AN EMPIRICAL EXAMINATION OF MANAGEMENT OF REAL OPTIONS IN THE U.S. VENTURE CAPITAL INDUSTRY

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Abstract

This study empirically examines how firms manage real options over time in the context of the U.S. venture capital industry. It tracks the venture-capital funding histories of U.S. portfolio companies founded during 1989-1993, and their outcomes, until 2004. An examination of sequential investments suggests asymmetries in the management of successful and unsuccessful companies. Signals of a company's progress, such as the number of its patents, are significant predictors of VC investment practices in the case of successful companies, but not in the case of unsuccessful companies. In contrast, VC firm characteristics, such as experience in the company's industry, IPO experience, and geographic proximity, appear to explain variance in investment policies for unsuccessful companies, but not successful ones. This suggests that signals of progress are relatively easier to interpret when the real options perform well over time, and investors can perhaps apply them equally effectively. In contrast, signals of failure are more ambiguous and complex; and firm-level differences are more pronounced in management of unsuccessful options.

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1. Introduction

Real options allow firms to deal with uncertainty surrounding investments (e.g. Bowman & Hurry, 1993; Dixit & Pindyck, 1994; Trigeorgis, 1996). Prior research reports that firms use real options logic in managing portfolios of uncertain investment opportunities, such as R&D investments (Kumaraswamy, 1996; McGrath & Nerkar, 2004), business development options (Folta & Miller, 2002; Kogut & Kulatilaka, 1994), and venture capital or corporate venture portfolios (Gompers, 1995; Hurry, Miller, & Bowman, 1992). While most research on real options has focused on the adoption of real option logic and valuation of the options, issues related to the management of these investments over time have only recently started to capture attention (Adner & Levinthal, 2004; Coff & Laverty, 2001). However, management of real options is key to performance, since realization of the value of these options requires successful implementation over time. This includes a set of activities following the initial selection of investments, such as collecting new information, evaluating expected payoffs according to new information, and subsequently deciding to continue or abandon investments. A thorough understanding of real options in action, therefore requires careful attention to the implementation of real options logic.

This study empirically examines how firms manage real options over time in the context of the U.S. venture capital industry. Venture capital investments provide an attractive setting for a study of real options. Each investment decision involves *expending resources* with a significant *opportunity cost* under conditions of *uncertainty* and *irreversibility* (Dixit & Pindyck, 1994).

Venture capital firms use real options logic in their investments on a regular basis. They typically invest in portfolio companies in multiple financing rounds, which provide them with options to continue or abandon investments over time. These investments are designed to help venture capital investors deal with uncertainty underlying the value of their investments. The ability to reap the most benefit from such investments depends on effective management of the options over time. Venture capitalists must identify the options that still offer positive value and continue investing in them, while abandoning options that are no longer valuable. I argue that both are important in managing portfolios of options, yet they may require different skills.

The study tracks the venture-capital funding histories of U.S. portfolio companies founded during the 1989-1993 period. It focuses on sequential investments in the portfolio companies, until 2004, and their outcomes. I identify companies that achieved a successful exit as of 2004, and the ones that did not. I then retrospectively examine VCs' sequential investment practices, and explore investment patterns in these two subsamples. The results suggest that asymmetries exist in the management of successful and unsuccessful investments. While signals of a company's progress, such as the number of its patents, are significant predictors of VC investment practices in the case of successful companies, they are not significant predictors of VC investments in unsuccessful companies. In contrast, VC firm characteristics, such as experience in the company's industry, IPO experience, and geographic proximity, appear to explain variance in investment policies for unsuccessful companies, but not successful ones. This suggests that signals of progress may perhaps be relatively easier to interpret in the case of successful companies, and venture capital firms can apply them equally as effectively. In contrast, signals of failure are more ambiguous and complex; and firm-level differences are more pronounced in management of unsuccessful companies. More generally, this finding lends

support to the argument that firms face challenges in the implementation of real options logic over time, especially when the investment is not performing well (Adner & Levinthal, 2004; Coff & Laverty, 2001). It highlights managerial challenges in implementing real options over time. It also demonstrates asymmetries in the management of options which perform well, and those that perform poorly. While management of "successful" options requires careful attention to objective signals of success, management of "unsuccessful" options requires subjective judgment about whether to continue or terminate investments. In consequence, firm-level differences in the management of unsuccessful options appear more pronounced, and may potentially affect firm performance.

2. Sequential Investments and Real Options

An option is the right, but not the obligation, to take an action in the future (Amram & Kulatilaka, 1999). By buying an option to buy or sell an asset at a predetermined exercise price, investors can protect themselves from the adverse affects of future price fluctuations. Since there is no obligation to exercise the option if its value falls below its exercise price, the downside of investment is limited to the purchase price of the option. The upside is unlimited, based on the value of the asset at the exercise date. Since the upside potential of options increases under uncertainty, options become more valuable when the level of uncertainty is high.

By analogy, real options provide firms with opportunities to make (or abandon) subsequent commitments to a project at a future date, without an obligation to do so. Real options can be growth options, which allow firms to make subsequent investments in a project that is going well, or to leverage the project as a platform for new investment opportunities (Amram & Kulatilaka, 1999; Kim & Kogut, 1996; Kogut & Kulatilaka, 1994). They can also be exit options, which allow the firm to abandon investment if the project is not going well. Firms

use real options logic in many decisions under uncertainty. For instance, firms leverage minority stakes in partner organizations as options to bring the partner in-house (Folta & Miller, 2002). Investments in R&D and patenting have been characterized as options to pursue further investment in a technological area (McGrath, 1997; McGrath & Nerkar, 2004). Foreign direct investments in a country may serve as options to expand to other countries (Kogut & Kulatilaka, 1994).

While some real option decisions may be one-shot (e.g. acquisition of a venture after a minority transaction), many occur sequentially, in multiple stages (e.g. pharmaceutical drug development that involves several phases of development and testing, or venture capital investments that involve several rounds of financing). In such cases, investment at each stage gives the firm the opportunity to participate in subsequent stages. These investments are akin to compound options, where the value of the option at any stage includes the value of the subsequent options as well as the immediate one.

Sequential investments involve an iterative process of information acquisition and incremental commitment over a substantial period of time. Each subsequent investment provides the investor with more information about the likelihood of success. However, each investment also has an opportunity cost because resources may be invested in exploring new alternatives. Therefore the investor decides between investing to gain more information about the ultimate payoff of existing projects and investing in new alternatives.

Uncertainty about each option's payoff structure may have both endogenous and exogenous components from the investor's point of view (Folta, 1998). The probability of success is endogenous to the extent that the outcome depends on the actions of the investor. To further explore the example of pharmaceutical drug development, the likelihood of discovering a

profitable drug molecule is almost zero unless the right amount of capital and effort are devoted to research and subsequent phases of product development. This likelihood increases with appropriate investment in R&D. This component of the likelihood of success captures the growth of the project's value with proper management of resources.

At the same time, there is a stochastic component of success that is exogenous to the investor. This part of the distribution may be affected by the intrinsic value of the project, as well as other, unobserved factors that may affect the project performance, regardless of the investor's actions. No matter how much investment the pharmaceutical company allocates to research, some projects are intrinsically more likely to become successful than others. This component of the probability distribution captures the uncertainty in the project's value.

Sequential investments help uncover additional information about the underlying value of the particular project. The advantage of utilizing a sequential approach to investments is that it provides firms with more flexibility in their investment process, compared to a one-shot investment. Instead of committing a large amount of capital upfront, the firm can invest small amounts to learn about the underlying value of the project, and decide whether to make subsequent investments based on information about the progress of the company. At each stage, the investor is to decide whether to invest further in discovering the underlying value of a particular project or to abandon the investment. The flexibility advantage can only be enjoyed if the firm abandons investments that are no longer "in the money", and utilizes its resources in other, more promising projects.

3. Venture Capital Investments as Real Options

Venture capital investments in portfolio companies comprise examples of real options logic (Amram & Kulatilaka, 1999; Gompers & Lerner, 2000; Hurry et al., 1992). This section briefly describes the venture capital investment process, and then explains how real options thinking applies to venture capital investments.

VC firms[i] are typically organized as limited partnerships, where general partners raise capital from limited partners for specific funds, and manage the funds over a fixed duration (typically 10 years). Limited partners include institutional investors and wealthy individuals. Among institutional investors, corporate and public pension funds comprise the largest investor group, followed by endowments and foundations, bank holding companies, insurance companies, investment banks, nonfinancial corporations, and foreign investors (Fenn, Liang, & Prowse, 1997). General partners manage funds by selecting and monitoring a portfolio of investments, and liquidating investments ('exit') to return the capital to limited partners. VC firms' performance is measured in terms of the returns to each fund. Returns on previous funds drive the general partners' ability to raise capital for new funds.

Venture capitalists select portfolio companies through a rigorous screening process. A typical VC firm invests in only 1% of the business proposals received (Fenn et al., 1997). VC firms often expect to remain involved in each portfolio company for 5-7 years (Fenn et al., 1997). During this period, they monitor the progress of the company, and provide resources and advice, to ensure that the company is moving toward a successful exit option. VC firms can exit portfolio companies through IPOs, acquisitions/mergers, or stock buybacks. Venture capitalists typically earn the highest rates of return when the portfolio company goes public (Gompers &

[i] In the discussion of the venture capital industry I use the term "firm" solely to refer to venture capital firms and "company" to refer to portfolio companies (entrepreneurial ventures).

Lerner, 2000). Therefore, successful exit options from the venture capitalists' perspective are public offerings, or acquisitions at favorable prices.

VC firms typically specialize in high-risk investment opportunities, such as start-up companies in unproven, high-technology industries. As a result, returns to VC investments are highly skewed, i.e. a small number of investments account for a large proportion of portfolio returns (Scherer, Harhoff, & Kukies, 2000). Only between 10-30% of VC investments result in an IPO (Fenn et al., 1997). The top 10% of VC investments between 1969-1988 accounted for 62% of the returns (Scherer et al., 2000). In this period, over 30% of VC investments resulted in a net loss (Sahlman, 1990).

It is this uncertainty over the likelihood of a successful exit that the VC firm attempts to uncover through sequential rounds of financing. Since a large proportion of portfolio companies provide little or no returns, estimation of the likelihood of success, and abandonment of unsuccessful investments, is key to overall portfolio performance. Each round of investment is an option to acquire more information about the developing prospects of the company. Additional investment helps reveal new information that gradually resolves the technological and demand uncertainty that the company faces. Venture capital firms typically manage this process by setting milestones for each portfolio company, and then evaluating the progress of the company toward the milestones. If the company has met the milestones, and is successfully moving toward a favorable outcome, the venture capital firm continues investment. If, on the other hand, the venture capitalist receives "bad news" about the opportunity, i.e. the company fails to show significant progress, the VC is to terminate investment in the company and explore other opportunities. Theoretical models of VC investment assume that firms revise their estimated probabilities of success through a Bayesian updating process as new information

becomes available, and choose to continue or abandon investments based on updated beliefs (Bergemann & Hege, 1998; e.g. Gompers, 1995).

3. Implementation Issues in Real Options

Recent work on real options has drawn attention to potential implementation problems, especially in abandonment of options. The reasons for difficulty in abandoning options can be traced to two observations. First, in contrast to financial options, real options do not have a predetermined exercise price and exercise date. This not only makes it difficult to precisely value the options, it also leaves firms with the imperative to identify and abandon projects that no longer have positive value. Especially when the incoming news about the project is negative, several studies have raised the possibility of irrational escalation of commitment (Staw, 1976), which makes it difficult to abandon investments (Coff & Laverty, 2001; Guler, 2003).

Second, the endogenous component of uncertainty, which allows firms to influence the final outcomes through their actions, may interfere with the discipline required to abandon options that are no longer valuable. Investors may prefer to modify project goals or standards instead of abandoning projects, in an effort to create a more favorable outcome (Adner & Levinthal, 2004). The effectiveness of firms in exercising real options may also be influenced by "rational overcommitment" (Adner, 2007), the tendency of individual managers to continue projects with the hope of improving the outcomes, especially when their personal interests are at stake.

Such implementation challenges may be more pronounced in the case of unsuccessful options than successful ones (Adner & Levinthal, 2004). It can be more straightforward to manage options that progress well, since signals of success are likely to be clearer than signals of

failure. If the external feedback about the project is positive, the decision to invest further is less ambiguous. However, if the feedback about the project contains "bad news", firms have to rely on more subjective judgments or criteria to decide whether the problems are just temporary setbacks, require a new course of action, or are severe enough to warrant termination.

My interviews with venture capitalists confirmed that they experienced difficulty in terminating investment in unsuccessful companies, since they lack an explicit way of measuring companies' accomplishments from one round to the next. While milestones provide useful benchmarks to measure performance, they are often insufficient in evaluating unsuccessful companies. When a company is doing well, it reaches the milestones as planned, and the follow-on investment decision is fairly easy. However, companies rarely meet all of the milestones before they require additional cash. As such, milestones only provide incomplete, ambiguous, and often conflicting information about the company's progress. Therefore VC firms' decision to invest further is based on subjective assessments. In such cases, VC firms often prefer to err on the side of investing more rather than less. In interviews, venture capitalists claimed that they stopped investment only if the company "woefully failed" to achieve the milestones:

> …Once you have invested first 3 million you're pretty much hooked in order to make the deal work. If the deal suddenly doesn't work 12 months from now, those milestones have not been achieved, what do you do? Do you leave them and say, 'Forget it, you didn't meet my requirements so I won't give you money?' Most people say 'No, let's try to fight and save the initial investment'.
>
> I don't think milestones are necessarily the ultimate achievement, but how well the company is [progressing] to achieve the milestones. It's not common that companies achieve what they set out to achieve. Entrepreneurs are overoptimistic and we factor that in. Rarely do they achieve or over-achieve what they set out to achieve. So it really comes down to more of a subjective analysis of how well the company has [progressed] toward the achievement of objectives, and reduced or eliminated the risks that we tried to identify as issues for the investment.
>
> Let's stage that investment by milestones. But what's the point? You put a million dollar if they put out the product, another million when they sign their first customer, sign so many customers. So my question is,

> what happens if they don't meet the milestone, do you walk away from it? If you do, what's the point of investing at the first place? [ii]

As a result, management of options that progress well and those that do not progress as expected may present different, asymmetric challenges. Achievement of milestones is helpful in identifying and continuing options that are still valuable. In contrast, termination of options that are no longer performing well cannot solely rely on milestones, and requires VC firms to use more subjective judgment, and managerial discipline.

In the following section, I explore the patterns of sequential VC investments over time. I split my sample into subsamples of successful and unsuccessful companies, and examine whether asymmetries in the management of the two subsamples indeed occur in a large-sample examination.

4. Empirical Analysis of Venture Capital Investments Over Time

Data

The empirical study examines VC investments in U.S. health care and life sciences companies founded between 1989 and 1993. I tracked the funding histories and exit events of these companies through 2004. The funding data were compiled from the VentureXpert database provided by Thomson Financial's Venture Economics[iii]. These data have been used extensively in earlier research (Barry, Muscarella, Peavy, & Vetsuypens, 1990; Gompers & Lerner, 2000; Megginson & Weiss, 1991; Sahlman, 1990; Shane & Stuart, 2002; Sorenson & Stuart, 2001).

[ii] The quotes are from my interviews with a sample of venture capitalists. The identities of interviewees are not disclosed, due to confidentiality agreements. More information about the interviews can be found at (Guler, 2003).

[iii] The data in the VentureXpert database includes "standard U.S. venture investing", where the company is domiciled in the U.S., at least one of the investors is a VC firm, VC investment is a primary investment, and it entails an equity transaction. I only included investments by VC funds, as explicitly identified by the database.

I used several sources to collect data on exit events. Data on the dates and valuation of initial public offerings were drawn from Ritter (2006), the Center for Research in Security Prices (CRSP), and Securities Data Corporation (SDC). I collected data on dates and valuations of acquisitions from the Mergers & Acquisitions Database of Securities Data Corporation (SDC). I limited the data to companies founded on or before 1993. Since a company typically takes 5-7 years to experience a liquidity event after the first VC investment (Fenn et al., 1997), limiting the data at 1993 provides an appropriate window to observe success or failure until 2004[iv].

In this study I focused on VC investments in companies operating in health care and life sciences. Focusing on companies operating in similar or related industries enables a more precise comparison of VC investment practices in these industries. I chose to focus on health care and life sciences sectors, since these investments have the typical characteristics of investments under high uncertainty and skewed returns distributions (Scherer et al., 2000). I used the classification provided by VentureXpert in determining companies in these industries,. Companies in this category correspond to SIC codes 283 (Drugs), 382, 384, 385 (Surgical, Medical, and Dental Instruments; Laboratory Apparatus, Analytical and Optical; Ophthalmic Goods); 504 (Professional and Commercial Equipment); 632 (Accident and Health Insurance); 737 (Computer Programming and Data Processing); 801, 805, 806, 807, 808, 809 (Health Services), 836 (Residential Care), and 873 (Research, Development and Testing Services)[v].

The final dataset includes investments by 175 VC firms in 148 companies. I organized the data into 393 VC firm-company pairs so that each VC-company pair appears only once. Each

[iv] Even though some companies may exit in shorter time, allowing 11-15 years to observe exit events reduces the likelihood of right censoring before the exit event takes place.

[v] The VentureXpert classification does not map onto the SIC codes perfectly. So some SIC categories (e.g. Computer Programming and Data Processing) do not appear in their entirety, but only in relation to health care and life sciences.

VC firm may appear more than once in the data if it has invested in multiple companies. Similarly, each company may appear more than once if it has more than one VC investor.

Analysis and Measures

In order to examine whether sequential investment practices differed for successful and unsuccessful investments, I split the sample in two subsamples, based on the final outcome. I assumed that companies that ultimately achieved a successful exit event would receive more positive indicators on average during the funding process, and companies that ultimately failed would receive more "bad news" on average. Since VC firms achieve the highest returns through IPOs or acquisitions (Gompers & Lerner, 2000), I identified companies as successful if they experienced one of these two events as of 2004. I labeled the remaining companies as unsuccessful.

I then analyzed the number of rounds that each VC invested in these companies. As suggested earlier, VC firms acquire information about the prospects of each company throughout the investment process. Each round of investment comprises an opportunity to continue or terminate investment. If a company was eventually successful, venture capitalists that participated in more rounds took the right course of action by maintaining their options, and exhibited more foresight in retrospect. In the case of companies that were not successful, the more effective strategy was to terminate investment as soon as possible. Firms that invested fewer rounds in unsuccessful companies interpreted and acted on negative information more swiftly than others.

Therefore, the dependent variable is *the number of rounds that a particular VC invested in a company*. The original data from VentureXpert overstates the number of rounds, since each distinctive date of cash infusion is counted as a new financing round even if the two dates are

only days apart. A similar problem was also noted by Gompers and Lerner (2000), who found that the amount of overstatement is as high as 28% for biotechnology firms. In order to reduce this problem, I corrected the data such that two or more consecutive rounds listed within a 90-day period were treated as a single round[vi]. This correction decreased the mean number of rounds per company from 3.76 to 2.21[vii].

I predicted the impact of two types of independent variables on the number of rounds invested. The first set involves indicators of the progress of the company in the funding process. I utilize the *number of patents* that the company acquired during VC funding as a proxy for the progress of the company. Patents are indicators of the intellectual capital developed by the venture (Shane & Stuart, 2002), and the number of patents is an indicator utilized by venture capital firms in funding (Baum & Silverman, 2004; Lerner, 1994). Prior research suggest that a portfolio company's patents are significant predictors of the likelihood of success (Stuart et al, 2001} as well as the likelihood of failure (Shane & Stuart, 2002). The number of patents is collected from the USPTO's Patent database. I calculated this measure as the count of patents that the company acquired after it received the first round of VC funding, and before the final round of investment by the focal VC.

The second set of independent variables includes the characteristics of the VC firm. VC firms may exhibit differential levels of proficiency in evaluating companies, and in deciding to continue or terminate each. As a result, the number of rounds invested in each company may vary as a function of VC firm characteristics. I proxied for the proficiency of the venture capital

[vi] The reason for choosing 90 days as a cutoff point is that most term sheets signed between entrepreneurs and investors at each round of financing specify a maximum 90-day closing date window, during which investors can schedule their cash infusions to the portfolio company. Typically, if there are more than 90 days between two capital infusions, the second infusion is considered a "new" round, and is subject to new terms.

[vii] This correction does not change the results of the analyses.

firm with three measures. The first is the *prior experience of the VC firm in health and life sciences investments*, calculated as the count of companies that the VC funded in these industries in the past 5 years. Venture capital firms with more experience in the industry will have an advantage in setting realistic milestones, and assessing progress towards those. They will also have a better understanding of market signals and technological challenges, and better assess the company's progress (Sorenson & Stuart, 2001).

The second measure is the *geographic proximity* of the VC firm to the company. Geographic proximity not only facilitates the monitoring role of the venture capitalists through frequent interaction and office visits, but also aids with their advisory role, where venture capital firms provide expertise and resources (Gorman & Sahlman, 1989; Gupta & Sapienza, 1992; Lerner, 1995; Norton & Tenenbaum, 1993; Sorenson & Stuart, 2001). I measured geographic proximity with a dummy variable which takes on the value of 1 if the VC firm operates in the same state as the company. The last measure is the VC firm's *prior IPO experience*, measured as the number of its portfolio companies that went public within the past 5 years, as a proportion of the total number the companies that it funded in the same period. The VC firm's prior success record is a proxy for its prior performance, and its capabilities in investment management.

I included a number of control variables in the models. First, I controlled for the *first round in which the VC invested in the company,* since VC firms that started investment at early rounds may invest more rounds than their counterparts that joined the investment in later rounds. To illustrate, if the VC has invested in the company for the first time in the third round of financing, this variable will take the value of 3. Second, I controlled for the *total amount VC invested in company,* which may affect the total number of rounds invested. Third, I controlled for the *year at which the VC invested in the company,* by including dummy variables for 1989-

2003. 2004 is the omitted variable. Note that industry variance is controlled for by limiting the sample to health and life sciences companies, and variance in the underlying quality of the companies is controlled for by creating subsamples according to realized outcomes.

Since the dependent variable (number of rounds) is a non-negative integer count, estimation with OLS is likely to produce biased estimates. I therefore estimate the number of rounds invested in each company using Poisson models. I also repeated the analyses with negative binomial models, and the results did not change. Multiple observations for the same company may create correlations between the error structure and the independent variables. Therefore, I estimated all models with the Huber-White-sandwich estimator of variance yielding robust standard errors, clustered on companies.

5. Results

Table 1 shows the summary statistics and correlations for the variables in the study. The mean number of rounds that a VC invested in a company is 2.21; however, the number of rounds can go up to 11. Correlations between variables are low, reducing concerns for multicollinearity. Table 2 presents a comparison of summary statistics, by the final outcomes of investments. The number of rounds for successful and unsuccessful companies was similar. Successful companies seem to acquire an average of 0.71 patents during funding, while unsuccessful firms acquire an average of 1.23 patents. The t-tests reveal that the difference between the two subsamples is not statistically significant, suggesting that companies may not differ significantly in their technological sophistication, and the number of patents may not be a significant predictor of company's ultimate success in the overall sample (Shane and Stuart, 2002).

Table 3 presents the results of the Poisson models predicting number of rounds in the overall sample, and including success as an explanatory variable. Model 1 shows results with all

four independent variables (number of patents, VC's experience in health care, geographic proximity, and VC's IPO experience). Models 2-5 add interactions of success with each of the independent variables, respectively. Overall, the results suggest weak explanatory power of independent variables in predicting success. The number of patents is positive, but only marginally significant. VC firms with more IPO experience appear to invest fewer rounds in each company. Two out of four interaction effects are significant. Accordingly, successful companies with more patents receive a larger number of rounds, as do successful companies which are in close geographic proximity to the VCs. Among controls, investment amount is positive and significant.

Table 4 splits the sample into two subsamples of successful and unsuccessful companies, in order to examine whether funding criteria differ across the two subsamples. Models 1a & 1b present the baseline model with control variables only. Models 2a & 2b add the number of patents. Models 3a &3b are the full models, with VC-firm characteristics (experience in health care, geographic proximity, and IPO experience).

Model 3a shows that the number of rounds invested in a company increases with the number of its patents in the sample of successful companies (Baum & Silverman, 2004). This model shows that VC-firm characteristics are not significant in explaining the number of rounds invested in successful companies. Level of prior experience, geographic proximity to the company, or IPO experience do not significantly influence the investment policies in the case of successful investments. Among control variables, the amount of investment is positive and significant.

Model 3b shows different patterns from the analysis of the successful subsample. First, number of patents is not a significant predictor of rounds invested in the case of unsuccessful

companies. In contrast, all three firm-level characteristics are significant. VC firms with more prior experience in health care seem to invest more rounds in unsuccessful companies. VC firms which are located in closer geographic proximity, and those that have more IPO experience, invest systematically fewer rounds in unsuccessful companies. The amount of financing is positive and significant, as in the successful sample.

I conducted Chow tests to examine whether the coefficient estimates for the explanatory variables are significantly different across the two subsamples. The tests suggest that the difference of each coefficient is significant. The chi-squares for each variable are as follows: 8.67 for patents ($p<0.05$), 13.59 for VC's experience in health care ($p<0.001$), 22.30 for geographic proximity ($p<0.000$), and -2.64 for VC's prior IPO experience ($p<0.01$).

The results are robust to a number of sensitivity analyses. First, I excluded companies with more than 11 patents, in order to examine whether these observations act as outliers. Second, I controlled for the number of patents that the company acquired before the start of the funding process, since VCs may use this information to screen potential investment opportunities. Third, I controlled for the total amount of financing that the company received from all VC firms. Fourth, I used negative binomial models instead of Poisson. The results were robust in each case. Finally, I ran logit models predicting likelihood of success, using number of rounds and independent variables as predictors. These analyses suggest that none of these variables are significant predictors of success in the sample, consistent with the descriptive statistics presented in Table 2. This result is interesting, because it suggests that the differences in the financing process of successful and unsuccessful companies are likely due to management of these companies, rather than objective differences that influence the likelihood of success.

6. Discussion

The results suggest an interesting asymmetry in the management of options that perform well over time, and those that do not. Interim indicators of progress, such as patents, seem to be significant predictors of VC investment practices in the case of successful companies. However, they are not significant in predicting investment practices for unsuccessful companies. In contrast, while VC characteristics such as industry experience, geographic proximity, and IPO experience do not significantly affect investment practices in the case of successful companies, all three are significant predictors of practices in unsuccessful ones.

These findings provide some support for the idea that milestones and interim indicators of progress only add significantly valuable information when the company is performing well. In such cases, signals of success are easy enough to interpret. However, when the company is not doing well, indicators, such as patents, do not provide clear guidance for investment practices, especially for termination. As suggested by the VC interviews, firms can continue funding despite some negative feedback, or in some cases, change goals of the project, or even its standards for success. Therefore, termination is not a straightforward decision:

> The problem is that you can never define the milestones at time 0. This is more of a problem in early stage investment. By the time of the next cash infusion, business may change so that milestones are not so relevant anymore. All the trouble that the firm took upfront is a waste of time in that case. For example, if the company is to release a new product, the milestone may be a successful launch. But maybe the product changes, or strategy changes, or other things that were not important before become more important. The original milestones don't apply. None of us are smart enough to see what these critical points may be.

Since termination decisions appear to be more complex and subjective than continuation decisions, firm-level differences may be significant predictors of firm actions in the case of unsuccessful investments rather than successful ones. Since management of successful investments is relatively more straightforward, firms do not seem to differ in the management of these investments. However, signals of failure are more ambiguous than signals of success, and

differences in how firms manage failing investments are more pronounced. Capabilities in accurately forecasting an investment's prospects are likely to vary across firms (Makadok & Walker, 2000), as well as the discipline in managing them.

The results suggest that firms are in close geographic proximity to their portfolio companies are likely to invest fewer rounds in unsuccessful companies. This result is consistent with prior research, which suggests that the monitoring and evaluation functions of the VC firms are facilitated when it is located in short physical distance to its companies (Sorenson & Stuart, 2001). Similarly, VC firms that have more prior experience with successful companies invest fewer rounds in unsuccessful companies. It seems that prior IPO experience helps improve the firm's capabilities in differentiating between successful and unsuccessful companies.

A surprising finding of the study is that VC firms with more prior experience in the industry invest more rounds in unsuccessful companies, and do not invest significantly more rounds in successful ones. Given that prior experience should also lead to improvements in firm capabilities in evaluating and managing investments (e.g. Zollo & Winter, 2002), this result presents a puzzle. It is possible that firms with more prior experience are more exposed to the problem of endogeneity, in which the firm changes project targets and standards in order to "save" the option rather than terminating it (Adner & Levinthal, 2004). Prior experience may lead firms to exhibit higher overconfidence, and to a misplaced belief that they can turn companies around, even when external signals suggest otherwise. However, the question remains: Under what conditions do firm characteristics (such as prior experience) become a burden by leading firms to overinvest in existing options, instead of adding value? Further research is needed to answer this question.

The study contributes to the real options literature by demonstrating how managerial challenges may present themselves differently in the case of successful and unsuccessful options. Normative literature on real options has focused mainly on the adoption of the real option logic in organizations, and methods of valuation to be used (e.g. Dixit and Pindyck, 1994). Recent work has pointed out the possibility of managerial challenges in the implementation of the real options logic over time, especially when the investment is not performing well (Adner & Levinthal, 2004; Coff & Laverty, 2001). This study provides empirical support for this argument in the venture capital industry. It demonstrates asymmetries in the management of options which perform as expected, and those that do not. While management of successful options requires careful attention to objective signals of success, management of unsuccessful options requires subjective judgment about whether to continue or terminate investments. In consequence, firm-level differences are more pronounced in the management of unsuccessful options, and may potentially affect firm performance.

The study presented in this paper suffers from several limitations. First, it examines investment decisions according to the observed outcome of the investment, after the fact. The assumption is that the interim signals of the company's progress will on average accurately represent the outcome of the investment. However, these signals may not be uniformly distributed over the duration of the investment. A more detailed analysis of the company's progress toward milestones over time can provide a more complete picture of the VC investment process. Moreover, I do not possess more detailed information about the company characteristics, such as founders' human and social capital (Shane and Stuart, 2002). While it would be ideal to control for all characteristics of the companies, I attempted to reduce concerns of unobserved heterogeneity by using robust standard errors.

Second, the study focuses on the investment policies with respect to observed outcomes. As such, it does not take into account the potential costs of terminating investments too early. These two costs can be thought as Type I/Type II errors in research. While overinvesting in a project with declining prospects clearly has costs (Type I error), terminating projects which might otherwise be profitable also imposes opportunity costs (Type II error). In reality, the decision to continue a project might be characterized as a tradeoff between these two potential costs (Coff & Laverty, 2007; Powell, Puranam, & Singh, 2002). Unfortunately the data does not allow a study of what might have happened to the terminated companies had the investment been continued. However, the interviews suggests that VC firms prefer to err on the side of investing more, since the downside is limited to the investment but the upside is much higher.

Despite these limitations, the study takes a preliminary step in understanding asymmetries in the management of successful and unsuccessful investments. The findings of this study may have implications for other investment situations that are broadly characterized by high uncertainty, and skewed distribution of returns (Scherer et al., 2000), such as pharmaceutical drug development, or new product development. While each of these investment situations have unique characteristics, they are similar in that few investments generate blockbuster returns while a vast majority result in a loss or modest returns. Received wisdom about these industries emphasizes the initial search for blockbuster investments in order to increase overall portfolio performance. However, this study suggests that management of unsuccessful investments could also be a critical component of performance. First, unsuccessful investments comprise a large proportion of all investments made. Second, the ability to find blockbuster investments also increases with firms' effectiveness in abandoning unsuccessful investments and shifting resources to better opportunities. Third, since uncertainty at the time of

initial investments is very high, the ability to spot winners may be limited. As a result, capabilities in managing ongoing investments may be as important a component of performance as initial selection of investments.

Since investment decision making is among the primary activities of venture capitalists, problems of implementation are less likely to be a function of poor managerial effort or lack of attention to decision making. VC firms have high incentives to ensure quality of investment decisions, and employ multiple safeguards to do so (Fenn et al., 1997; Gompers & Lerner, 2000). Moreover, venture capitalists are removed from the operations of their portfolio companies, and are likely to have more objective assessments compared to managers in other organizations (Coff & Laverty, 2007). Consequently, the results here might represent the upper bound on the quality of decisions in a typical organizational situation, and the observed patterns in the management of the real options logic may be generalizable to other organizations.

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TABLES

Table 1. Summary statistics and correlations (N=393)

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7
1	Number of Rounds	2.21	1.59	1	11	1.00						
2	Number of patents	0.90	2.28	0	16	0.09	1.00					
3	VC's experience in health care	17.69	19.20	0	92	0.08	0.01	1.00				
4	Geographic proximity	0.50	0.50	0	1	0.03	0.03	0.01	1.00			
5	VC's IPO experience	0.04	0.06	0	0.33	-0.10	-0.02	0.06	-0.11	1.00		
6	Round VC first invested in company	2.22	1.79	1	10	-0.17	0.22	0.02	0.01	0.01	1.00	
7	VC's investment amount in company (million USD)	2.47	2.87	0.002	28	0.25	0.16	0.05	0.08	-0.10	-0.03	1.00

Table 2. Comparison of summary statistics for subsamples of successful and unsuccessful companies

		Successful companies (N=251)		Unsuccessful companies (N=142)		T-tests of equality
	Variable	Mean	Std. Dev.	Mean	Std. Dev.	
1	Rounds	2.207	1.519	2.209	1.702	0.015
2	Number of patents	0.713	1.643	1.237	3.078	1.890
3	VC's experience in health case	18.808	19.897	15.727	17.796	-1.582
4	Geographic proximity	0.474	0.500	0.538	0.500	1.227
5	VC's IPO experience	0.043	0.062	0.026	0.048	-2.951*
6	Round VC first invested in company	2.059	1.572	2.510	2.085	2.246*
7	VC's investment amount in company (million USD)	2.412	2.673	2.565	3.197	0.506

* p significant at 5% level.

Table 3. Results of Poisson models predicting number of rounds invested

	(1)	(2)	(3)	(4)	(5)
Number of patents	0.032+	0.005	0.033+	0.029	0.033+
	(0.020)	(0.015)	(0.019)	(0.019)	(0.019)
VC's experience in health care	0.002	0.002	0.005*	0.002	0.002
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Geographic proximity	-0.002	-0.011	-0.008	-0.223*	-0.003
	(0.061)	(0.062)	(0.061)	(0.096)	(0.061)
VC's IPO experience	-1.426**	-1.340*	-1.424**	-1.530**	-2.066*
	(0.522)	(0.521)	(0.523)	(0.544)	(0.953)
Round VC first invested in company	-0.037	-0.030	-0.038	-0.034	-0.037
	(0.033)	(0.033)	(0.034)	(0.034)	(0.034)
VC's investment amount in company	0.054**	0.052**	0.055**	0.053**	0.054**
	(0.016)	(0.015)	(0.016)	(0.016)	(0.016)
Success	-0.121	-0.188+	-0.043	-0.291*	-0.146
	(0.102)	(0.108)	(0.115)	(0.121)	(0.113)
Success * Patents		0.066**			
		(0.025)			
Success * VC's experience			-0.004		
			(0.003)		
Success * Geographic proximity				0.345**	
				(0.119)	
Success * VC's IPO experience					0.877
					(1.145)
Investment year dummies	Sig.	Sig.	Sig.	Sig.	Sig.
Constant	-0.228	-0.069	-0.244	0.005	-0.229
	(0.179)	(0.127)	(0.177)	(0.179)	(0.179)
Observations	393	393	393	393	393
Log likelihood	-640.35	-637.69	-639.71	-637.55	-640.19

Robust standard errors in parentheses
+ significant at 10%; * significant at 5%; ** significant at 1%

Table 4. Results of Poisson models for successful and unsuccessful companies

	Successful companies			Unsuccessful companies		
	(1a)	(2a)	(3a)	(1b)	(2b)	(3b)
Number of patents		0.078**	0.075**		0.007	0.009
		(0.022)	(0.023)		(0.019)	(0.017)
VC's experience in health care			0.000			0.007**
			(0.002)			(0.002)
Geographic proximity			0.116			-0.230**
			(0.073)			(0.087)
VC's IPO experience			-1.054			-2.642**
			(0.659)			(0.965)
Round VC first invested in company	-0.019	-0.022	-0.018	-0.038	-0.041	-0.046
	(0.058)	(0.059)	(0.064)	(0.026)	(0.029)	(0.032)
VC's investment amount in company	0.049*	0.041*	0.039*	0.065**	0.065**	0.061**
	(0.022)	(0.019)	(0.019)	(0.023)	(0.023)	(0.022)
Investment year dummies	0.330	0.421	0.419	-0.045	-0.077	0.102
Constant	(0.379)	(0.382)	(0.374)	(0.102)	(0.123)	(0.133)
	N.S.	N.S.	N.S.	Sig.	Sig.	Sig.
Observations	251	251	251	142	142	142
Log likelihood	-410.06	-404.36	-402.59	-232.32	-232.27	-226.07

Robust standard errors in parentheses
+ significant at 10%; * significant at 5%; ** significant at 1%