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The role of R&D intensity, technical development and absorptive capacity in creating entrepreneurial wealth in high technology start-ups

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Abstract

This study uses 80 newly public pharmaceutical biotechnology companies to explore the relationship between a high technology venture's R&D intensity, technical capabilities and absorptive capacity and the amount of entrepreneurial wealth created by the venture. A novel measure of absorptive capacity based on co-citation analysis of a firm's scientific publications is developed and several indicators of technical capabilities are used to develop early and late stage measures of a firm's technical capabilities. The results provide strong evidence of a positive relationship between a high technology venture's R&D intensity, late stage technical capabilities and absorptive capacity and the amount of entrepreneurial wealth created by a high technology venture.

Keywords: High technology ventures; Entrepreneurship; Scientific capabilities; Technical capabilities

1. Introduction

Entrepreneurship plays an important role in the development and commercialization of new technologies. Recent examples of new technologies that owe much of their development and commercialization to entrepreneurial high technology ventures include the personal computer, biotechnology, and the Internet. At its core, entrepreneurship is about the creation of new wealth through innovative activities (Dollinger, 1994; Drucker, 1985; Knight, 1921; Ronstadt, 1984). A high technology venture's ability to create entrepreneurial wealth is its reason for existence. If a venture is unable to create new wealth then the funding for the specific venture will dry up. If a population of high technology ventures fail to create significant wealth for investors then an important source of funding for the development

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and commercialization of a new technology will dry up. But, how do research-driven entrepreneurial high technology firms create value for their shareholders? Where should these firms invest their efforts and resources in order to maximize the amount of entrepreneurial wealth they create? These are interesting questions which have significant implications for the management of entrepreneurial high-technology ventures.

The resource-based view of the firm (Penrose, 1959; Barney, 1991) proposes that a firm's ability to create wealth is largely determined by its unique resources/capabilities. Firm success or failure is not entirely dependent upon industry structure, but rather a function of the resources and capabilities controlled by the firm, deployed by managers and developed and extended by the organization (Schendel, 1994). A basic premise in this theory is that those firm capabilities which are rare, inimitable and difficult to trade form the basis for sustainable competitive advantage (Barney, 1991). Subsequent researchers have highlighted the importance of intangible resources such as knowledge and scientific capabilities to competitive advantage (Deeds et al., 1997; Henderson and Cockburn, 1994; Hill and Deeds, 1996; Kogut and Zander, 1992; Petraff, 1993). These capabilities are usually difficult to observe, quantify and measure making the study of organizational capabilities difficult.

However, firms 'going public' provide researchers with a unique opportunity to study the relationship between the performance of the entrepreneurial firm and organizational resources. The implications of the resource-based view are that new venture performance will be dependent upon the ability of the venture to develop resources and capabilities that are rare, inimitable and difficult to trade. Within the context of the biotechnology industry new ventures face a hostile environment in which numerous new firms, as well as a cadre of large well financed pharmaceutical companies, compete to develop new drugs or diagnostics. In most cases these firms are years away from any significant revenue stream, have very few tangible assets, are sustaining significant accounting losses, and are desperate for capital (Burrill and Lee, 1992). Most of these firms have little more then the talent and skills of the individual members of the firms. Thus, their research capabilities are their only valuable assets, as these capabilities represent the potential to develop billion dollar drugs. Several studies have provided empirical support for the proposition that firm specific capabilities may lead to persistent performance differences among firms (Deeds et al., 1997; Henderson and Cockburn, 1994). Recent research also indicates that firm specific differences will also lead to differences in research productivity among firms (Henderson and Cockburn, 1994; Pisano, 1994). There is also evidence that a firm's research and development skills are important to the creation of shareholder value (Kelm et al., 1995). This leads to our basic premise that in the biotechnology industry the quality of the firm's scientific and research capabilities is a critical determinant of the wealth created by the firm.

Given that scientific and technological capabilities are complex asset structures that are built over time, what are the key components of these capabilities? An examination of the existing literature has led us to develop a model of scientific/technological capabilities that has three distinct components. The first is the creation of internal scientific and technological capabilities through investment in R&D. The second component is what we refer to as the firm's technical development capabilities. These are the skills and knowledge that allow the firm to turn basic research into patents and tangible products. Finally, there is the firm's connection to and involvement in the external scientific community. It has long been

acknowledged that a firm's ability to access external sources of knowledge is critical to its ability to innovate (Cohen and Levinthal, 1990; March and Simon, 1958).

The balance of this paper will focus on the relative merits of these components of scientific/technical capabilities in the creation of entrepreneurial wealth. This paper will address this issue by examining which, if any, of these components create value within the context of the biotechnology industry. The next section will present our theoretical framework and research hypotheses. This section will be followed by a discussion of research design and measures, the presentation of the findings of our analysis, a discussion of the results and limitations of the study, and finally a discussion of the implications of our study and some directions for future research.

2. Theoretical framework and research hypotheses

2.1. Internal research and development expenditures

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 internal development of new discoveries as well as enhance the flow of new scientific information into the firm. The relative amount of expenditures on research and development has traditionally been used as an indicator of a firm's 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; Hill and Snell, 1989; Vernon and Gusen, 1974), and have come to conflicting results. However, recent research has examined the role of technology context on returns to R&D spending and found that in complex technological contexts, such as biotechnology, there are significant positive returns to R&D investments (McEvily and Chakravarthy, 1999).

High technology new ventures have both limited resources and numerous investment needs including R&D, organizational building, market development, etc. The allocation of their limited resources is perhaps the critical decision an entrepreneur makes. The entrepreneurial manager of a new venture must try to determine the level of investment in each of these areas that maximizes the amount of entrepreneurial profit/wealth created by the firm. In a knowledge intensive industry, such as biotechnology, a significant strategic commitment to R&D appears to be critical to the firm's ability to develop the competencies required to succeed. 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).

Studies have tested and found support for the relationship between commitments to R&D and market value (Hirschey, 1985; Jose et al., 1986; Lustgarten and Thomadakis, 1987; Morck et al., 1991). However, other studies have argued that R&D expenditures in certain industries have been pursued by management at the expense of shareholders as a means of fostering diversification and entrenching the current managers in their positions (Dial and

Murphy, 1995; Hill and Snell, 1989). Whether an intense focus of expenditures on R&D creates shareholder wealth in entrepreneurial settings remains an open question. However, given the demands of a high technology environment and the need for the firm to develop its internal capabilities, R&D expenditures should lead to the creation of entrepreneurial profit/wealth.

Hypothesis 1. The R&D intensity of a high technology venture should be positively related to the amount of entrepreneurial wealth created by the venture.

2.2. Technical development

One of the key challenges of innovation is not simply the discovery of the new idea, process, or means of organizing, but in technically developing the product or process to the point where it can be produced and/or replicated at a commercially viable level (Pisano, 1994). Within the biotechnology industry technical development encompasses the process of moving the recently discovered protein or therapeutic compound through a series of stages including filing a patent application, receiving a patent, pre-clinical trials, clinical trials and finally onto the market. Success in technical development in biotechnology requires the firm to posses a broad range of both technical and regulatory skills. These skills include developing basic biological compounds into potential therapeutic or diagnostic products, developing manufacturing processes capable of producing the amount of the compound required for testing and commercial usage, creation of testing protocols that will be acceptable to the appropriate regulatory body, and conducting and managing the regulatory trials to the satisfaction of the FDA and other regulatory bodies. The outputs from the technical development process of a pharmaceutical biotechnology company are patent applications, patents, products in pre-clinical trials, products in clinical trials and products which have reached the market. These outputs serve as a proxy for the level of technical development capabilities controlled by a specific firm and these outputs weigh heavily in the financial community's evaluation of a pharmaceutical biotechnology company. This leads to our second hypothesis:

Hypothesis 2. The technical development component of a high technology venture's scientific and technical capabilities should be positively related to the amount of entrepreneurial wealth created by the venture.

2.3. Absorptive capacity

Cohen and Levinthal (1990) introduced the concept of absorptive capacity to the field of strategy. The concept comes from economic theories (primarily Schumpeterian) that examine the role of R&D in economic performance. In the first-half of the 20th century, Schumpeter argued that economic growth is rooted in technological innovation. This was not the dominant argument in economics (the dominant paradigm focused on price competition and allocative efficiency). This argument was picked up in the second half of the 20th century with some compelling evidence that R&D had a significant effect on economic growth (Solow, 1957). The stream of literature that emerged from these Schumpeterian roots

is quite broad covering a variety of issues critical to the question of R&D and economic performance (for reviews, see Scherer, 1980; Kamien and Schwartz, 1982; Baldwin and Scott, 1987).

The concept of absorptive capacity evolved from prior research on organizational learning. Organizational learning has been defined as the growing insights and successful restructuring of organizational problems (Simon, 1969), the process of improving actions through better understanding (Fiol and Lyles, 1985) and the ability of the firm to assess and act upon internal and external stimulus in a cumulative, interactive and purposeful manner (Meyers, 1990). There is a marked similarity between these definitions and the definition of absorptive capacity, however, the distinguishing feature of the "absorptive capacity" of an organization is that it is a function of the level of a firm's prior related knowledge.

A firm's prior related knowledge enables it to recognize valuable new information, assimilate it and apply it to commercial ends. A firm which 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 which 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. In competence based competition the ability of the firm to recognize the type of assets and capabilities that will be most useful in the future becomes critical to firm success (Sanchez and Thomas, 1995).

Absorptive capacity is qualitatively different from technology development. Absorptive capacity involves learning and acting on the scientific discoveries and technical activities occurring outside the boundaries of the firm. The information gathered from outside the firm is then used to redirect scientific discovery and technology development activities. In the biotechnology industry the primary source of this information is the scientific community of the universities and non-profit research institutions (McMillan et al., 2000). The scientific community or 'science club' is a social network of scientists and researchers with shared norms and values (Dasgupta and David, 1994). Membership in the community requires the disclosure of new knowledge through presentations at conferences and the publication of articles in academic journals (Dasgupta and David, 1994; McMillan et al., 1995). Pake (1986) and Hicks (1995) argue that publications are required for access to cutting-edge (e.g. ethical pharmaceuticals) research, while simultaneously they suggest that cutting-edge companies will publish a great deal. While some companies may make a strategic decision not to publish research, this choice will diminish the company's status, ability to participate and benefit from the scientific community. It is well established that surprising levels of trust and mutual forbearance frequently exist within a social network and that social networks provide access to information unavailable to those outside of the network (Granovetter, 1985; Powell, 1990). Thus, pharmaceutical biotechnology firms whose employees are members of the scientific community will learn more efficiently than those firms which are not network members.

The information gathered through membership in the scientific community can be used to redirect scientific discovery and technology development activities. If R&D activities are seen as investments, then superior absorptive capacity will result in more effective R&D expenditures (Cohen and Levinthal, 1994; Gambardella, 1992). In essence, absorptive

capacity enhances a firm's ability to judge the probability of successfully turning a given piece of basic research into a profitable product. Firms with greater absorptive capacity are more likely to pursue projects with a higher probability of success due to their superior knowledge. If the probabilities for a particular research stream change, due to new discoveries beyond the boundaries of the firm, then firms with higher absorptive capacity will sense this change faster and be quicker to adjust their research efforts in accordance with the new information.

Merck's rapid reaction to the ground breaking research on the process of cholesterol formation by Brown and Goldstein in 1972–1974 is an example of the impact absorptive capacity can have on research productivity. Scientists at Merck originally isolated Mevalonic acid, a link in the cholesterol chain, in 1956. However, this research remained on the back burner until the research by Brown and Goldstein caused Merck to reconsider the possibilities. By 1975, Merck had reinvigorated the research project and the outcome was Mevacor (Gambardella, 1992).

In recent years, Information Science has become very interested in measuring knowledge and understanding the growth and development of science. Bibliometric techniques (citation analysis, co-citation analysis, etc.) were developed to analyze the evolution of science. What all bibliometric techniques have in common is their reliance on the bibliographies of scientific publications to determine the links between scientific papers. Recently, bibliometric techniques have been used to map the development of particular fields of science, estimate the quality of the scientific capabilities of countries; to measure the performance of academic departments and as the basis for the assessment of scientific and technical research programs. We propose to use one of these techniques, co-citation analysis, as a measure of a biotechnology firm's absorptive capacity.

Co-citation analysis uses the bibliographies of current articles to develop a list of pairs of articles that are commonly cited in the same papers. These cited pairs are then linked with other citation pairs that have a number of citing documents in common. These linked pairs are then used to cluster documents into research communities. These communities represent groups of scientists addressing the same phenomena from a similar intellectual base. In essence these communities represent groups of scientists addressing the same question, from the same viewpoint using a shared language. Members of these communities are reading and referencing the same prior art, indicating a shared understanding of the phenomena understudy. Firms which are members of a research community have researchers who have demonstrated that they are players in particular community by their ability to get an article published in peer reviewed scientific journal which builds on prior work that is recognized by other researchers in the area. A firm which decides to protect their secrecy by not publishing research will not be included in a research community. As we noted earlier, we believe this is appropriate because status and participation in the community is predicated on the creation and dissemination of knowledge through conferences and academic journals. Therefore, a firm that is a member of a research community is well positioned to benefit from knowledge generated within the community. In turn, the larger the number of communities the firm participates in the broader the firm's connection to the scientific community and the more externally developed information is available to it. In essence, the aggregate number of research communities in which a firm participates is a proxy for the firm's absorptive capacity.

Hypothesis 3. The absorptive capacity component of a high technology venture's scientific and technical capabilities should be positively related to the amount of entrepreneurial wealth created by the venture.

3. Research design and measures

3.1. The model

The variables of interest in this paper are R&D investment, technical development and absorptive capacity — they are all components of a firm's scientific and research capability. Therefore, our model investigates the impact of each of these components on the entrepreneurial wealth created by our sample of new biotechnology firms. The proposed model is a linear model — where the dependent variable of the amount of entrepreneurial wealth created by the firm is approximated by the market-value-added (MVA) created by the firm between its inception and the end of the first day on which the firm's equities are publicly traded. The independent variables are R&D intensity, several measures of the outputs from the firm's technical development capability and the number of research communities in which the firm participates as a proxy for the firm's absorptive capacity. The model was tested using regression analysis.

3.2. The sample

The firms in our sample are homogeneous along the three key dimensions of competence suggested by Sanchez and Thomas (1995): organization, intention, and goal attainment. All of the firms are involved in scientific discovery and technical development. They collect and intend to use scientific and technical knowledge to decide which research options to pursue. They have issued an initial public offering, and they are-for-profit high technology ventures.

The sample used in this study consists of 80 pharmaceutical biotechnology companies, which went public between 1982 and 1993. It was gathered from the total population of 198 publicly held pharmaceutical biotechnology firms (Burrill and Lee, 1993). The sample was limited to firms that had gone public since 1982. This limited our sample to 191 firms. All 191 were contacted by phone and a copy of the prospectus from their initial public offering was requested. A total of 87 companies were able to provide a prospectus. Two companies were excluded from the sample because warrants for shares in their parent company were included in the IPO and five were excluded due to missing data (number of patent applications).

To test for biases in our sample, we compared the average total assets and total liabilities of the firms in our sample to the average total assets and liabilities reported by Ernst and Young (1993) for all 225 public biotechnology firms (pharmaceutical and non-pharmaceutical). Our sample averaged US$ 11,687,000 in total assets and US$ 3,927,000 in total liabilities. Ernst and Young (1993) reported the average total assets for the 225 public biotechnology firms to be US$ 11,377,000 and total liabilities to be US$ 3,313,000. Based on these comparisons and the size of our sample, we believe we have a fairly representative sample of the publicly held biotechnology companies.

3.3. Data sources

The data used in our analysis was gathered from three sources, the Center for Research in Security Prices (CRSP) tapes, The Center for Research Planning (CRP) provided data on the research communities in which these 80 pharmaceutical biotechnology firms participated, and the firm's IPO prospectus.

The CRP data came from yearly analysis of bibliometric data. The bibliography of worldwide scientific publications is analyzed using a technique called co-citation analysis (Garfield et al., 1964; Small and Griffith, 1974). The particular algorithms developed by CRP builds on the theoretical insights of Price (1963), additional theoretical developments by Kuhn (1970), and overcomes some of the commonly known problems associated with co-citation analysis of the scientific literature (Hicks, 1987; Leydesdorff, 1986; Mombers et al., 1985). An independent assessment of CRP's model can be found in Franklin and Johnston (1988).

3.4. The dependent variable

3.4.1. Market value added

MVA is an attempt to overcome the weaknesses of both accounting and market based measures. The basis for MVA begins with the concept of free cash flow (FCF) first developed by Modigliani and Miller (1958). FCF is essentially cash from operations that is available to lenders or shareholders. MVA is an attempt to estimate the FCF generated by a company by adjusting the distortions created in the accounting system. Stewart (1991) developed the system by examining the underlying cash implications of bookkeeping adjustments to earnings, such as goodwill amortization, deferred taxes, LIFO Reserve and R&D expense. While these adjustments are considered expenses under General Accepted Accounting Principles, these items bias a true economic valuation of the firm based upon the FCF Model (Stewart, 1991).

MVA emphasizes the amount of net or actual wealth, which has been created by the organization by considering contributed capital in the evaluation of new venture performance. If a firm's market value falls below the amount invested in the firm, then entrepreneurial wealth has not been created and MVA will be negative. Wealth is created only when the value of the firm exceeds the amount of capital that has been invested in the firm. Therefore, to measure the absolute amount of wealth created by a firm at a given point in time requires the total value of the capital contributed to the firm be netted out from the market value of the firm's equity. Eq. (1) presents the calculation.

$$\mathrm{MVA}_t = \mathrm{MV}_t - C_t \tag{1}$$

where MVA_t is the market value added at time t, MV_t the market value of the firm at time t, and C_t the value of the capital invested in the firm at time t.

MVA has generated a significant amount of interest in the corporate community and the fields of finance and economics (Armitage and Jog, 1996; Burkette and Hedley, 1997; Greene et al., 1996; Grant, 1996; O'Hanlon and Peasnell, 1996; Lee, 1996; Lehn and Makhija, 1996). A survey by the Manufacturer's Alliance found that more than 30% of senior executives who responded had adopted the use of MVA (Christinat, 1996). A recent study

of 241 large US companies between the years 1987 and 1993 by Lehn and Makhija (1996) has found that MVA is significantly positively correlated with stock price performance and a Herfindahl index measuring corporate focus and significantly negatively correlated with CEO turnover. In fact, while MVA was significantly related to CEO turnover and corporate focus traditional accounting measures of ROA and ROE were not related to CEO turnover and ROS and ROE were not related to corporate focus. These results lead the authors to conclude "... MVA are effective performance measures that contain information about the quality of strategic decisions and serve as signals of strategic change" (Lehn and Makhija, 1996: p. 37).

Newly public firms present a unique opportunity to apply MVA and to assess the impact of the strategies followed by the entrepreneurial managers on wealth creation in their new venture. In new ventures, MVA is a market-based measure of how much entrepreneurial wealth has been created by the firm during the period from inception to going public. Essentially, MVA measures how much entrepreneurial profit[1] the firm has created. Of course, if a new venture succeeds in issuing an IPO it has achieved a certain level of success. Yet, the performance of all newly public firms is far from equal. For example, in our sample of 80 newly public pharmaceutical biotechnology firms, the amount of shareholder wealth created as measured by MVA varied from a low US$ 1.6 million to a high of US$ 318 million. We measured MVA at end of the first day of public trading of the firm's equity.

MVA is the difference between two figures — an approximation of the fair market value of all the companies' debt and equity capitalization and the capital employed by the company. The market value is the actual market value of the company's common equity plus the book value of preferred stock, minority interests, long-term non-interest bearing liabilities, all interest bearing liabilities and the present value of all non-capitalized leases. The capital employed by the company is essentially the company's assets less non-interest bearing current liabilities plus certain equity equivalent accounting reserves (Bad debt, LIFO, Goodwill amortization, R&D, Unusual losses). In the case of biotechnology companies the important adjustments are the addition of the accumulated deficit during the startup phase, which was considered an unusual loss, and depreciated R&D. Investment in R&D is depreciated at a rate of 20% per year. These are both added into total capital because in an economic sense they represent investments by the organization, and therefore, should be considered part of the capital employed by the firm. The market value of the firm's common equity was gathered from the CRSP data tapes at the end of the first day of trading. The accounting information was gathered from the most current financial statements included in the prospectus for the initial public offering.

3.5. Independent variables

3.5.1. 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 3 years. The data were gathered from the IPO prospectus.

[1] Schumpeter defined entrepreneurial profit as the "expression of the value of what the entrepreneur contributes to production in exactly the same sense that wages are the value expression of what the worker 'produces'... It attaches to the creation of new things, to the realization of the future value system" (Schumpeter, 1936: pp. 153–154).

Table 1
Factor analysis of technology indicators

	Factor 1	Factor 2
Patent applications	0.891	0.050
Patents	0.803	0.066
Products in pre-clinical	0.674	0.360
Products in clinical	0.177	0.727
Products on market	0.019	0.779
Eigenvalue of factor	2.261	1.018
Variance explained (%)	45.29	20.36

3.5.2. Technical development capability

The measure of technical development capability employed in this study builds on prior work which used outcomes of the technical development process as a proxy for technical capabilities (Eun et al., 1996; Henderson and Cockburn, 1994; Yeoh and Roth, 1999; Zander, 1998). This study uses several indicators of the productivity of a firm's technical development process as proxies for the firm's technical development skills: the number of patent applications by the firm, the number of patents by the firm, the number of products in pre-clinical trials, the number of products in clinical trials and the number of products on the market. We decided upon these indicators because they cover the different stages of the development process. We then ran a factor analysis on these measures in order to develop a single factor for the model. However, as the results of the factor analysis in Table 1 indicate there were two distinct factors. Patent applications, patents and pre-clinical products all loaded on the first factor. Products in clinical trials and on the market loaded on the second factor. Therefore, we created two variables as proxies for technical development capabilities. The first uses patent applications, patents and pre-clinical products. This variable represents early stage technical development. The second uses products in clinical trials and products on the market, which represents later stage technical development.

In order for a product to reach pre-clinical trials the firm has to have achieved a significant level of technical development with the product. This includes an initial formulation, a delivery method and the ability to manufacture enough of the product to support the pre-clinical studies. In order to advance to clinical trials and beyond the firm's technical development capabilities have to include formulation, delivery system development, and successful clinical trial design. In addition, the FDA has to have approved the firm's investigational new drug (IND) application prior to the product entering clinical trials. Therefore, while there is some commonality among the early and late stages of the technical development process there are clear distinctions between the two stages. The early stage is more reliant upon basic laboratory research skills and the later stage of technical development is more dependent upon clinical and regulatory skills.

The data for these variables were gathered from the IPO prospectus of the firm. Raw counts of patent applications, patents and products in the various stages were normalized and then factor analyzed. The factor analysis was then used to determine the appropriate measures to be included in each factor. The early stage factor included patent applications, patents and products in pre-clinical trials. The later stage factor included products in clinical trials and products on the market. The factors were calculated by averaging the normalized variables.

3.5.3. Absorptive capacity

The number of research communities that the firm's scientists and engineers participate in is used to indicate absorptive capacity. This proxy for absorptive capacity is based on participation of the firm's scientists and engineers in research communities and development communities whose members are primarily 'outside' the boundary of the firm. Research communities (communities of scientists in labs around the world) are considered the basis for scientific progress (Price, 1963; Kuhn, 1970). Participation in these research communities can be indicated by raw publication counts or (as used in this study) co-citation analysis of the firm's publication activity (Klavans, 1994).

A research community is composed of current research papers addressing the same problem that have appeared in refereed scientific journals. These communities are defined through co-citation analysis of the bibliography of worldwide scientific publications (Garfield et al., 1964; Small and Griffith, 1974). Papers within these groups represent the work of researchers who share a common interest, intellectual heritage and cognitive focus (Healey et al., 1986). The validity of co-citation analysis is supported by two systematic studies of the co-citation algorithm used by the Center for Research Planning (CRP) (Healey et al., 1986; Franklin and Johnston, 1988). A detailed discussion of research communities and the CRP algorithm can be found in Franklin and Johnston (1988). The variable is operationalized as a count of the total number of research communities that a firm participated in during the year in which it floated its IPO.

3.6. Control variables

3.6.1. Hot markets

Ibbotson and Jaffe (1975) first documented the existence of a number of 'hot markets' for IPOs during the last 20 years. These 'hot markets' are characterized by a high volume of IPO activity. During these periods both the number of IPOs brought to the market and the average value of the IPOs brought to market is significantly higher than during a normal period. In addition, Ritter (1984b) documents that the 1980 'hot market' was really a hot market for natural resource issues, establishing that certain market segments may experience 'hot markets' independent of the broader market.

We examined the number of IPOs per year to identify 'hot markets'. In the case of biotechnology the years 1986, 1991 and 1992 show all the characteristics of a 'hot market'. The data clearly show that the amount of capital raised, the average market value of each offering firm and the number of offerings in 1986, 1991 and 1992 at least doubled during the hot years. Therefore, to control for the 'hot market' phenomena a dummy variable was created which was coded as 1 for all offerings during 1986, 1991 and 1992 and was coded 0 for all other offerings.

3.6.2. Number of employees

To control for any possible effects of size on a firm's ability to generate wealth we entered the total number of employees into the model as a control. The number of employees was chosen as the control for size because total assets are being used in the calculation of the dependent variable. Because this variable was highly skewed a logarithmic transformation was employed.

Table 2
Descriptive statistics[a]

Variable	Mean	S.D.
Market value-added	70493122	52446051
R&D intensity	0.62	0.22
Early stage technology	0.552	0.299
Late stage technology	0.392	0.288
Number of research communities	12.23	16.06
log(Number of employees)	1.66	0.40
Hot market dummy	0.81	0.39

[a] $n = 80$.

4. Results

Descriptive statistics are presented in Table 2. The average shareholder wealth created by the firms in our sample was US$ 70,493,122. The average firm had 1 product in clinical trials and 2.11 products in pre-clinical trials. The average firm participated in 12.23 research communities, although 24 firms participated in no research communities. One firm participated in 95 research communities. Sixty five of the IPOs were issued during 'hot markets'. Table 3 presents the correlation matrix.

The regression results are presented in Table 4. The adjusted R^2 is 0.486 and the F-statistic for the model is 13.47 ($P < 0.0001$) indicating that our model explains a significant amount of the variance of the market value added of the firm's in our sample. The regression results provide strong support for Hypothesis 1. R&D intensity is positively related to the firm's MVA at the 0.007 level of significance. The results provide mixed support for Hypothesis 2. Both early and late stage technology development are significantly related to MVA, but early stage technology development is negatively related to MVA while late stage technology development is positively related. Strong support is provided for Hypothesis 3. The number of research communities in which the firm operates is positively related to MVA at the 0.001 significance level.

5. Discussion and study limitations

5.1. Discussion of findings

Our results provide strong evidence that high technology ventures create entrepreneurial wealth by investing resources in the development of scientific/technical capabilities. The magnitude of the beta coefficients indicates that increases in three components of the scientific/technical capability were positively correlated to the creation of entrepreneurial wealth: R&D intensity, late stage development activity and absorptive capacity.

The results for R&D intensity are in line with current research that highlights the value of R&D investments in a complex technical context (McEvily and Chakravarthy, 1999). In a high technology environment, such as biotechnology, investors clearly value investments

Table 3
Correlation matrix

	Market value-added	R&D intensity	Early stage technology	Late stage technology	Number of research communities	log(Number of employees)	Hot market dummy
Market value-added	1.000*						
R&D intensity	0.427****	1.000*					
Early stage technology	0.275***	0.275***	1.000*				
Late stage technology	0.217**	0.217**	0.515****	1.000*			
Number of research communities	0.577****	0.383****	0.378****	0.018*	1.000*		
log(Number of employees)	0.507****	0.213**	0.366****	0.237**	0.431****	1.000*	
Hot market dummy	0.278***	0.069*	0.141*	0.005*	0.195**	0.080*	1.000*

* $P < 0.10$.
** $P < 0.05$.
*** $P < 0.01$.
**** $P < 0.001$.

Table 4
Regression results with market value added as the dependent variable[a]

	Beta coefficient	*t*-Statistic	Significance
R&D intensity	0.26	2.80	0.007
Early stage technology	−0.23	−2.11	0.038
Late stage technology	0.21	2.11	0.038
Number of research communities	0.39	3.93	0.001
log(Number of employees)	0.30	3.25	0.002
Hot market dummy	0.19	2.31	0.024
Constant		−2.69	0.009

[a] $n = 80$; $F = 13.47$; $P(F) = 0.001$; Adjusted $R^2 = 0.486$.

in R&D. The average firm in the sample allocated over 62% of its expenditures to R&D and over one-third of the sample allocated over 75% of their expenditures to R&D. The results make it very clear that within a research-intensive environment, such as biotechnology, a narrow strategic focus on the development of product by a new venture results in the creation entrepreneurial wealth.

The results for our technology development indicators provide some interesting insights. These results appear to be due to the extreme uncertainty associated with the movement of a pharmaceutical compound through the development process. The high level of uncertainty about the potential of any given patent application, patent or pre-clinical compound leads investors to heavily discount the value of the outcome of these early stage development activities. It is only when the product reaches clinical trials or actually reaches the market that investors begin to recognize that the firm has created something of value. This appears to indicate that the entrepreneurial wealth cannot begin to be realized until the product has reached the later stages of development. Firms which attempt to issue an IPO while still in the early stages of the development process leave money on the table, due to the high level of discounting applied to compounds in the early stage of development. The significant negative results for early stage developments are confounding, because it appears to indicate that a firm is better off with fewer patent applications, patents and pre-clinical compounds. However, it is important to consider that all the firms in the sample were successful enough to issue an IPO, not an insignificant hurdle. I believe when interpreting these results it has more to say about the timing of a firm's IPO, then the value created by the different stages of technical development. It is important to recognize that early stage development processes are critical to the successful development of new pharmaceutical compounds and the success of high technology ventures.

As it has often been argued in the public science debates, the results seem to show that the financial markets place very little value on early stage development activities. This outcome supports the continuing need for the involvement of public research institutions and government funding in the early stage development processes. In particular, the early discovery process leading to patenting. The later stage technical development processes are clearly appropriable by the firm because they facilitate the advance of the products, which they own, into the regulatory process and hopefully on to the market. However, the appropriability of the wealth created in the early stage technical development processes appears to be much lower. Early stage work, while furthering knowledge and providing the

basis for future research and potential products, only rarely results in marketable products whose value is appropriable by the firm which invested in the early stage development. Given, the resource poverty faced by most new ventures the market is sending a clear signal for them to focus their efforts on later stage technological development.

Absorptive capacity creates appropriable benefits by increasing the productivity of the firm's R&D investments. Continually absorbing information from beyond the boundaries of the firm allows it to continually re-evaluate its portfolio of R&D projects based on the new information. Improving the odds of success by decreasing the gap between the perceived value of the firm's R&D options and real value of the options. Decreasing this gap allows a firm to more accurately allocate scarce resources among its portfolio of R&D projects. This is critical in a rapidly developing highly technical field such as biotechnology in which the knowledge base of the field is relatively immature and developing rapidly (Pisano, 1994). In this situation the costs and probability of failure are high and the relative merits of potential avenues of exploration are unclear. Under these conditions, absorptive capacity allows a firm to adjust its portfolio of R&D projects to minimize the odds of failure by avoiding repetition of the failures and the dead ends of competitors and other research organizations in the field, and by speeding up the firm's ability to recognize unprofitable avenues of exploration. Therefore, as the absorptive capacity of the firm increases the return on its R&D investments will increase.

5.2. Research limitations

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, we still believe that our results are generalizable beyond the biotechnology industry. Basic science appears to be playing a more significant role in the success and failure of individual firms (Dasgupta and David, 1994). This trend increases the importance of scientific capabilities to all types of high technology firms.

It is also important to recognize the cross-sectional nature of the research and the dependence upon outcome based proxies for measures of the core constructs. The productivity of a firm's investment in R&D will be effected by the internal processes, skills and capabilities of the members of the firm. Patent counts are messy measures, that fail to take into account the large variation in the value of patents, as well as the type (product versus process and basic versus applied) of patent. Compound counts fail to take into account the high variation in size and value the potential markets of these compounds. Finally, the use of co-citations to create research communities indicates that the scientists in the community are building off of the same work, but there is no direct evidence of a social interaction or information exchange. Overall, the reliance upon outcome measures provides interesting indirect evidence that scientific/research capabilities create entrepreneurial wealth in high technology venture, but no direct evidence that relates internal firm processes to the creation of entrepreneurial wealth.

Finally, the limitations of the market-based dependent variable must be taken into account. A firm's MVA depends upon the financial markets perception of the firm. This is not a measure based on some scale of skills or talents of the firm, some objective outcomes, or some expert panel's informed opinion of the firm, but rather the combined opinion of the investors in the US financial markets. 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 that have made superior decisions and investments will have greater potential and in turn a higher market value upon entering the market. Some studies on the long run performance of IPOs have provided some evidence of significant under-performance by IPOs due to investor over-optimism (Ritter, 1991; Loughran and Ritter, 1995; Rajan and Servaes, 1997). However, a recent study concluded that there is no statistically significant long run performance differences between IPO firm's 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.

6. Implications and directions for future research

There are several implications for entrepreneurs and managers of high technology ventures from this research. The first is that in complex technology contexts the market rewards firms which focus on R&D. Second, while the early stages of technology development provide the foundation for the later stages of technology development, it is the later stage outcomes through which entrepreneurial wealth is realized. An interesting patent or pre-clinical compound's value will be highly discounted by the financial markets and provide little return to shareholders. However, later stage products in clinical trials and on the market will be valued by the markets and allow the firm to realize entrepreneurial profit. Finally, participation and membership in the scientific community through publication of papers, participation in conferences, etc. contributes to a firm's ability to create entrepreneurial wealth.

While there is strong empirical support for the model it should also be noted that there is still a significant amount of variation in the MVA of the firm's in our sample which remains unexplained. Obviously, there remain other variables of potential interest, which demand further study. It is clear that further work needs to be done to refine and expand our ability to measure the various aspects of R&D competence. Studies of entrepreneurial wealth creation in other technology and industry contexts need to be conducted to expand our understanding. Qualitative studies, and large-scale survey or interview based studies, which relate the internal processes and procedures used by high technology ventures to the creation of entrepreneurial wealth also need to be undertaken. Finally, the relationship between the R&D intensity, technical development capabilities and absorptive capacity and other measures of a high technology venture's performance, such as survival, growth,

profitability, etc. needs to be studied. The results of this study are interesting, but there remains a pressing need for more studies of technology management practices and their impact on high technology ventures' outcomes.

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