ELSEVIER

THE IMPACT OF FIRM-SPECIFIC CAPABILITIES ON THE AMOUNT OF CAPITAL RAISED IN AN INITIAL PUBLIC OFFERING: EVIDENCE FROM THE BIOTECHNOLOGY INDUSTRY

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EXECUTIVE SUMMARY

Going "public" has a magical sound to most entrepreneurial managers. By going public the firm increases its legitimacy in the business community, improves access to debt financing, and creates a means of exit for major shareholders. However, by far the most important reason for going public is to infuse a significant amount of investment capital into the firm. It is well documented that small businesses frequently fail because of insufficient funding and heavy debt loads. Issuing an initial public offering (IPO) allows entrepreneurial firms to overcome these pitfalls. Clearly, if access to capital is the major goal of going public, then the success of an offering is measured by the amount of capital raised by the firm.

This study presents a model of the total amount of capital raised by a firm through an IPO. The

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explanatory variables include several indicators of the scientific capabilities of the firm including the location of the firm, the quality of the research staff, the number of products under development, the number of patents held by the firm, and the firm's prior spending on research and development (R&D). The model is empirically tested on a sample of 92 biotechnology IPOs. The results provide strong support for the hypothesized positive relationship between the total amount of capital raised by a firm's IPO and the scientific capabilities of the firm.

Our results have important implications for entrepreneurs. First, an entrepreneur needs to develop and send credible signals indicating the value of the firm's intangible assets to the market. Second, the market values as deep a product pipeline as possible given a firm's resource constraints. Third, choice of location is a key strategic decision that should not be overlooked. Fourth, the market values firm-specific capabilities and will increase the capital it is willing to invest in a firm accordingly. Finally, the amount of capital a firm raises in its IPO can be influenced by entrepreneurial managers' strategic decisions.

INTRODUCTION

Going "public" has a magical sound to most entrepreneurial managers. By going public the firm increases its legitimacy in the business community, improves access to debt financing, and creates a means of exit for major shareholders (Sutton and Benedetto 1988). However, according to a survey of 542 entrepreneurs who had just taken their firm public, by far the most important reason for going public was to infuse a significant amount of investment capital into the firm (Arkebauer 1991). It is well documented that small businesses frequently fail because of insufficient funding and heavy debt loads (Jones 1979; Peterson, Kozmetsky, and Ridgway 1983; Wucinich 1979). Issuing an IPO allows entrepreneurial firms to overcome these pitfalls. Seed and start-up capital are generally provided by a mix of sources including personal and family assets, venture capitalists, and lending institutions (Van Auken and Carter 1988; Van Auken and Doran 1990). However, to raise the significant sums of capital required to pursue extensive research and development (R&D) projects or to finance rapid growth and expansion, the firm is usually required to access the public equities market by issuing an initial public offering (IPO). Clearly, if access to capital is the major goal of going public, then the success of an offering is measured by the amount of capital raised by the firm.

Preparing a firm to go public is particularly problematic for entrepreneurial managers of high technology firms. The uncertain and risky nature of the R&D process makes it difficult for investors to value these firms. Entrepreneurs, fearing expropriation of the firm's proprietary knowledge, are hesitant to fully disclose the details of the firm's R&D. Hence, these firms find it difficult to raise capital due to the information asymmetries that exist between themselves and potential investors. Overcoming this situation presents a clear strategic challenge to an entrepreneur who is trying to position a firm to go public.

This challenge is particularly acute for entrepreneurs in biotechnology. These firms are years away from any significant revenue stream, have very few tangible assets, are usually sustaining significant accounting losses, and require large amounts of capital (Burill and Lee 1992). Overall, these firms do not generally match the profile of the healthy young firm ready to raise capital for expansion via an IPO. Exacerbating these problems, start-up biotechnology firms generally have no products in the marketplace. Thus, their research capabilities are their only valuable assets, as these capabilities represent the firm's potential to develop and deliver state-of-the-art drugs.

To finance the drug development process, biotechnology firms require tremendous

R&D funding. It has been estimated that the average cost of development for a new drug is approximately $100 million, and the average development time is approximately five years from conception to market (Sapienza 1989). Whereas venture capitalists and pharmaceutical companies provide the initial capital, in order to maintain their independence and complete the research process, biotechnology firms generally have to sell equity on the public market. This is evidenced by the effects of the recent downturn in the market for biotechnology IPOs. A significant number of biotechnology firms are currently on the edge of bankruptcy, and others have been forced to sell or are considering selling out to large pharmaceutical companies (Burill and Lee 1994).

The preceding arguments make it clear that positioning a small biotechnology firm to go public is a major strategic challenge. The uncertain nature of the R&D process and its ultimate success or failure in delivering drugs makes it difficult for investors to properly assess the value of these companies. Furthermore, traditional historical indicators of performance such as return on assets, sales growth, or profit margin are not particularly illuminating because of the early development stage of these companies. The investor's assessment of the future value of the firm then must be based on indicators other than accounting measures of past activities.

The purpose of this study is to present and test a model of the variables that impact the ability of a biotechnology company to raise capital in its IPO. Specifically, our model includes the following strategic variables: (1) geographic location, (2) products in development, (3) R&D expenditures, (4) the publication record of the firm's top researchers, and (5) the number of patents.

The contributions of this study are fourfold. First, we combine insights from finance, technology management, and strategic management to create and empirically test a model of the amount of capital raised by a biotechnology firm's IPO. Second, we use a bibliometric technique to measure a firm's scientific capabilities, the number of times the research of the key scientists of the firm have been cited in the scientific literature, to explain the variation in IPO value. Third, we develop theory and empirical evidence attesting to the strategic importance of the geographic location decision to the future competitiveness of the firm. Finally, our results provide some insight into the value investors place on firm-specific capabilities.

THEORETICAL FOUNDATIONS

Theories of market signaling mechanisms suggest that certain variables or indicators send signals to potential investors about the capabilities and thus future value of firms (Akerlof 1970; Spence 1973). This literature has suggested a number of signaling mechanisms such as the percentage of equity retained by the entrepreneur (Leland and Pyle 1977), the level of planned capital expenditure (Trueman 1986), and the level of debt (Ross 1977).

Market signaling mechanisms are particularly crucial for start-up biotechnology firms. Research and development in this area is not "visible" to potential investors. New products have long gestation periods, and there is no guarantee the product will pass Federal Drug Administration requirements, or, if they do, that the drugs will be profitable.

Moreover, secrecy is an issue for the biotechnology firm. Entrepreneurs in this industry need to retain proprietary information to sustain a competitive edge. The more details about their research they communicate, the more they risk the expropriation

of their proprietary knowledge. Thus, although these firms need to signal to the market their strengths and potential, they must also retain a level of secrecy.

To help investors overcome these obstacles, entrepreneurs can signal to the market the quality of the of the firm's research capabilities (Spence 1973). For example, 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 companies and pharmaceutical companies. These start-up firms typically have no products in the marketplace—only in the pipeline. Further, their research pursuits are 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: (1) the industry is based on highly complex and specific knowledge that is still emerging, unlike the mature knowledge structure of the traditional pharmaceutical companies; (Pisano 1994); (2) these firms typically do not generate the number of new products that pharmaceutical companies do; and (3) they are much smaller in size and scope than the pharmaceutical companies.

Given this quandary, the question is what mechanisms exist through which start-up biotechnology companies can signal potential investors about the value of their company, while at the same time retaining a level of confidentiality about the processes and research methods being used for their new products. The following section describes a number of market signaling mechanisms that accomplish both goals for the entrepreneur in start-up biotechnology firms.

THEORY AND HYPOTHESES

Location and IPO Value

Process and product innovations do not occur in the isolated confines of a firm's R&D department. External sources of knowledge are critical to innovation. This is evidenced not only at the national level as in the case of Japan (Mansfield 1988; Rosenberg and Steinmuller 1988) but also at the industry level as illustrated in the case of computers (Brock 1975), aluminum (Peck 1962), and semiconductors (Saxenian 1990). In fact, 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 ability to absorb information from the external environment has been described as a firm's "absorptive capacity."

The absorptive capacity of an organization is the ability of an organization to evaluate and assimilate external knowledge (Cohen and Levinthal 1990). Absorptive capacity is a function of the level of a firm's prior related knowledge, which enables it to recognize valuable new information, assimilate it, and apply it to commercial ends. A firm that has a well-developed knowledge base in a particular field will have a high absorptive capacity and is ready to evaluate and act on any new information or ideas developed in the field. In contrast, a firm that has little or no knowledge of a particular field will be unable to evaluate and act on new information that is important to their products

or markets. In fact, this firm is unlikely to even recognize that valuable new information or ideas have been developed. Clearly, a firm with superior absorptive capacity has a competitive advantage in a rapidly developing market.

Interfacing with the external environment is critical to an organization's absorptive capacity. 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 absorptive capacity through communication flows. Close proximity of organizations with similar interests promotes the natural exchange of ideas through established networks. The idea that location matters to competitive advantage is not new (Marshall 1920) and is receiving renewed attention (Almeida and Kogut 1994; Jaffe, Trajtenberg, and Henderson 1990; Saxenian 1990; Krugman 1991).

Marshall (1920) describes how, throughout history, economic activity was clustered in areas rich in the "atmosphere" of ideas. Krugman (1991) expands on Marshall and highlights three factors that affect the concentration of certain industries in particular geographic locations. The first two factors are economic: (1) the pooling of demands for specialized labor and (2) the development of specialized intermediate goods industries. The last factor Krugman cites for geographic proximity of industries is based on knowledge spillovers. That knowledge spillovers exist among firms has tremendous implications for their internal capabilities.

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 acquisition. Informal channels of knowledge may be found in the interfirm mobility of scientists and engineers (Rogers and Larsen 1984). These informal mechanisms 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 (1990) 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 to 1994. They found significant *intraregional* mobility, particularly in Silicon Valley.

Saxenian (1990) performed a comprehensive comparative case study of two semiconductor regions: California's Silicon Valley and Boston's Route 128. Her findings suggest that the Silicon Valley is much more successful than Route 128 due to the embedded network of relationships and communications that simply do not exist on Route 128. She points to the importance of regional infrastructure and relationships, collective learning, and collaborative relationships with customers and suppliers as contributing to the resurgence of Silicon Valley in the 1980s. This was not the case on Route 128 where firms were characterized by independence and isolation from one another. Finally, regional institutions (such as Stanford University), trade associations, local business organizations, and varied consulting, market research, and public relations firms provide needed services for the area's businesses that often are unable to afford them.

Therefore, a firm located in a geographic area with a high concentration of similar firms will have access to information, personnel, and support structures unavailable to firms that are geographically isolated. Because of this increased access to scientific and technological resources, a firm's absorptive capacity is enhanced by its geographic location. Thus, the location of a firm acts as a signal to investors of the propensity of the firm to absorb new information and to develop the scientific capabilities required to succeed. These location advantages should be reflected in the market's valuation of a firm's intangible scientific assets. Thus, firms located in a geographic region with a concentration of similar firms should be able to raise more money through their IPO.

H1: The concentration of biotechnology firms located in a firm's geographic area will have a direct positive relationship with the amount of capital raised by the company's IPO.

Products in Development and IPO Value

A common indicator of technological competence or expertise in the pharmaceutical industry is the number of drugs in development or in the "pipeline." Financial analysts and potential investors monitor the products being pursued by firms in the pharmaceutical industry (Burill and Lee 1994). The strength of a firm's pipeline is considered an important indicator of a companies future cash flows. The amount and type of new drugs in a company's research pipeline reveals to the financial markets the future value of the company's current capabilities. Therefore, the number of products under development by a firm should influence the amount of capital the firm will be able to raise through its IPO.

H2: The number of new drugs in a biotechnology company's research pipeline will have a direct positive relationship with the amount of capital raised by the company's IPO.

Research and Development Expenditures and IPO Value

Expenditures on R&D have traditionally been used as an indicator of innovative activity in many industries (Scherer 1980). Several studies have examined the relationship between R&D spending and productivity returns (Comanor 1965; Grabowski and Vernon 1990; Graves and Langowitz 1993; Vernon and Gusen 1974). Therefore, the market will view the level of R&D expenditures as an indication of the intangible scientific assets of the firm and a predictor of the probability of the firm successfully completing the R&D process.

H3: A biotechnology company's R&D expenditures will have a direct positive relationship with the amount of capital raised by the company's IPO.

Citation Analysis and IPO Value

Product development in high technology environments is increasingly being driven by basic scientific research (Dasgupta and David 1994). 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 quality of a firm's scientific team is critical to the product development process and critical to an investors

evaluation of the firm's future prospects. However, attempting to make comparisons of scientific teams across firms leads to the problem of measuring the quality of the scientific research team. One method of judging research quality is well known in the academic community—citation analysis. Citation analysis uses the number of times a study or an author is cited as an indication of the importance of the work to the field. The more frequently a study, or an individual's body of work is cited, the more important, and hence the higher the quality of the work. Those 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 (Franklin and Johnston 1988; Small and Griffith 1974); to estimate the quality of the scientific capabilities of countries in specific fields (Healey et al. 1986) and 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). Citation data have also been used in a prior study of the biotechnology firms (Zucker, Brewer, and Darby 1994). 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 an indication of the quality of the firm's scientific capabilities. Firms with a higher level of citations should have higher quality scientists and, in turn, a more productive R&D team. These capabilities will be transmitted to potential investors via the reputations of the scientists. Scientists that are more highly cited will have a superior reputation, which, in turn, will signal investors that the firm's scientific capabilities and projects are of a high quality. This leads to our final hypothesis:

> *H4:* The total number of times the works of a firm's top scientists have been cited will have a direct positive relationship with the amount of capital raised by the firm's IPO.

Patents and IPO Value

Patents have been associated with innovation and performance at many levels: region, country, company. Patents are indicators of important technology positions and innovative activity. Further, patents are widely accepted measures by policy makers and analysts (Van der Eerden and Saelens 1991). Therefore, the market will use the number of patents controlled by the firm as an indicator of the value of a firm's intangible scientific assets.

> *H5:* The number of patents controlled by a biotechnology company will have a direct positive relationship with amount of capital raised by the firm's IPO.

METHODOLOGY

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

TABLE 1 Firm Location

Location	% of Industry	% in Sample
San Francisco Bay Area	15	17
New York Tri-State Area	11	9
Boston Area	10	18
San Diego Area	8	11
Washington, DC Area	9	5
Los Angeles/Orange County Area	6	2
Philadelphia/South Jersey Area	3	12
Seattle Area	4	5
Other	34	21

limited to firms that went public after 1982. Thus, the initial sample was limited to 218 firms. These firms were then contacted by phone requesting of copy of the prospectus from their IPO. A total of 106 companies provided a full or partial prospectus. However, due to missing data or the inclusion of warrants in a parent firm, 14 of these companies were excluded from the sample. Thus, our final sample consisted of 92 firms representing 41% of the total population of public biotechnology 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 with the average total assets and liabilities reported by Burill and Lee (1993) for all 225 public firms. Our sample averaged $11,123,000 in total assets and $3,515,000 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.

The data used in our analysis were gathered from: (1) the prospectus for each of the IPOs by the firms in our sample, (2) Ernst and Young's industry annual reports on the biotechnology industry, (3) the Center for Research on Stock Performance data tapes of stock prices, market value, and other variables for publicly traded companies, and (4) The Institute for Scientific Information's Science Citation Index. The Institute for Scientific Information is located in Philadelphia, Pennsylvania.

Dependent Variable

IPO Value

Given this study's focus on the role of the IPO in providing capital to entrepreneurial firms, we defined the value of a firm's IPO as the amount of capital from the offering that is actually transferred to the firm and its owners. This was calculated by subtracting the underwriter's fees from the total value of the capital raised by the IPO.

Independent Variables

Location

Based on the location of the firm's headquarters, firms were coded into geographic territories based on zip code and MSA. These locations were then compared with the eight areas identified by Burill and Lee as concentrations of biotechnology activity (see Table 1). 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 areas of geographical concentration.

Total Products

In the business section of each prospectus, companies report the number of products under development or that have reached the market. Only products that had reached the preclinical stage of development or beyond were included. Multiple applications of the same product were counted as a single product.

Research and Development Expenditures

The measure of total R&D expenditures was defined as the total R&D spending by the firm in the five years before the IPO. The five-year period was chosen, because this is what is communicated by the firm to potential investors via the offerings prospectus. A logarithmic transformation was used to control the skewness of the distribution.

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 IPO. 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 IPO.

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.

Control Variables

Several types of potential control variables were considered for inclusion in this study. These variables included controls for size, such as total assets and number of employees; controls for signals previously developed in the finance literature, such as the percentage of equity retained by the entrepreneurs, the level of planned capital expenditures and the level of debt and finally, controls specific to the offering such as the percentage of equity offered, the inclusion of warrants, and the timing of the offering. All of these variables were regressed against the dependent variable, and those that reached a level of significance of 0.10 or better were included as controls within the model.

TABLE 2 Descriptive Statistics and Correlation Matrix

	Mean	Standard Deviation	1	2	3	4	5	6	7	8
1. IPO value	20382170	12839872	1.00	0.32[a]	0.34[a]	0.33[a]	0.18[a]	0.30[a]	0.15[a]	0.45
2. Hot market	0.79	0.41	0.32[a]	1.00	0.09	0.03	0.21[a]	−0.01	−0.05	0.08
3. Location	7.52	5.14	0.34[a]	0.09	1.00	0.19[a]	0.07	0.07	−0.03	0.20[a]
4. Products	3.12	4.19	0.33[a]	0.03	0.19[a]	1.00[a]	0.05	0.17	−0.16	0.18[a]
5. Log (R&D spending)	6.69	0.71	0.18[a]	0.21[a]	0.07	0.05	1.00	0.26[a]	−0.41[a]	0.16
6. Firm citations	125.28	138.04	0.30[a]	−0.01	0.07	0.17	0.26[a]	1.00	−0.07	0.09
7. % of equity	0.29	0.12	0.15[a]	−0.05	−0.03	−0.16	−0.41[a]	−0.07	1.00	−0.24[a]
8. Log (assets)	6.77	0.58	0.45[a]	0.08	0.20[a]	0.18[a]	0.16	0.09	−0.24[a]	1.00

Total Assets

The total assets of the offering firm was used to control for the influence of size on market value. Total asset value was measured prior to the IPO. These figures were reported in the prospectus of each of the IPOs. A logarithmic transformation was used to control the skewness of the distribution.

Percentage of Equity

To control for the effect of the difference in the percentage of the total equity of the firm offered in the IPO, we included the percentage of the total equity sold during the IPO in the equation as a control. These data were collected from the prospectus of the firm's IPO.

Hot Market Dummy

It has been well documented (Ibbotson and Jaffe 1975; Ritter 1984) that the market for IPOs experiences periods in which the value of firms going public is substantially higher. The years 1983, 1986, 1991, and 1992 were hot markets for biotechnology IPOs. Therefore, to control for the effects of the "hot market" on firm value, a dummy variable was included in the model. Those firms that made offerings during hot years were coded as "1," and all other firms were coded as "0."

RESULTS

The data were analyzed using ordinary least squares regression. Descriptive statistics of the variables and the correlation matrix are presented in Table 2. The average value of the IPO in our sample was $20.4 million. The average firm had 3.2 products in the pipeline and 3.5 patents. Of the firms in our sample, 76% issued IPOs during hot markets. With respect to location, the average firm was located in a metropolitan area with 7.5% of the total national biotechnology firms. A list of the locations and the percentage of the total biotechnology industry located in these areas and the percentage of the firms in our sample in each area is presented in Table 1. Average R&D spending was $9.39 million, and average total assets were $11.9 million. The work of the average firm's team of scientists had been cited 125 times.

TABLE 3 Regression Results with IPO Value as Dependent Variable

	Model 1	Model 2	Model 3
Constant	−77,164,628[c]	−99,004,339.36[c]	−86,319,831[c]
	(13,968,823)	(16,678,942)	(16,729,514)
% of Equity	30,155,937[b]	34,139,755[b]	31,479,337[c]
	(9,008,364)	(10,731,744)	(10,773,002)
Log (assets)	12,074,864[c]	10,845,230[c]	9,897,656[c]
	(1,890,182)	(1,914,797)	(1,887,115)
Hot market	9,608,417[c]	10,413,811[c]	9,722,991[c]
	(2,478,214)	(2,352,889)	(2,374,686)
Products		1,054,570[c]	825,580[b]
		(246,555)	(248,410)
Log (R&D spending)		3,912,601[a]	2,519,088
		(1,552,843)	(1,580,051)
Patents		−434,968	−384,789
		(289,292)	(285,255)
Firm citations			19,031[b]
			(7,586)
Location			375,049[a]
			(181,909)
Adj. R^2	0.367	0.459	0.535
F-Statistic	18.81	14.53	13.37
p	< 0.0001	< 0.0001	< 0.0001

[a] $p < 0.05$.
[b] $p < 0.01$.
[c] $p < 0.001$.
$n = 92$.

Table 3 presents the results of the regression analysis with value of the IPO as the dependent variable. Three different models were run. Model 1 presents the base case controlling for the percentage of equity offered, the total asset value of the firm, and the hot market phenomena. The results confirm the importance of these control variables. Model 2 examines the impact of the traditional measures of scientific capabilities on the value of the IPO. The results indicate that an offering made by a firm with a deep product pipeline and strong R&D spending will have a significantly higher value. The coefficients for both products and R&D spending are significant, and the change in the adjusted R^2 is significant. However, the coefficient for patents is negative and insignificant. Model 3 presents the full model adding in the measures of the firm's scientific capabilities—location and firm citation. Both of the additional variables are significant. The adjusted R^2 for the model is 0.534, and the F-statistic is 15.35. The change in adjusted R^2 between Model 2 and Model 3 is highly significant. These statistics indicate that our model is explaining a significant amount of the variation in the value of a firm's IPO and suggest that our model is a very good fit.

H1 was supported. Location has a significant ($p < .05$) 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 market value than those located in areas with lower concentrations. This strongly suggests that the market believes that the location of a firm is an indicator of its probability of future success.

In support of H2, the number of new products a biotechnology firm has in its pipeline has a significant ($p < .01$) positive impact on the value of its IPO. These results indicate that the market uses the number of products under development as a signal of firm potential.

H3 was not supported. The total R&D spending by the firms was not significantly related to the value of the firm's IPO.[1]

H4 was supported. The number of times the work of the firm's scientists had been cited was significantly ($p < .01$) positively related to the value of the firm's IPO.[2] These results indicate that investors believe that the capabilities of the scientific team have an important impact of the probability of biotechnology firm's success.

H5 was not supported. The number of patents owned by a firm was not significantly related to the value of the firm's IPO.

DISCUSSION OF RESULTS

As stated earlier, the purpose of this study has been to present a model of the amount of capital raised by the IPOs of biotechnology companies using indicators of the scientific knowledge and research expertise contained within the firm as explanatory variables. Ambiguity concerning the research potential and ultimate profitability of biotechnology firms poses significant informational obstacles for financial markets. This situation forces biotechnology companies and investors to rely upon credible signals to communicate the value the quality of the firm. The strength of our results supports the hypothesized relationship among IPO value and three of our hypotheses, location, products, and our citation measure. This clearly demonstrates that investors in biotechnology firms believe that several of these indicators are signals of the future performance of the firm. High levels of these variables significantly improve a firm's ability to raise capital through an IPO.

There has been much theoretical/anecdotal discussion of the link between a firm's location and its performance. Our results provide empirical support for the assumption that firms located close to other firms in the same industry will benefit from their location. Trying to discern the separate impact of each of these on our results is difficult, but it is very clear that the market places value on a firm being within a cluster of similar firms.

Perhaps even more significant is the magnitude of the difference geographic location makes in a firm's ability to raise capital. Based on our results, a firm that relocated from outside of one of the geographic concentrations to Silicon Valley would increase the amount of capital it could raise through its IPO by $5.6 million, all other things being held equal. Given that the average size of the IPOs in our sample is $20.4 million, this is a very significant increase in a firm's ability to raise capital. The strength of our results lends credence to the idea that choice of geographic location is an important strategic decision that should be given careful consideration by entrepreneurs.

The results for products in the pipeline strongly support a link to the value of a firm's IPO. Industry analysts always list products in the pipeline as information relied upon to evaluate biotechnology companies (Burill and Lee 1992, 1993), and our results indicate they directly impact the market's expectation of the future cash flows that will be earned by a firm. Although these results are as expected, they are not trivial. The size of the coefficient indicates that each additional product in preclinical or clinical

[1] We also tested depreciated R&D spending using a 20% depreciation rate. The results remained insignificant. The results for the other variables remained essentially the same.

[2] We also tested a broader measure of citations including those named by the firm as key consultants and advisors. The results were substantially the same, but the significance level dropped to 0.05. The results for the other variables remained essentially the same.

trials increases the capital a firm can raise through an IPO by $825,000. Our results clearly indicate that the market believes value is created through product development. Therefore, part of preparing a high technology firm for issuing an IPO is developing as broad a program of product development, prior to the offering, as possible given the resource constraints of the firm.

Finally, the results for our citation measure indicates that the market values what it perceives as superior capabilities or talent. A one standard deviation improvement (138 citations) in the level of citations increases the value of the firm's IPO by over $2.6 million, strongly indicating that the market is willing to pay more for superior scientific capabilities. Thus, as a manager this means that hiring quality personnel based on accepted measures, such as citations in the scientific community, will improve the firm's ability to raise capital through an IPO.

CONCLUSION

One of the interesting implications of our results is the importance of the credibility of the signal being sent by the entrepreneurial firm. Each of the predictors that was significantly positively related to the value of a firm's IPO was easily verified, and in two of the three cases was certified by an external objective organization. Location is obviously easily observed and verified by potential investors. Products are verified by government regulatory bodies, and the citation measure is an objective measure of the value placed on the firm's scientific work by the larger body of researchers in the appropriate field. Clearly, Spence's (1973) observation that signals must be both credible and observable is well supported by our results. In fact, the lack of results for R&D spending may be due to the fact that simple accounting data lack credibility as a signal to investors, because there is no verification of the effectiveness or efficiency with which the firm is using its R&D resources. Similarly, given the uncertainty of patent protection in the biotechnology industry and the lack of any objective evaluation of the value of the patents, our results for the number of patent seem to reflect that patents lack credibility as a market signal. Another possible explanation for why the patent variable yields less robust results goes back to the argument that patent counts are an ambiguous measure given firm-specific variations in the propensity to patent (Deeds and Hill 1996). In other words, there may be more "noise" in patent statistics than in other measures of scientific capabilities. Given our results, it is quite clear that signaling theory has something of importance to offer both entrepreneurs and the study of entrepreneurship.

Our results provide some evidence to support the capabilities position in the current debate between the industry and resources/capabilities schools within the field of strategy. Several of our measures of firm-specific scientific capabilities were significantly positively related to the value of a firm's IPO. In addition, the magnitude of the coefficients indicates investors place a significant value on indicators of firm-specific capabilities. A firm that moved from outside of a geographic cluster to Silicon Valley and increased by one standard deviation the number of citations and number of products in the pipeline (138 citations and three products) could increase the amount of capital it raised in its IPO by over $11.7 million. Considering the size of these firms and the size of the average IPO, this provides very strong evidence that the financial markets invest in firm-specific capabilities.

Although our results provide strong statistical support for our conclusion, we must also acknowledge that our focus on biotechnology raises questions about the generaliz-

ability of our study. However, given the unique characteristics of the biotechnology industry, we still believe that our results are generalizable. 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 investors in all types of high technology firms, and the importance of effectively signaling these capabilities to investors by entrepreneurs interested in taking their companies public.

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 value of a firm's IPO that remains unexplained. Obviously, there remains other variables of potential interest that demand further study, including the effects of CEO and management team background, personal characteristics, and remuneration. In addition, the ability of a firm to return to the market and successfully issue subsequent offerings may well be linked to some of these characteristics as well as to the performance of the firm in the intervening period. Overall, the strategic issues of going to the markets for capital are ripe for further research and are critical issues for entrepreneurial firms.

Finally, important implications for entrepreneurs follow from our results. First, entrepreneurs need to understand that issuing an IPO is a serious strategic challenge and requires significant preparation over a long period of time. Second, signaling the market improves a firm's access to capital and the credibility of the signal appears to be key in the market's evaluation of the signal. An entrepreneur preparing to take a firm public, if possible, needs to develop signals that are verified by an external body, such as the Food & Drug Administration or academe. Third, the market values as deep a product pipeline as possible given a firm's resource constraints. Fourth, our results clearly indicate that location matters. Choice of geographic location is a key strategic decision that should not be overlooked by the entrepreneurial manager. Fifth, the market values a quality team and will increase the capital it is willing to invest in a firm if key members of the firm have a superior reputation in their field. Finally, the success of a firm's IPO can be influenced by strategic decisions, indicating that entrepreneurs need be proactive in preparing their firm for an IPO.

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