number of new products initially increasing with concentration and then decreasing after the competition for resources intensities. We used a quadratic model to test this hypothesis. This has the following form:

$$\text{New Product Development} = a + b_1.\text{Location} + b_2.\text{Location}^2 + b_3.Z_1 + b_4.Z_n + \ldots\ldots b_n.Z_n + e$$

If b_1 is positive and b_2 is negative, and both coefficients are statistically significant, there is evidence for a inverted U-shaped relationship. However, if b2 is negative and statistically significant, and b3 is insignificant then the relationship between geographic concentration and new product development matches that of hypothesis 1.

RESULTS

The data was analyzed using ordinary least squares regression. Descriptive statistics of the variables are presented in Table 1. The average firm in our sample was 5.48 years old, had 81 employees, 3.8 products in the pipeline, spent 59% of its total expenditures on R&D, 4.8 alliances, and was located in a metropolitan area with 7.5 % of the total national biotechnology firms. The scientific research team of the average firm had been cited 125 times during their careers prior to the firm's initial public offering. On average 47% of the firm TMT had a Ph.D. and 28% of the firms had a CEO who had prior R&D management experience. The correlation matrix is presented in Table 2.

Table 3 presents the results of the regression analyses with the log of the number of products a firm has on the market or in trials as the dependent variable. The base model presents the results from regressing our control variables on the number of products. The adjusted R2 for the model is 0.23 and the f-statistic is highly significant. However, only R&D intensity is significant beyond the 0.10 level. Model 1 is presented to provide a comparison of the explanatory power of our variables of interest and the base model. In this run only the explanatory variables were regressed on the number of new products. Model 1 has an adjusted R2 of 0.23, and location, firm citations, and CEO R&D experience are all significant at the 0.05 level. Model 2 presents the full model excluding the square of the geographic concentration. The adjusted R2 for the model

TABLE 2 Correlation Matrix

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Log (total products)	1.00	0.32	0.25	0.32	0.21	0.25	0.17	0.10	0.16	0.49
Location	0.32	1.00	0.95	0.12	0.20	−0.11	0.08	0.10	0.19	0.17
Location^2	0.25	0.95	1.00	0.09	0.21	−0.18	0.05	0.14	0.14	0.16
Firm citations	0.32	0.12	0.09	1.00	0.20	0.08	0.20	0.16	0.06	0.21
Alliances	0.21	0.20	0.21	0.20	1.00	0.09	0.13	−0.06	0.18	0.33
CEO R&D experience	0.25	−0.11	−0.18	0.08	0.09	1.00	0.17	0.01	0.14	0.01
TMT % w/Ph.D.	0.17	0.08	0.05	0.20	0.13	0.17	1.00	−0.10	0.17	0.46
Age	0.10	0.10	0.14	0.16	−0.06	0.01	−0.10	1.00	0.17	0.10
Log (# employees)	0.16	0.19	0.14	0.06	0.18	0.14	0.17	0.17	1.00	0.13
R&D intensity	0.49	0.17	0.16	0.21	0.33	0.01	0.46	0.10	0.13	1.00

$p < 0.05$ when $r > 0.18$; $n = 94$.

is 0.36 and the f-statistic is highly significant. The coefficients for location, firm citations, and CEO R&D experience are all significant at the 0.05 level with signs as expected. However, the percentage of the top management team with a research degree is negative and significant at the 0.10 level. Model 3 includes the squared geographic concentration measure. The adjusted R2 for this model is 0.39 and the f-statistic is highly significant. The signs and significance level of all the variables remains steady with the inclusion of the squared term. The coefficient of the square of the geographic concentrations measure is negative and significant at the 0.10 level. These statistics indicate that Model 3 is the best fit for our data and is explaining a significant amount of the variation in number of new product developed by the firms in our sample. The remaining discussion will be based upon the results from Model 3, since it provides the best fit with our data.

Hypothesis 1 is supported as well. Hypothesis 1A also has weak support ($p < 0.10$). Location has a significant ($p < 0.01$) positive impact on a firm's new product development. Specifically, a firm located in an area with a higher concentration of biotechnology firms has a significantly higher number of products completed or in trials than those located in areas with lower concentrations. However, when at the high end of the concentration the negative impact of competition for resources appears to have an impact and actually decreases the firms ability to develop products. In comparing Model 2 and

TABLE 3 Regression Results—Standardized Beta Coefficients

	Base Model	Model #1	Model #2	Model #3
Location		0.76†	0.27‡	0.75‡
Location^2		−0.49		−0.50*
Firm citations		0.22†	0.20†	0.19†
Alliances		0.11	−0.02	0.01
CEO R&D experience		0.22*†	0.29‡	0.26‡
TMT % w/Ph.D.		0.03	−0.16*	−0.16*
Age	0.04		0.01	0.03
Log (# employees)	0.08		−0.03	−0.05
R&D intensity	0.49‡		0.48¶	0.48*¶
Adj. R^2	0.23	0.23	0.36	0.39
f-Statistic	10.84	5.70	7.78	7.43

* $p \leq 0.10$; † $p \leq 0.05$; ‡ $p \leq 0.01$; ¶ $p \leq 0.001$; $n = 94$.

Model 3 the adjusted R2 is higher for Model 3 and the coefficient for the squared term is statistically significant at the 0.10 level. Therefore, the results appear to support the inverted U-shaped relationship of Hypothesis 1A.

The point at which competition for resources due to concentration becomes effective can be found by taking the partial derivatives of our models with respect to the location variable, setting them equal to zero, and solving for location.

$$\text{d(New Products)/d(Location)} = 0.0568 - 2(0.0025)\text{Location} = 0$$
$$\Rightarrow \text{Location} = 0.0568/0.005 = 11.36\%$$

If we examine the derivative we can see that competition for resources does appear to begin to play a role within the current levels of concentration. In fact, the negative effects of geographic concentration appear to outweigh the positive effects in Silicon Valley which has over 14% of the biotechnology companies in the country.

The number of times the top scientists of a biotechnology firm have been cited has a significant ($p < 0.05$) positive impact on the number of products the firm has developed or in trials supporting Hypothesis 2. This clearly indicates that the quality of the scientific team is an important determination of new product development.

Hypothesis 3 is not supported. There is no statistically significant relationship between the number of strategic alliances and new product development. The results for Hypothesis 4 are mixed. The results indicate a barely significant negative ($p < 0.10$) relationship between R&D productivity and the percentage of Ph.D.'s in the TMT. However, there is a significant ($p < 0.01$) positive relationship between the prior R&D management experience of the CEO and the firm's R&D productivity.

DISCUSSION OF RESULTS

Modeling the relationship between a firm's scientific capabilities and the development of new products poses significant obstacles particularly in the biotechnology industry. This is due to many factors, such as the uncertain nature of research and development, the relatively immature knowledge base, the rapid rate of change in the knowledge base, and the inherently complex and tacit nature of the scientific discovery process. Developing a competence in product development requires a significant commitment on the part of a new venture, but, as argued earlier, has a substantial payoff. Our results highlight several firm specific characteristics which can enhance a new venture's product development capability: geographic location, quality of the scientific team, and a CEO who has experience in managing product development.

There has been much theoretical/anecdotal discussion of the role of geographic location in the research process. Our results provide empirical support for the contention that there are both benefits and costs to concentration. Firms which are located close to other firms in the same industry will reap benefits from knowledge spillovers, specialized suppliers, and labor pooling, but our results also indicate that there is a point at which competition for resources within a given geographic location interferes with a firm's ability to develop new products. Within each of the eight biotechnology clusters, there exist not only biotechnology firms but also major non-profit research institutions. The universities and non-profit research institutions provide basic scientific research upon which biotechnology firms build, experienced research and technical personnel, and specialized technical expertise unavailable elsewhere. In addition, these organizations attract skilled personnel to the geographic area which helps create and sustain a

superior labor pool. Trying to discern the separate impact of each of these on our results is difficult, but it is clear that geographic location makes an important contribution to the development of firm's scientific capabilities. However, it also appears that too high a level of concentration can overtax the resources of a local environment and decrease the productivity of a firm's new product development process. Geographic location needs to be an important consideration for managers of research-intensive firms.

The strong positive relationship between a firm's new product development and the number of times the members of the scientific team have been cited provide strong evidence that the capabilities of the individual members of the firms research team does translate into new products. Quality research is recognized and built upon by others in the scientific community. Citation analysis provides a means of objectively assessing the scientific communities evaluation of the research quality of the firm's team. Our results indicate that the scientific community's judgment of the quality of a research team's output is as valid a proxy for the quality of the scientific capabilities of a commercial firm, as it is of the capabilities of an academic research institution. In addition, our results have important implications for managers. In an environment which requires rapid new product development for success, our results indicate that managers should incorporate the scientific communities reaction to the current and previous work of the members and potential members of the firm's scientific team into their evaluation of potential team members. This result does present an interesting question for future research—is the big idea the paper or papers with a large number of cites, or consistent productivity—ie., is a large number of sparsely cited papers a better indicator of a firm's scientific capabilities?

Perhaps the most interesting results are those for our top management team and CEO. A CEO with prior experience in R&D management is clearly beneficial to a biotechnology firm's productivity, but, in contrast, it appears that having too many Ph.D.'s at the top maybe detrimental to a firm's research productivity. The decline in research productivity may be due to the misallocation of human capital. Simply, by placing their research scientists on the TMT the firm's are wasting the time of these scientists on day to day management activities, rather then allowing them to focus on their research. This explanation is consistent with the R&D intensity findings, if you consider these research scientists' time as valuable expenditures away from R&D. In this light, focused expenditures of both monetary and human capital are critical to the development of the capabilities in a new venture.

Although our results provide strong statistical support for our conclusion, we must also acknowledge that our focus on biotechnology raises questions about the generalizability of our study beyond this industry. Biotechnology has several unique characteristics, including a long product development and approval cycle, heavy reliance upon often arcane basic scientific research and a very expensive product development process. However, given these unique characteristics in our sample, we still believe that our results are generalizable beyond the biotechnology industry. Basic science appears to be playing a more significant role in the success and failure of individual firms (Dasgupta and David 1994). This trend increases the importance of scientific capabilities to a firm's new product development capability in all types of high technology firms. In addition, geographic concentration is not unique to the biotechnology industry and there is no reason to believe that the benefits of geographic concentration are any different or any greater for biotechnology than for other industries.

Although we have found strong empirical support for our model, it should also

be noted that there is still a significant amount of variation in the rate of new product development of the firms in our sample which remains unexplained. Obviously, there remain other variables of potential interest which demand further study. There may be other indicators of the scientific capabilities of a firm, including more complex measures built on bibliometric techniques for both citations and patents. The field of information science has spent years examining the creation, development, and transmission of knowledge. Significant research has gone into the field of bibliometrics, and application of this research to the problems of strategy presents significant opportunities for researchers interested in measuring firm specific capabilities and advancing resource based/dynamic capabilities theory.

The link between geographic location and firm performance demands further study. Research needs to be undertaken which attempts to distinguish the impact of the three distinct benefits from geographical concentration outlined by Krugman (1991).

Our approach to measuring capabilities has important ramifications for future attempts to measure other types of capabilities. If capabilities are complex assets based on combinations of routines, skills, organizational knowledge, and tangible assets, we need to use multiple indicators to capture the capabilities. Single measures are destined to miss important aspects of the capability or capabilities of interest. In addition, knowledge of industry context is crucial in developing the appropriate measures of firm specific capabilities.

Finally, important implications for entrepreneurs/managers of high technology firms follow from our results. First, entrepreneur/managers need to view the choice of geographic location as an important strategic decision which will impact their firm's access to the skilled research personnel and the streams of knowledge upon which the firm will develop its specific dynamic capabilities. Our results seem to indicate that a choice location has a significant concentration of similar firms, but has not yet reached a point where competition for resources in the local environment offsets the advantages of the location. In the case of biotechnology, this would seem to indicate that the prime locations would be expanding areas such as San Diego, Seattle, and Philadelphia, rather then the established locations of Silicon Valley and Boston.

Second, as scientific knowledge plays an ever more important role in a firm's success, the quality of the firm's scientific team is a critical ingredient in a firm's new product development capability. But how do you evaluate the quality of scientific personnel? Our results indicate that there is a strong positive relationship between the impact—as measured by citations—of a team's prior research in the academic community and the productivity of that team in a commercial research laboratory. Therefore, the judgment of a scientific field, captured by citations or perhaps expert judgment, should prove to be a useful tool when evaluating personnel for a firm's research team.

Third, the results from our measures of CEO experience and the percentage of the top management team with a Ph.D. are interesting. As expected the prior experience of the CEO in managing a commercial research facility enhances a firm's new product development capabilities. However, results for our top management team variable appears to indicate that the over reliance on technical personnel in the management of the organization detracts from the product development process. Taken together these results seem to imply that it is important that the leadership of the organization have knowledge of and experience in managing the new product development process, but that focusing technical talents energies away from the laboratory and into the management of the organization may be counter-productive. Therefore, what a high technology

venture appears to need is leadership which understands and has experience in the new product development process, but which keeps the scientific team focused on research and development, and out of the boardroom.

REFERENCES

Almeida, P. and Kogut, B. 1994. Technology and Geography: The Localization of knowledge and the Mobility of Patent Holders. *Working Paper. The Wharton School of Business.*

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

Barney. J. 1991. Firm resources and sustained competitive advantage. *Journal of Management* 17(1):99–120.

Blau, J. 1991. The disjunctive history of U.S. museums, 1869–1980. *Social Forces* 70:87–105.

Brock, G. 1975. *The U.S. Computer Industry.* Cambridge, MA: Ballinger.

Burrill, Steven G., and Lee, Kenneth B. 1993. *Biotech 93: Accelerating Commercialization.* San Francisco: Ernst and Young.

Carroll, G. and Hannan, M. 1989. Density dependence in the evolution of populations of newspaper organizations. *American Sociological Review* 54:524–541.

Carroll, G. and Wade, J. 1991. Density dependence in the organizational evolution of the brewing industry across different levels of analysis. *Social Science Research* 20:271–302.

Chauvin, K.C. and Hirschey, M. 1993. Advertising, R&D expenditures and the market value of the firm. *Financial Management* 23:451–467.

Child, J. 1972. Organizational structure, environments and performance: The role of strategic choice. *Sociology* 6:1–22.

Cohen, W. and Levinthal, D. 1990. Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly* 35:128–152.

Dasgupta, P. and David, P. 1994. Toward a new economics of science. *Research Policy* 23:487–521.

Deeds, D, D. DeCarolis, and J. Coombs. 1997. The impact of firm specific capabilities on the amount of capital raised in an initial public offering: evidence from the biotechnology industry. *Journal of Business Venturing* 12(1):31–46.

Deeds, David L. and Hill, Charles W.L. 1996. Strategic Alliances, Complimentary Assets and New Product Development: An Empirical Study of Entrepreneurial Biotechnology Firms. *Journal of Business Venturing* 11(1):41–55.

della Valle, F. and Gambardella, A. (1993). Biological revolution and strategies for innovation in pharmaceutical companies. *R&D Management* 23:287–302.

Dierickx, I. and Cool, K. 1989. Asset stock accumulation and sustainability of competitive advantage. *Management Science* 35:1504–1513.

Doukas, J. and Switzer, L. 1992. The stock markets valuation of R&D spending and market concentration. *Journal of Economics and Business* 44:95–114.

Grabowski, H. and Vernon, J. 1990. A New Look at the Returns and Risks to Pharmaceutical R&D. *Management Science* 36:804–821.

Graves, S. and Langowitz, N. 1993. Innovative Productivity and Returns to Scale in the Pharmaceutical Industry. *Strategic Management Journal* 14:593–605.

Hagedoorn, J. 1993. Understanding the Rationale of Strategic Technology Partnering: Interorganizational Modes of Cooperation and Sectoral Differences. *Strategic Management Journal* 14(5):371–385.

Hall, R. 1993. A framework linking intangible resources and capabilities to sustainable advantage, *Strategic Management Journal* 14(8):607–618.

Hambrick, D.C. 1994. Top Management Team Groups; A Conceptual Integration and Reconsideration of the 'Team' Label. In B.M. Staw and L.L. Cummings, eds. *Research in Organizational Behavior* 16:171–214. Greenwich, CT: JAI Press.

Hannan, M. and Freeman, J. 1989. *Organizational Ecology*, Cambridge, MA: Harvard University Press.

Healey, P., Rothman, H., and Hock, P.K. 1986. An experiment in science mapping for research planning. *Research Policy* 15(5):233–252.

Henderson, R. and Cockburn, I. 1994. Measuring Competence? Exploring firm effects in pharmaceutical research. *Strategic Management Journal* Winter Special Issue 15:63–84.

Hill, C.W.L. and Deeds, D.L. (1997) The importance of industry structure for the determination of firm profitability. *Journal of Management Studies* 28:312–328.

Jaffe, A., Trajtenberg, M., and Henderson, R. 1993. Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. *Quarterly Journal of Economics* 108(3):577–598.

Kelm, K., Narayan, V.K., and Pinches, G.E. 1995. Shareholder value creation during R&D innovation and commercialization stages. *Academy of Management Journal* 38(3):770–786.

Kogut, B. and Zander, U. 1992. Knowledge of the firm, combinative capabilities and the replication of technology. *Organization Science* 3(3):383–396.

Krugman, Paul. 1991. *Geography and Trade.* Cambridge, MA: MIT Press.

Leonard-Barton, D. 1992. Core capabilities and core rigidities: A paradox in managing new product development. *Strategic Management Journal* Summer Special Issue 13:111–126.

Mansfield, E. 1988. The Speed and Cost of Industrial Innovation in Japan and the United States External vs. Internal Technology. *Management Science* 34(10):1157–1168.

March, J. and Simon, H. 1958. *Organizations.* New York: Wiley.

McMillan, G.S. 1995. *Firm Management of Scientific Information: The Predictors and Implications of Openness Versus Secrecy.* Unpublished Doctoral Dissertation. Temple University, Philadelphia, PA.

McMillan, G.S. and Deeds, D.L. 1997. The impact of scientific reputation on recruitment of researchers in the pharmaceutical industry. *R&D Management.* Forthcoming.

McMillan, G. Steven, Klavans, Richard A., and Hamilton, Robert D. (1995). Firm management of scientific information: Some predictors and implications of openness versus secrecy. *R&D Management* 25(4):411–419.

Narin, Francis and Rozek, Richard. 1988. Bibliometric Analysis of U.S. Pharmaceutical Industry Research Performance. *Research Policy* 17(3):139–154.

Pakes, A. 1985. Patents, R and D, and the stock market rate of return. *Journal of Political Economy* 93:390–409.

Peck, M. 1962. Inventions in the postwar aluminum industry. In R.R. Nelson (ed.) *The Rate and Direction of Inventive Activity.* Princeton: Princeton University Press.

Penrose, E. 1959. *The Theory of the Growth of the Firm.* Blackwell, Oxford.

Petraff, M. 1993. The cornerstone of competitive advantage: A resource-based view. *Strategic Management Journal* 14(3):179–191.

Pisano, G. 1994. Knowledge, Integration and the Locus of Learning: An Empirical Analysis of Process Development. *Strategic Management Journal* 15:85–100

Pouder, R. and St. John, C.H. 1996. Hot Spots and Blind Spots: Geographical Clusters of Firms and Innovation. *Academy of Management Journal* 21(4):1192–1225.

Reed, R. and DeFillippi, R. 1990. Causal Ambiguity, Barriers to Imitation, and Sustainable Competitive Advantage. *Academy of Management Review* 15(1):88–102.

Rogers, E. and Larsen, J. 1984. *Silicon Valley Fever.* New York: Basic Books.

Rosenberg, N. and Steinmuller, W.E. 1988. Why are Americans Such Poor Imitators? *American Economic Review* 78(2):229–234.

Rumelt, R.P. 1991. How much does industry matter? *Strategic Management Journal* 12(3):167–185.

Saxenian, A. 1990. Regional Networks and the Resurgence of Silicon Valley. *California Management Review* Fall:89–113.

Schendel, D. 1994. Introduction to Competitive organization behavior: Toward an organizationally based theory of competitive advantage. *Strategic Management Journal* Winter Special Issue, 15:1–4.

Scherer, F. M. 1980. *Industrial Market Structure and Economic Performance.* Boston: Houghton-Mifflin.

Scherer, F.M. and Huh, K. (1992) Top managers' education and R&D investment. *Research Policy* 21:507–511.

Schoonhoven, C.B., Eisenhardt, K.M., and Lymman, K. 1990. Speeding products to market: Waiting time to first product introduction in new firms. *Administrative Science Quarterly* 35:177–207.

Shan, W., Walker, G., and Kogut, B. 1994. Interfirm cooperation and startup innovation in the biotechnology industry. *Strategic Management Journal* 15:387–394.

Small, H.G. and Griffith, B.C. 1974. The structure of scientific literature, I: identifying and graphing specialties. *Science Studies* 4:37–53.

Teece, D. 1986. Profiting from technological innovation. Implications for integration, collaboration, licensing and public policy. *Research Policy* 15:285–305.

Teece, D.J., Pisano, G., and Shuen, A. 1992. "Dynamic capabilities and strategic management", Mimeo, Haas School of Business, University of California, Berkeley, CA.

Terpstra, V. and Simonin, B.L. 1993. Strategic Alliances in the Triad. *Journal of International Marketing* 1:4–25.

Van der Eerden, C. and Saelens, F. H. 1991. The Use of Science and Technology Indicators in Strategic Planning. *Long Range Planning* 24(3):18–25.

Vernon, J. M. and Gusen, P. 1974. Technical Change and Firm Size: The Pharmaceutical Industry. *Review of Economics and Statistics* 56:294–302.

Vinkler, Peter. 1986. Management Systems for a Scientific Research Institute Based on the Assessment of Scientific Publications. *Research Policy* 15(2):77–87.

Wallmark, J.T., McQueen, D.H., and Sedig, K.G. 1988. Measurement of Output from University Research: A Case Study. *IEEE Transactions on Engineering Management* 35(3):175–180.

Wiersema, M.F. and Bantel, K.A. 1992. Top management team demography and corporate strategic choice. *Academy of Management Journal* 35:91–121.