The Impact of Stocks and Flows of Organizational Knowledge on Firm Performance: An Empirical Investigation of the Biotechnology Industry

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THE IMPACT OF STOCKS AND FLOWS OF ORGANIZATIONAL KNOWLEDGE ON FIRM PERFORMANCE: AN EMPIRICAL INVESTIGATION OF THE BIOTECHNOLOGY INDUSTRY

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INTRODUCTION

As management researchers, one of our prime areas of interest is theories of the firm, which explain their behavior, structure and performance differences. Models of business enterprises have been advanced from several academic disciplines. Economic theories of the firm focus on predicting the behavior of firms in external markets. Neoclassical economics employs partial equilibrium analysis to predict the firm's purchase and supply decisions. Organizational theory explains the firm as a complex organization of individuals and focuses on analyzing the internal structure of firms and relationships among departments and units. Strategic management, drawing from both economics and organization theory, focuses on performance differences among firms and the causes of these differences.

One of the recent contributions of strategic management to the theory of the firm has been the resource-based view (Barney, 1991; Mahoney and Pandian, 1992; Wernerfelt, 1984) which proposes that the firm is a bundle of unique capabilities. Within this perspective, it is the manager's role to cultivate these capabilities and deploy them in product-market strategies to achieve competitive advantage. The resource-based view suggests that firm capabilities which are valuable, rare and inimitable (Barney, 1991) will determine long term competitive advantage.

This approach to firm behavior differs from previous theories of the firm in that it escalates the importance of cumulative and unique firm capabilities and management's role in developing and exploiting these capabilities. By highlighting

Key words: stocks and flows of knowledge; biotechnology; firm performance

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the importance of firm specific capabilities, the resource-based view has focused significant attention on intangible resources which play a critical role in competitive advantage. In fact, the focus on intangible resources has led to an extension of the resource-based view—the knowledge-based view of the firm. In this perspective, knowledge is the most strategically important of the firm's resources (Grant, 1996; Hill and Deeds, 1996).

The knowledge-based view provides a new lens through which we may view and understand the primary rationale for a firm's existence—the creation, transfer and application of knowledge (Demsetz, 1991; Grant, 1996; Nonaka, 1994; Spender, 1996). The knowledge-based view argues that the heterogeneous knowledge bases and capabilities among firms are the main determinants of performance differences. This approach to understanding what occurs in the "black box" of the firm suggests that organizations not only use different knowledge bases and capabilities in developing knowledge but also have differential access to externally generated knowledge.

The underlying knowledge of firms may be conceptualized by both stocks and flows (Dierickx and Cool, 1989) of knowledge which contribute to superior firm performance. Stocks of knowledge are accumulated knowledge assets which are internal to the firm and flows of knowledge are represented by knowledge streams into the firm or various parts of the firm which may be assimilated and developed into stocks of knowledge.

As researchers, how is it possible to capture the construct of organizational knowledge? This article addresses that question in the biotechnology industry. This industry is an interesting arena in which to study organizational knowledge and firm performance. The most valuable assets of biotechnology companies are their intangible research capabilities, which represent the potential to develop and deliver new drugs which, in fact, differ from the traditional drug products of the established pharmaceutical companies. These research capabilities stem from their knowledge bases, which need to be continually nurtured and developed.

Organizational knowledge is a firm specific asset which is not easily imitated and nontradeable (Barney, 1986). Nontradeable assets cannot be bought and sold in factor markets (Dierickx and Cool, 1989). There are no factor markets for corporate reputations, or dealer loyalty for example. People are endowed with firm-specific skills and values, which are accumulated through on the job training and learning. The idiosyncratic nature of firm-specific assets makes them non-tradeable. These assets are not only nontradeable but they are also accumulated internally through a number of mechanisms over time.

Asset stocks are accumulated over time by choosing appropriate time paths of flows over a period of time. Corporate reputations, dealer loyalties, R&D capabilities are stocks of assets which have been accumulated over time. The "bathtub" metaphor (Dierickx and Cool, 1989) illustrates the differences and connections between asset stocks and flows. At any point in time, the stock of water in a bathtub is indicated by the level of water in the tub. This stock of water is the cumulative result of flows of water into the tub (through the tap) and out of the tub (through a leak). With respect to R&D capabilities, the amount of water in the tub may represent the stock of know-how at a particular point in time; current R&D spending is represented by the water flowing into the tub and the water leaking out illustrates knowledge depreciation over time. Flows like water coming into and leaking out of the tub may be adjusted; stocks cannot.

An appropriate context for examining stocks and flows of knowledge and their relationship to firm performance would be a dynamic industry in terms of knowledge generation, such as the pharmaceutical industry in general. This industry is dependent on the knowledge embedded in its research departments. In the pharmaceutical industry, firm research capabilities may be assessed by the number of new drugs the company has brought to market, its R&D expenditures, and its past history in terms of financial and technological performance.

Although part of the overall pharmaceutical industry, there are distinct differences between biotechnology and pharmaceutical companies. Biotechnology firms typically have no products in the marketplace—only in the pipeline. Further, their research pursuits are very limited in scope. Most biotechnology firms are pursuing a very limited number of potential drug treatments. Therefore, they must differentiate themselves in terms of potential new products that provide an attractive risk/return reward for investors.
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 also 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.

With such an emergence of 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 such an atmosphere where new knowledge generation is occurring at such a rapid pace, biotechnology companies are continually receiving flows of knowledge (both internal and external) and accumulating stocks of knowledge. Competitive advantage in this industry depends upon the continual accumulation of relevant knowledge. Given these conditions, the performance of biotechnology firms should be dependent upon both their stocks of organizational knowledge and their access to flows of knowledge.

This article focuses on the relationship between organizational knowledge in the form of stocks and flows and firm performance. We suggest several variables, which capture stocks and flows of organizational knowledge. We propose three measures of the flows of knowledge into the firm. First, we suggest that knowledge flows may be captured by a firm's geographical location. Firms located in a "hot spot" (Pouder and St. John, 1996) have increased access to knowledge due to the benefits, which accrue from that area. Knowledge flows from being located in particular geographical locations are absorbed by the firm and should increase competitive advantage. Second, we examine the impact of alliances as explicit mechanisms for creating the flow of knowledge into the firm. Third, we examine the firm's commitment to research and development as internally generated flows of knowledge.

We then measure stocks of firm knowledge through the following variables, which represent an accumulation of knowledge at a moment in time: scientific citations; products in development; and patents. Each of these measures is an attempt to quantify the stock of knowledge held by the firm.

Thus, in the biotechnology industry, firms accumulate their stocks of knowledge through several flows. In the following section, we detail our model of stocks and flows of organizational knowledge in the biotechnology industry and their relationship to firm performance. We then present our methodology, results and a discussion of the results.

HYPOTHESES

FLOWS OF KNOWLEDGE

Geographic location and firm performance

The phenomena of geographic clusters within industries is receiving renewed attention. Marshall (1920) was responsible for the initial theoretical treatment of the phenomena of geographic clusters in which he proposed a rationale for geographic clustering based on the economic benefits of labor pooling, specialized suppliers and knowledge spillovers. Krugman (1991), Melecki (1985) and recently Pouder and St. John (1996) have contributed to our theoretical understanding of the relationship between geography and firm performance. In addition, recent work by Audretsch and Feldman (1996) provides evidence that in industries where new knowledge is important firms cluster together to take advantage of knowledge spillovers.

Building on these works and others, we suggest that the munificence of the local environment in terms of knowledge potential provides an avenue of knowledge flows for a particular firm and will impact firm performance. Environmental munificence is the extent to which the environment can sustain growth (Starbuck, 1976). It is our contention that the munificence of the geographical environment within which the firm is located will be positively related to firm performance.

Innovation is the result of both internal knowledge development and the acquisition and application of external knowledge. Process and product innovations do not occur in the isolated confines
of a firm’s research and development department. External sources of knowledge are equally critical to innovation. 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.

Close proximity of organizations with similar interests promotes the natural exchange of ideas through the networks established. Lynn, Reddy and Aram (1996) proposed the term “innovation community” to refer to “the organizations directly and indirectly involved in the commercialization of a new technology.” This definition includes all of the firms and organizations previously included in definitions of organizational communities and adds any other organization or group involved in commercializing a given technology. When an innovation community is centered in a geographic area, the concentration of successful firms, qualified suppliers, skilled workers, informed investors, idea generators and shared resource arrangements will be partly responsible for an increasing proportion of industry innovations (Pouder and St. John, 1996). The emerging networks within the innovation community also help in creating an environment of creativity and idea exchange (Saxenian, 1990).

Recent treatments of the importance of location to innovation and firm capabilities have focused on the development of “hot spots” defined as geographically clustered firms within industries which begin as start-up firms, grow more rapidly than other industry participants and have similar immobile physical resource requirements in the long run (Pouder and St. John, 1996). There are many examples of such “hot spots” around the world: the biotechnology and communications industries in San Diego, California, the ceramics industry in Corning, New York and Sassuolo, Italy, and the computer industry in Austin, Texas.

As a few firms in a single area start to become successful, a ripple effect occurs in that suppliers, qualified workers and investors become available to these firms. Consequently, similar firms and spin-offs created from parent firms will be attracted to the area due to the availability of the resources in this area. It is agglomeration economies (i.e., the net benefits of a firm being in a location will increase with the number of firms in that location) which provide lower costs and

superior resources for clustered firms (Melecki, 1985). There is then a resource advantage for a firm being located in a cluster. Continual reduction of the costs of production due to the availability of supplies, workers and capital are the source of unique assets which firms outside the cluster are not privy to (Bania, Calkins and Dalenberg, 1992; Maarten de Vet and Scott, 1992; Saxenian, 1990).

In the case of biotechnology firms, the munificence of the geographic environment is manifested not just in terms of available pools of knowledgeable workers, but also in the form of access to local university researchers, university research projects, and a cluster of similar firms. The existence of such entities within a particular geographical location is an opportunity for firms to informally exchange information. Case evidence has pointed to the interdependent relationships among firms in such clusters as Silicon Valley, Route 128, and the ceramics production complex in Sassuolo, Italy (Porter, 1990; Saxenian, 1990; Scott, 1989).

Within a geographic cluster there are ample opportunities for inter-organizational knowledge flows and communications. The proximity of firms to competitors, suppliers, and a qualified labor pool increases the flow of knowledge across a firm’s boundary. Social interactions, both formally and informally, stimulate information exchange about such topics as competitor’s plans, developments in production technology, and recent developments within the local university’s labs. Interaction among employees of different firms and organizations from the same industry located in a geographic cluster may be facilitated through membership in local political and religious organizations, involvement in local art, athletic and community groups, residing in the same neighborhoods (Yates, 1984) and through local industry events such as trade and professional association meetings (Almeida and Kogut, 1994; Saxenian, 1990).

Employee mobility among firms is another opportunity for information exchange. Evidence suggests that managers and other professional employees will seek jobs within the same geographic area rather than move to other locales (Angel, 1989). Thus, organizational knowledge will “move” from one firm to another through a mobile labor pool, which moves within the cluster.
If a particular geographic location is able to provide such a munificent environment with the benefits suggested above, one outcome should be localized knowledge production. Jaffe, Trajtenberg and Henderson (1993) investigated the extent to which knowledge spillovers are geographically localized by examining 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 and found significant intra-regional mobility among these inventors particularly in the Silicon Valley.

Therefore, a firm located in a geographic area with high munificence (a high concentration of similar firms, specialized suppliers, such as research universities, and a large pool of trained labor) will have access to knowledge flows which may be unavailable or difficult to attain by similar firms which are geographically isolated. It is likely that firms located in geographic hot spots have more and frequent access to knowledge flows which will be accumulated internally and generate superior performance.

**Hypothesis 1:** The munificence of a firm's geographic area will have a positive relationship with firm performance.

**Alliances**

In the biotechnology industry, the drug discovery and development process is a complex and multidisciplinary process requiring new ventures to access a broad range of knowledge. However, most of these firms have limited capabilities that are narrowly focused on a few specific applications. Under these circumstances, biotechnology firms are forced to reach beyond their boundaries to access complementary knowledge (Teece, 1986). In addition to providing access to knowledge for immediate projects, information from these external linkages may evolve into important sources of new product idea. Consistent with these arguments, Deeds and Hill (1996) and Shan, Walker and Kogut (1994) found a positive relationship between the number of a firm's strategic alliances and the research productivity of the firm. This leads to our next hypothesis.

**Hypothesis 2:** The total number of strategic alliances of a firm will have a positive relationship with firm performance.

**Research and development**

As suggested by Dierickx and Cool (1989) the amount of R&D spending is a flow variable that may be adjusted instantaneously. To achieve a desired change in a strategic asset stock such as research capabilities there needs to be a consistent pattern of resource flows—R&D spending. Greater commitment to R&D should result in greater flows of new scientific information into the firm. The relative amount of expenditures on research and development has traditionally been used as an indicator of innovative activity in many industries (Scherer, 1980). Several studies have looked at the relationship between R&D spending, productivity returns and firm performance (Comanor, 1965; Grabowski and Vernon, 1990; Graves and Langowitz, 1993; Vernon and Gusen, 1974).

In a knowledge intensive industry, such as biotechnology, a significant strategic commitment to R&D is critical to the firm's ability to develop new products. Recent studies have used R&D intensity not only as a measure of internal learning, but also as a requirement for external learning as firms need to develop a certain level of internal knowledge so they can understand and apply external knowledge (Bierly and Chakrabarti, 1996; Cohen and Levinthal, 1990). Other studies have tested and found support for the relationship between commitments to R&D and market value (Hirschey, 1985; Jose, Nichols and Stevens, 1986; Lustgarten and Thomadakis, 1987; Morck, Shleifer and Vishny, 1988; Morck and Yeung, 1991).

**Hypothesis 3:** A biotechnology company's R&D intensity will have a positive relationship with firm performance.

**STOCKS OF ORGANIZATIONAL KNOWLEDGE**

**Products in development and market value**

A common indicator of technological competence or expertise in the pharmaceutical industry is the number of drugs in development or in the "pipe-
line”. Financial analysts and potential investors monitor the products being pursued by firms in the pharmaceutical industry. The strength of a firm’s ‘pipeline’ is considered an important indicator of a company’s future cash flows. Products in the pipeline represent accumulated stocks of organizational knowledge. Therefore, the number of products under development by a firm should have a direct relationship to firm performance.

Hypothesis 4: The number of new drugs in a biotechnology company’s research pipeline will have a positive relationship with firm performance.

Patents

Patents may be considered as representative of stocks of organizational knowledge. They are physical, codifiable manifestations of innovative ideas, techniques, and products that embody the knowledge of one or several employees. Patents have been associated with innovation and performance at many levels: region, country, and company. Patents have been used as indicators of inventive activity in several empirical studies (Ashton and Sen, 1988; Pakes, 1985). Further, patents are widely accepted measures by policy makers and analysts (Van der Eerden and Saele, 1991) in terms of technology strategy and competitive analysis. In this study we suggest that patents are indicators of stocks of organizational knowledge which impact firm performance.

There is some concern with using simple patent counts as a measure of the stock of a firm’s knowledge. Simple patent counts have been criticized as being crude for basically two reasons. First, simple patent counts do not in and of themselves reflect the value of knowledge. This is better captured by patent citations—that is, how many times a firm’s patents are cited by subsequent issued patents. Although recent research has used patent citations to weight the patents, citations accrue with age and this measure is therefore biased towards old patents. In the case of biotechnology companies, the relative youth of the firms and their patents when they went public indicates that very few of the patents had been cited by subsequent issued patents.

Second, firms tend to differ in their policies toward patents. Some firms generally patent more than others. In addition, the estimated minimum costs of an issued patent are $12,000, which may be a fairly insignificant sum to an established pharmaceutical company like Merck, but to a cash strapped startup biotechnology firm, this expenditure would be a significant investment. For these reasons in this particular industry we believe that patent counts adequately capture organizational stocks of knowledge.

Moreover, research has suggested the link between patent counts and organizational innovative activity. Basberg (1982) found that increased commitments to research and development do not precede increased patenting but are simultaneous with it. This suggests that the number of patents is a better indicator of corporate commitment to pursue innovation than the actual amount of innovation. Comanor and Scherer (1969) found that simple patent counts are more highly correlated with inputs to development such as research personnel than to the rate of new product introduction. These studies suggest then that simple patent counts are more of an indicator of a firm’s commitment to innovation than quality of innovation. Accordingly, in the biotechnology industry, we suggest that increased patenting is an indicator of a firm’s commitment to innovation.

Therefore, given the relative young age of the firms and their cash flow situation, we suggest that patent counts are an appropriate proxy for a biotechnology firm’s stock of codifiable knowledge.

Hypothesis 5: The number of patents controlled by a biotechnology company will have a positive relationship with firm performance.

Firm citations

As stated earlier, the scientific knowledge base of a biotechnology firm is a critical component of the firm’s competitive position. This knowledge base resides in the skills and knowledge of the individual members of the firm’s research team. One way to capture a firm’s stock of knowledge is in the development of a measure of the knowledge held by the key participants in the organization. Biotechnology in particular is highly dependent upon basic research, due to the highly complex and evolving nature of the knowledge base of the industry (Pisano, 1994). Therefore, the stock of knowledge contained within a firm’s scientific team is critical to the
firm’s future prospects. However, attempting to make comparisons of a scientific team’s stock of knowledge across firms leads to the problem of measurement. One method of judging research quality is well known in the academic community—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 a 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, Rothman and Hock, 1986); to assess the performance of academic departments (Wallmark, McQueen and Sedig, 1988) and 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, mergers and acquisition targeting and research strategy. Therefore, it is our contention that the number of citations a firm’s scientists have is a proxy for the stock of knowledge contained within the firm’s scientific team. Firms with a higher level of citations have larger stock of basic scientific knowledge.

Hypothesis 6: The number of times the published papers of a firm’s research team is cited will have a positive relationship with firm performance.

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). The sample from this population was limited to firms that went public after 1982. Thus, the initial sample was limited to 218 firms. These firms were then contacted by phone with a request for a copy of the prospectus from their IPO. A total of 106 companies were willing to provide a prospectus representing a response rate of 48%. However, two of these companies were willing to provide a prospectus representing a response rate of 48%. However, two of these companies were excluded from the sample because warrants for shares in their parent company were included in the IPO. Missing data also forced us to drop 8 firms from our sample. Thus, our final sample consisted of 98 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 Burrill and Lee (1993) for all 225 public biotechnology firms. Our sample averaged $11,123,000 in total assets, $3,515,000 in total liabilities, $11,034,000 in total revenues, $2,276,000 in revenues from collaborative/contract research and $7,034,000 in research expenditures in 1992. Burrill and Lee (1993) reported these averages for all public biotechnology companies firms in 1992 and they were as follows: $11,377,000 total assets, $3,313,000 total liabilities, $20,196,000 in total revenues, $2,440,000 in contract/collaborative research revenues and $10,342,000 in total R&D spending. Based on these comparisons our sample is similar to the Burrill and Lee (1993) sample, with the exception of notable differences from the industry averages on total revenues and total R&D spending. However, these differences are adequately explained by the inclusion of two companies in the Burrill and Lee sample which are not in our sample—Amgen and Genentech. They constitute the “outliers” of the biotechnology firms. Sales of Amgen’s Epogen and Neupogen and Genentech’s Activase accounted for over $750 million in product revenues of approximately $3.5 billion in total product revenues for the industry. However, as can be seen in the contract research numbers, the research revenues for our sample and the population are comparable. Overall, we believe we have a fairly representative sample of the publicly held biotechnology companies.

Variables

Firm Performance. Measuring the performance of entrepreneurial biotechnology firms is difficult. Typically, they have no products in the market-
place and thus, very little sales. Past measures of performance used for entrepreneurial firms, such as return on assets, sales growth or profit margin are inappropriate because these firms do not have any history of revenues or earnings. Their value is contained in intangible assets represented by their knowledge and access to knowledge. They are years away from any significant revenue stream, have very few tangible assets, are sustaining significant accounting losses, and require large amounts of capital (Burrill and Lee, 1992; Pisano, 1996). Their most valuable assets are their knowledge capabilities, which represent the potential to develop and deliver state of the art billion dollar drugs. However, the point at which these firms go public presents a unique opportunity to measure their performance up to that time.

Issuing an initial public offering (IPO) is an important strategic objective for an entrepreneurial biotechnology firm. A key factor in a venture capitalist’s evaluation of a new business as an initial investment and as an ongoing investment is the probability that the venture will issue an IPO (Guild and Bachher, 1996; Fiet et al., 1997). By going public the firm is able to provide initial investors an avenue of exit, increase its legitimacy, and gain improved access to both equity and debt capital (Sutton and Bennedetto, 1988). These benefits are directly linked to the value the market places on the firm.

Going public also allows the financial markets to make a judgment about the value and future earnings potential of the firm based upon the firm’s past actions and accomplishments. According to the efficient market hypothesis, a firm’s market value is assumed to capture all available relevant information about a company, including the potential of a firm’s knowledge (Fama, 1976; Rappaport, 1981). The state of the firm and its knowledge base at the time at which it issues an IPO are the culmination of the actions of the entrepreneurs/managers of the firm since its inception. Therefore, the value placed on a newly public firm is the market’s evaluation of the firm’s performance over its lifetime. Firms which have made superior decisions and investments will have greater potential and in turn a higher market value upon entering the market. However, several authors have found that IPOs under perform the market in the long-run due to investors’ over-optimism at the time of the offering (Ritter, 1991; Loughran and Ritter, 1995; Rajan and Ser-
of human knowledge capital. These data were collected from the labor department statistics. This measure was also normalized.

Finally, to assess the level of knowledge generating activity occurring in particular geographical locations, we measured the number of grants awarded by the National Institute of Health (NIH) per MSA and the total value of grants awarded by the NIH per MSA. These data were gathered from the NIH publication titled _Extramural Data Trends 1994_.

The normalized variables were then factor analyzed. The results of the factor analysis are reported in Table 1. The factor analysis produced a single factor with an eigenvalue of 5.67 that explained 70.9% of the variance among the variables and all of the variables loaded on the factor at 0.5 or greater. Based on the strong results of the factor analysis we created a single score to measure the munificence of a geographical area by averaging the normalized variables.

(Number of alliances): This is count of the number of active alliances the firm has with both non-profit and for profit research institutions and universities at the time of the IPO. This information was gathered from the prospectus.

(Research and development intensity). R&D intensity is measured as the average percentage of total expenditures spent on the R&D process during the last three years. The data were gathered from the IPO prospectus.

(Number of products): In the business section of each prospectus the company reports the number of products under development or which have reached the market. We created our measure of the firm's product pipeline by totaling the number of products they had in each of the significant stages of the pharmaceutical testing process. None of the firms actually had products on the market at the time of their IPO. Therefore, we counted the number of products the firm had in pre-clinical trials, stage one, stage two, and stage three trials.

(Patents). From the offering firm's prospectus, a count of the total number of patents held by that firm was obtained. This includes both patents granted directly to the firm and patents in which the firm is the sole licensee.

(Citation data). In this study we are using citation analysis as an indication of the quality of the scientific personnel of the biotechnology firm. 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 their career prior to the year in which the IPO was issued. 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.

(Control variables)

(Timing). It has been well documented (Ibbotsen and Jaffee, 1975; Ritter, 1984) that the market for initial public offerings experiences periods in which the value of firms going public is substantially higher. Ibbotsen and Jaffe (1975) first documented the existence of a number of 'hot markets' for IPOs during the last 20 years. Theoretically, what appears to happen is that investors are periodically over-optimistic about the earnings potential of young growth companies (Ritter, 1984). These so-called 'hot markets' are windows of opportunity which entrepreneurs may use to improve their access to capital by taking advantage of investors' optimism.

These 'hot markets' are characterized by a high volume of IPO activity. During these periods both the number and average value of the IPOs

<table>
<thead>
<tr>
<th>Table 1. Factor analysis of location measures</th>
<th>Factor score</th>
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<tbody>
<tr>
<td># of Biochemistry Departments</td>
<td>0.88</td>
</tr>
<tr>
<td># of Bioengineering Departments</td>
<td>0.77</td>
</tr>
<tr>
<td># of Medical Schools</td>
<td>0.90</td>
</tr>
<tr>
<td># of Microbiology Departments</td>
<td>0.93</td>
</tr>
<tr>
<td># of NIH Grants</td>
<td>0.95</td>
</tr>
<tr>
<td>Value of NIH Grants</td>
<td>0.93</td>
</tr>
<tr>
<td>Percentage of Biotechnology Firms</td>
<td>0.73</td>
</tr>
<tr>
<td>Level of High Technology Employment</td>
<td>0.57</td>
</tr>
<tr>
<td>Eigenvalue of Factor</td>
<td>5.67</td>
</tr>
<tr>
<td>% of Explained Variation</td>
<td>70.9</td>
</tr>
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brought to market is significantly higher than during a normal period. In the case of biotechnology, the years 1983, 1986, 1991 and 1992 show all the characteristics of a ‘hot market’ and have been designated as such by industry analysts (Burrill and Lee, 1993). IPOs during the ‘hot market’ years were coded as “1”; all others were coded as “0”.

Total assets. The total assets of the offering firm were used to control for the influence of size on market value. Given that this study is concerned with the market valuation of knowledge stocks and flows, that is intangible assets, we felt it is important to control for the impact of the overall size of the asset base on the market valuation of the firm. Total asset value was measured prior to the IPO. These figures were reported in the prospectus of each of the initial public offerings. A logarithmic transformation was used to control the skewness of the distribution.

ANALYSIS AND RESULTS

The data were analyzed using ordinary least squares regression. Descriptive statistics of the variables are presented in Table 2. The average market value of the firms in our sample was $95 million. The average firm had 3.26 products in the pipeline and had control of 3.41 patents. Seventy-five percent of the firms in our sample issued IPOs during ‘hot markets’. With respect to location, the average firm was located in a metropolitan area with 7.4% of the total national biotechnology firms. Average research and development spending was $9.8 million and average total assets were $11.2 million. The correlation matrix is presented in Table 3, which does not indicate significant problems with multicollinearity.

In order to test for the effect of the stock and flows of knowledge on the market value, we performed a series of regression models the results of which are depicted in Table 4. In Model One, we entered only the control variables: size and hot market. This model was significant and explained 51% of the variance in the regression equation.

In Model Two, we entered the “knowledge flow” variables together with the control variables. The percentage of variance explained was greater than the first model. Further, all three knowledge flow variables, location, R&D intensity and the number of alliances are significant predictors with R&D intensity exhibiting the greatest amount of significance, followed by location and then number of alliances.

In our third model, we test the effect of the “knowledge stock” variables on market value along with the control variables in our base model. Compared to Model Two, there is a greater amount of variance explained by the stock variables as indicated by the increase in the R2 over the base model. Model Three yields an R2 of 60% compared to the base model, while Model Two yields an R2 of 58%. Again, all three stock variables are significant with number of products being significant at the 0.001 level followed by firm citations at the 0.05 level. Patents are significant only at the 0.10 level but the relationship is inverse to market value.

In the final model, all variables are entered and the result is the greatest amount of variance explained with an R2 of 63%. In this regression, location is the only significant flow variable (0.05). Three stock variables remain significant with products in the pipeline being the most significant at the 0.01 level, followed by firm citations at the 0.05 level. Patents again are significant at the 0.10 level with an inverse relationship.

Hypothesis 1 was supported. Location has a significant (p < 0.05) positive relationship on a biotechnology firm’s market value. Specifically, a firm located in an area with a higher concentration of biotechnology firms has a significantly higher performance than those located in areas with lower concentrations.
Table 3. Correlation matrix

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Log (day)</td>
<td>1.00</td>
<td>0.27</td>
<td>0.41</td>
<td>0.27</td>
<td>0.24</td>
<td>0.36</td>
<td>0.04</td>
<td>0.63</td>
<td>0.36</td>
</tr>
<tr>
<td>2. Location</td>
<td>0.27</td>
<td>1.00</td>
<td>0.08</td>
<td>0.09</td>
<td>0.05</td>
<td>0.20</td>
<td>0.15</td>
<td>0.14</td>
<td>0.04</td>
</tr>
<tr>
<td>3. R&amp;D Intensity</td>
<td>0.41</td>
<td>0.08</td>
<td>1.00</td>
<td>0.33</td>
<td>0.18</td>
<td>0.33</td>
<td>0.08</td>
<td>0.30</td>
<td>0.05</td>
</tr>
<tr>
<td>4. # of Alliances</td>
<td>0.27</td>
<td>0.09</td>
<td>0.33</td>
<td>1.00</td>
<td>0.20</td>
<td>0.11</td>
<td>0.00</td>
<td>0.17</td>
<td>0.03</td>
</tr>
<tr>
<td>5. Firm Citations</td>
<td>0.24</td>
<td>0.05</td>
<td>0.18</td>
<td>0.20</td>
<td>1.00</td>
<td>0.18</td>
<td>0.07</td>
<td>0.09</td>
<td>0.01</td>
</tr>
<tr>
<td>6. # of Products</td>
<td>0.36</td>
<td>0.20</td>
<td>0.33</td>
<td>0.11</td>
<td>0.18</td>
<td>1.00</td>
<td>0.40</td>
<td>0.17</td>
<td>0.02</td>
</tr>
<tr>
<td>7. # of Patents</td>
<td>0.04</td>
<td>0.15</td>
<td>0.08</td>
<td>0.00</td>
<td>0.07</td>
<td>0.40</td>
<td>1.00</td>
<td>0.07</td>
<td>0.03</td>
</tr>
<tr>
<td>8. Log (Assets)</td>
<td>0.63</td>
<td>0.14</td>
<td>0.30</td>
<td>0.17</td>
<td>0.09</td>
<td>0.17</td>
<td>0.07</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>9. Hot</td>
<td>0.36</td>
<td>0.04</td>
<td>0.05</td>
<td>0.03</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

N = 98

Table 4. Regression results—Beta coefficients

<table>
<thead>
<tr>
<th></th>
<th>Model #1</th>
<th>Model #2</th>
<th>Model #3</th>
<th>Model #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>0.148**</td>
<td>0.141**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R&amp;D Intensity</td>
<td>0.185***</td>
<td></td>
<td>0.111</td>
<td></td>
</tr>
<tr>
<td># of Alliances</td>
<td>0.118*</td>
<td></td>
<td>0.094</td>
<td></td>
</tr>
<tr>
<td>Firm Citations</td>
<td></td>
<td>0.148**</td>
<td>0.132**</td>
<td></td>
</tr>
<tr>
<td># of Products</td>
<td></td>
<td>0.282****</td>
<td>0.219***</td>
<td></td>
</tr>
<tr>
<td># of Patents</td>
<td></td>
<td>-0.133*</td>
<td>-0.133*</td>
<td></td>
</tr>
<tr>
<td>Log (Assets)</td>
<td>0.628****</td>
<td>0.532****</td>
<td>0.575****</td>
<td>0.517****</td>
</tr>
<tr>
<td>Hot</td>
<td>0.363****</td>
<td>0.351****</td>
<td>0.362****</td>
<td>0.355****</td>
</tr>
<tr>
<td>Adjusted R2</td>
<td>0.514</td>
<td>0.586</td>
<td>0.602</td>
<td>0.636</td>
</tr>
<tr>
<td>F-Statistic</td>
<td>51.91</td>
<td>28.14</td>
<td>30.05</td>
<td>21.97</td>
</tr>
<tr>
<td>Significance of F</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

N = 98 for all models
*p < 0.10; **p < 0.05; ***p < 0.01; ****p < 0.001

Hypotheses 2 suggesting a proposed relationship between number of alliances with other organizations and performance is not supported. While there was weak support in the restricted Model Two, there is no statistical support for the relationship between alliances and performance in the full model.

The results with respect to the hypothesized positive relationship between R&D intensity and performance are inconsistent across models. R&D intensity is a highly significant predictor of firm performance (p < 0.01) in the restricted Model Two in which only the flow variables are entered. However, its significance declines (p < 0.12) in Model Four which includes the stock variables as well.

In support of Hypothesis 4, the number of new products a biotechnology firm has in its pipeline has a significant (p < 0.001) positive impact on firm performance.

Hypothesis 5 was not supported in any of the models. The number of new patents held by these firms had a small impact on firm performance in our sample. One possible explanation for the less than robust results for our patent measure is that patent counts are an ambiguous measure subject to firm specific variations in the propensity of firms to patent given the resource expenditure required by the patent process (Mansfield, 1977; Pakes, 1985). In sum, there is probably significantly more 'noise' in the patent variable than in our other measures.
Finally, the proposed direct relationship between firm citations and performance is supported (p < 0.05) in all models.

DISCUSSION OF RESULTS

The primary research question investigated in this article is the impact of stocks and flows of organizational knowledge on firm performance. The knowledge-based view of the firm suggests that firms exist to create, share and capitalize on their knowledge. Value creating knowledge should lead to competitive advantage.

In order to investigate this premise, we examined the relationship between knowledge and performance in the biotechnology industry. In this industry, superior performance clearly pivots on a firm's knowledge. Highly complex and specific knowledge which is still emerging is the foundation of the biotechnology industry, unlike the mature knowledge structure of the traditional pharmaceutical companies (Pisano, 1994). The products generated by these companies are radical in nature compared to traditional pharmaceutical products, as are the new methods used to discover these new drugs. Biotechnology firms need to seek knowledge from multiple areas both inside and outside of firm boundaries.

Knowledge accumulation then is the result not only of internal development but also of assimilation of external knowledge. Knowledge may be conceived of as stocks of assets representing accumulated knowledge at a point in time and by flows of knowledge assets into the firm which may be adjusted at any point in time (Dierickx and Cool, 1989).

We operationalized knowledge flows through three variables. First, we proposed that a firm's geographic location is representative of the munificence of knowledge available for a particular firm to absorb. We considered several variables which captured the munificence of a firm's geographic location: the number of medical schools in the area, the number of bioengineering, biochemistry and microbiology programs, number of NIH grants, the value of the NIH grants, and the level of high technology employment in the area. We then performed a factor analysis to test whether or not these variables were capturing the construct of geographic munificence. The results of this analysis showed that all of the variables loaded on a single factor and this factor explained over 70% of the variance. Thus, we believe we have developed a valid measure of the knowledge munificence found in a geographic location. We then used this aggregated location measure in the regression models and it is consistently positive and significant (p < 0.05) in all the models.

There has been much theoretical and anecdotal discussion of the link between a firm's location and its performance. To begin with, within each of the twelve biotechnology clusters, there exist not only biotechnology firms but also major research institutions. We utilized variables outlined above to capture the level of knowledge generation in the area. In many ways these institutions resemble the specialized intermediate goods industries which Krugman (1991) addresses. The research institutions provide basic scientific research upon which biotechnology firms can access experienced research and specialized technical expertise unavailable elsewhere.

In addition, these research institutions attract skilled personnel to the geographic area, which helps create and sustain a superior labor pool. We utilized the variable of high technology employment in the local area to capture this and included it in our location variable. Our results lend credence to the idea that geographic location may be important to firm performance in the context of accumulating the knowledge needed for competitive advantage.

Our results are mixed for the impact of R&D intensity on firm performance. As mentioned above, in restricted Model Two this variable was highly significant (p < 0.01) yet in the full model, it loses all significance (p < 0.12). This may be explained by the fact that the correlation between R&D intensity (a flow variable) and the number of products (a stock variable) is significant indicating a potential problem with multi-collinearity which leads to understatement of the impact of R&D intensity on firm performance.

The final knowledge flow variable, the number of alliances, is not significant in the full model (and only weakly significant in the restricted Model Two). While the number of alliances represents the number of connections to other research institutions, it does not capture the quality of these alliances, the quality of the partner(s), nor does it capture whether or not knowledge is actually flowing into the biotechnology firm.

The results for products in the pipeline strongly
support a link to performance. Industry analysts always list products in development as information relied upon to evaluate biotechnology companies (Burrill and Lee, 1992, 1993; Business Week, 1994, 1995). Products in the pipeline may in fact be considered physical manifestations of a company's stock of accumulated knowledge. Our results indicate that products in the pipeline are a strong predictor of firm performance. The hypothesized relationship between number of patents and firm performance was not supported. This result is not surprising for a number of reasons. First, the number of firm patents does not reflect the quality of those patents. Second, given the expense required for patent filings and applications, extensive patenting may be cost prohibitive for some biotechnology firms. Third, these firms are too young to have developed an extensive library of patents upon which other firms may rely. Thus, patent citation analysis may not be relevant in this context. Although they represent a stock of knowledge, it appears that in this industry, simple patent counts are not a valid predictor of firm performance.

Firm citations are significant predictors of firm performance (p < 0.05) representing organizational knowledge in the form of intellect and research ability. This result suggests that the aggregated knowledge of the firm's scientific team is critical to competitive advantage in this dynamic environment.

Interestingly, the results of our full model suggest that two stocks of knowledge, products in the pipeline and firm citations—and only one variable representing knowledge flows—geographic location—are important to firm performance. In comparing the restricted Models (Two and Three) and the full model it also appears that knowledge stocks have a greater impact on firm performance than flows of knowledge. The knowledge stock restricted model has a higher R² then the flow model and the addition of the stock variables significantly increases the explanatory power of the model (Change R² > 0.05). It is interesting that R&D intensity, a flow variable, shows no significance in the full Model Four. Previous research has typically found a significant relationship between R&D and performance. Yet, our results indicate that the R&D performance relationship is minimized in the presence of the stock variables—products in the pipeline and citations. The relative importance of stocks versus flows of knowledge is an interesting question. It would appear that the market follows the bird-in-hand adage and places greater weight on the internal stocks of knowledge. Given the potential uncertainties of the value of the flows, particularly in an emerging industry such as biotechnology, this would appear to be a logical outcome. The results provide intriguing indications of the relative importance of stocks versus flows, but it also indicates the need for additional research. A longitudinal study examining changes in these variables and their impact (direct and lagged) on firm performance under various industry conditions needs to be undertaken.

We believe the results with respect to the location variable are a valuable contribution. Although location has been linked via theory and anecdote to innovation and superior performance, this study provides objective empirical evidence of a relationship between munificence of the local environment and the performance of firms in a knowledge intensive industry. Location has been viewed, particularly within the knowledge-based view of the firm, as an important source of flows of knowledge for firms. Prior research has used fairly simple measures of the munificence of the local geographical environment (Deeds et al., 1997). By broadening the measure to include measures of not only industry concentration, but also the quality and size of the research activity in a given geography and the local labor supply, we were able to provide fairly convincing evidence of the importance of the local environment to knowledge intensive firms.

While 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 knowledge capabilities to investors in all types of high technology firms.
While the results for our model are strong the interpretation of our results is limited by the dependent variable. The market value of a newly public firm, as we argued previously, is a reflection of the market's evaluation of the firm and its potential to create future cash flows at the time of the offering. Some studies on the long run performance of IPOs have provided some evidence of significant underperformance by IPOs due to investor over-optimism (Ritter, 1991; Loughran and Ritter, 1995; Rajan and Servaes, 1997). However, a recent study concluded that there are no statistically significant long run performance differences between IPO firms and firms of similar size and book-to-market ratios which have not issued equity (Brav and Gompers, 1997). These contradictory findings indicate the complexity of market value as a dependent variable despite its appropriateness for our study.

Given these findings, the generalizability of our results to the post-IPO performance of these firms and other public firms may be limited. While it is clear that the quality of the stock of knowledge controlled by the firm, as well the knowledge being generated in its geographic location, is related to the value the firm creates up to the point it issues an IPO, it is unclear whether these same relationships will hold in its post-IPO environment. This issue is an important area which demands further study.

Although we have found strong empirical support for our model it should also be noted that there is still a significant amount of variation yet to be explained indicating the need further research. In particular, the role of geographic location in determining firm performance warrant continued exploration. There also needs to be effort invested in the development of additional measures of firm knowledge in the biotechnology and other industries. The management of stocks and flows of knowledge appears to be critical to firm success. Yet, additional empirical research needs to be completed to enhance our understanding of the relationship between organizational knowledge and firm performance.

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