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When are venture capital projects initiated?

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A B S T R A C T

This paper examines how public market information relates to the initiation of venture capital projects. Analysis of venture capital investments in the U.S. between 1980 and 2007 indicates that venture capitalists tend to defer new investment projects in target industries with substantial market volatility. This delay effect of market volatility is reduced if the target industry experiences high sales growth or if competition among venture capitalists is intense in the target industry. The paper provides further evidence to corroborate the view that venture capitalists rationally respond to market shifts in their investment decisions.

1. Executive summary

When an investment opportunity emerges, should the venture capitalist initiate the investment project immediately or should the venture capitalist defer the investment until uncertainty is reduced? This decision concerning the timing of initial investment has received little research attention.

This study addresses this decision from a real options perspective. We propose that the venture capitalist initially has an option to invest or defer when an investment opportunity emerges. Once the initial investment is undertaken, the venture capitalist will obtain access to future investment opportunities or growth options. Whether the venture capitalist should defer investing until more favorable market conditions arrive or initiate the investment project immediately to take better advantage of growth opportunities, depends on factors that affect the relative value of the deferral and growth options.

We suggest that the venture capitalist should defer initiating an investment project when market uncertainty is high, all else being equal. On the other hand, it is not always beneficial to defer investment in an uncertain market. The opportunity costs of deferral are likely high under two conditions. First, the possibility for downside scenarios to occur is lower in high-growth industries, and thus downside loss protection – an important benefit of the deferral option – becomes less valuable for the venture capitalist. Even if the venture capitalist dominates the venture industry, waiting when the industry experiences great growth potential means a potential loss of profit streams. Second, in a competitive industry, the focal venture capitalist's growth opportunities may be eroded or lost when other active venture capitalists invest in ventures with similar growth opportunities.

Our analysis of 18,678 initial investments during 1980–2007 indicates that market uncertainty has a strong delay effect in venture capital investment. Nonetheless, industry sales growth accelerates the time to initial funding of new projects.

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Furthermore, the delay effect of market volatility is significantly reduced by sales growth in target industries and competition among venture capitalists.

Our study indicates that, in determining the timing of investment, venture capitalists should consider factors that affect the value of real options embedded in investment projects. Further, our study suggests that absent sufficient information about ventures and venture capital industries, public market information can be useful in assessing venture prospects.

2. Introduction

Venture capital has been credited with fueling corporate innovation, job creation, and economic growth (Dushnitsky and Lenox, 2005; Global Insight, 2007; Kortum and Lerner, 2000). A critical issue in venture capital investment concerns when to initiate a project in the presence of new investment opportunities. Because of the high uncertainty that typically surrounds venture capital projects (Bygrave et al., 1989; Cochrane, 2005; Ruhnka and Young, 1991), when an investment opportunity emerges, the venture capitalist can defer investing in a portfolio company until more information arrives or the venture capitalist can initiate the project immediately to gain access to subsequent growth opportunities. The current study explains and predicts when the venture capital project is initiated.

The extant research literature has examined venture capital investment decisions primarily from an agency perspective. According to this perspective, the *raison d'etre* of venture capitalists is their capability to reduce the costs of informational asymmetries. Furthermore, venture capital investments should be concentrated in industries where informational concerns are important and where venture capitalists have a comparative advantage over other investors in selecting and monitoring investments (Amit et al., 1998; Gompers, 1995). Existing research studies have also suggested that agency problems have important implications for financial contract design. In particular, convertible securities and stage financing can be used to reduce the entrepreneur's incentive to engage in window dressing and bias towards the short-term performance of the project (Cornelli and Yosha, 2003; Wang and Zhou, 2004).

While these research studies have offered insights concerning how agency problems between the investor and the entrepreneur shape venture capital contracts, existing studies have largely overlooked the role of market uncertainty in venture capitalists' investment decisions. As one exception, Kaplan and Stromberg (2004) differentiate between "internal risk" (such as information and agency concerns) and "external risk" (such as market uncertainty), yet their focus is on how external risk influences venture capital contract design rather than on the timing of new venture capital projects.[2]

The current study extends existing research by examining how market uncertainty influences the timing of new venture capital projects. Venture capitalists can partly resolve information and agency concerns by taking actions to learn about the efforts of entrepreneurs and the quality of ventures. By contrast, because market uncertainty is attributed to unexpected market developments, it is generally beyond the control of individual venture capitalists, and typically resolves with the passage of time.

This study takes a real options perspective to examine how venture capitalists respond to market uncertainty in deciding when to initiate new projects. Classical real options theory has been found a useful theoretical lens to analyze investment under uncertainty (Dixit and Pindyck, 1994; McDonald and Siegel, 1986). This theory has been employed to examine investment level (Guiso and Parigi, 1999), market entry (Campa, 1993; Folta and O'Brien, 2004), R&D investment (McGrath, 1997; McGrath and Nerkar, 2004), and joint ventures (Chi, 2000; Kogut, 1991; Tong et al., 2008), but the application of real options theory to venture capital investment decisions has been limited (Li, 2008; Li et al., 2007).

The current study posits conceptually that the venture capitalist initially has an option to invest or defer when an investment opportunity emerges. Once the initial investment is undertaken, the venture capitalist will obtain future investment opportunities or growth options. Whether the venture capitalist initiates the investment in a portfolio company immediately to take better advantage of growth opportunities, or defers investing until the market becomes less uncertain, depends on the relative value of the deferral and growth options. Market information provides important environmental signals during the investment process. Market uncertainty will increase the value of the deferral option and have a negative effect on the timing of a new investment project: By deferring the investment, the venture capitalist can take advantage of incoming market information and choose to invest only when market conditions turn favorable.

The current study further suggests that it is not always beneficial to defer the initial investment in an uncertain market, especially when the opportunity costs of doing so are high. We investigate industry conditions that may enhance the value of the growth option or decrease the value of deferral option. We follow real options theory and identify two industry factors: growth potential and competition (Dixit and Pindyck, 2000; Smit and Trigeorgis, 2004). First, industry growth potential will increase the value of the growth option relative to the deferral option and will lessen the delay effect of market uncertainty. Second, competition can drive down the value of growth options and the venture capitalist will have a greater incentive to initiate its investment project in a competitive market to capitalize on future growth opportunities.

In the empirical analysis, the current study focuses on how venture capitalists respond to one particular type of market uncertainty – market volatility in target industries – in determining the timing of new investment projects. The high uncertainty of the venture capital market is well documented (Bygrave et al., 1989; Cochrane, 2005).[3] Much of this uncertainty appears to be tied

[2] Kaplan and Stromberg's (2004) analysis of investments in 67 portfolio companies by 11 venture capitalists between 1987 and 1999 shows that higher internal risk is associated with more VC control, more contingent compensation for the entrepreneur, and more contingent financing in a given round, and that external risk is associated with more VC control, more contingent compensation, increases in the strength of VC liquidation rights, and tighter staging.

[3] This volatility manifests itself in a number of ways: the fund commitments to venture capitalists, the investments that firms make in portfolio companies, and the financial performance of portfolio companies and venture capitalists (Gompers and Lerner, 2002).

to valuations in public equity markets. Recent research shows that returns of venture capital funds are correlated with market returns (Cochrane, 2005; Kaplan and Schoar, 2005). Gompers et al. (2008) analyze over 30,000 venture capital investment decisions between 1975 and 1998, and find that venture capitalists are highly responsive to market signals of investment opportunities. Gompers et al. (2008) suggest that an important component of volatility in venture capital investment activity is driven by the volatility of market fundamentals as reflected by changing market signals. The current study represents one of the first real options analyses to examine the influence of market volatility on the timing of initial venture capital investments.

Our analysis of 18,678 initial investments during 1980–2007 provides supportive evidence for the delay effect of market uncertainty and the attenuating effects of sales growth and competition on the relationship between market uncertainty and the timing of initial funding. It is evident from our study and others (e.g., Cochrane, 2005; Gompers et al., 2008) that absent sufficient information about private entrepreneurial companies, public market information is highly relevant to venture capitalists' investment decisions.

The remainder of the paper is organized as follows. The following section provides theory and hypotheses. The paper then presents the empirical methods and reports the results. The final part of the current paper discusses implications of this study for theory and practice and suggests avenues for future research.

3. Theory and hypotheses

Venture capitalists typically raise funds from outside investors such as pension funds and wealthy individuals, invest in a portfolio of entrepreneurial companies, and obtain returns from successful exits through venture IPO or sale. High uncertainty is the hallmark of venture capital investments (Bygrave et al., 1989; Cochrane, 2005; Dean and Giglierano, 1990), and a venture capitalist must consider a proper investment strategy to deal with uncertainty. Specifically, when an investment opportunity emerges, should the venture capitalist initiate the investment in a portfolio company immediately or should the venture capitalist defer the investment until uncertainty is reduced? This decision concerning the timing of the initial investment has received little research attention. From an agency perspective, Gompers (1995) proposes and observes that the intensity of monitoring, as reflected by the duration of staging, depends on the severity of information asymmetry and agency problems: Venture capitalists need to monitor entrepreneurs more closely and invest more frequently in those portfolio companies with higher agency costs.

The current study proposes a real options framework about when to initiate a venture capital project in an industry. Specifically, the initial investment opportunity can be viewed as an option to invest or defer. Distinct from a non-deferrable project or a project with delayed commitment, a venture capital project usually represents a discretionary investment opportunity. This investment opportunity is an option because the venture capitalist has the right but not the obligation to invest in the portfolio company. Upon the initial investment, the venture capitalist will gain access to growth options, i.e., subsequent opportunities to invest until a successful exit (though venture IPO or sale). The timing of a new venture capital project depends on the factors that affect the relative value of the deferral and growth options.

The deferral option is economically valuable whenever an investment decision entails significant uncertainty and cannot be costlessly reversed (Dixit and Pindyck, 1994; Kogut and Kulatilaka, 1994; McDonald and Siegel, 1986). Venture capital investments are at least partially irreversible since they cannot be fully recovered and costlessly redeployed in the event of a negative shock. Portfolio companies may only have business concepts, product prototypes, or initial marketing and manufacturing, but have not accumulated substantial tangible assets and financial wealth. In addition, unlike public firms or firms with established track records, portfolio companies do not have a liquid secondary market to trade their equity shares (Wright and Robbie, 1998). The lack of a secondary market creates substantial problems for venture capitalists that wish to sell their equity shares to third parties in case of adverse market and firm developments. For these reasons, downside loss protection is a major concern for venture capitalists, as reflected in this statement: '[The] company has little in the way of underlying asset value and thus offers limited downside protection' (Kaplan and Stromberg, 2004: 2187). Although the venture capitalist can use staging and other contractual features to contain the downside losses of sunk cost investments, staging itself does not alter the irreversible nature of venture capital investments.

Since market uncertainty changes whether or not investment is taking place and the venture capital investment is at least partially irreversible, there is a value of waiting for new information before the venture capitalist starts to invest in a particular portfolio company. As uncertainty resolves over time, the venture capitalist has the opportunity to invest if market conditions turn favorable, but to back off if market conditions remain unfavorable. If the venture capitalist exercises the option and undertakes the investment the moment the opportunity emerges, the venture capitalist forgoes the possibility of deferring the investment until more information is revealed. For these reasons, market uncertainty will increase the value of holding the deferral option and motivate the venture capitalist to delay its investment in a new project. We thus expect that the venture capitalist will be reluctant to initiate a new project when there is substantial market uncertainty in target industries.

Hypothesis 1. The higher the level of market uncertainty, the less likely a venture capital project will be initiated.

In addition to uncertainty, two industry conditions can affect the relative value of the deferral and growth options. First, because the possibility for downside scenarios to occur is lower in industries with higher growth potential, downside loss protection – an important benefit of the deferral option – becomes less valuable for the venture capitalist. While deferring the investment under market uncertainty may still be sensible in high-growth scenarios, such a wait-and-see strategy may incur substantial opportunity costs. Even if the venture capitalist dominates the venture industry, waiting when the industry experiences great growth potential means a potential loss of profit streams. In low-growth scenarios, the potential downside loss of an investment project associated with environmental shocks becomes more of a concern, and the opportunity costs of the wait-and-see strategy are lower. This line of reasoning suggests that industry growth potential will decrease the value of holding the deferral option, and increase a venture capitalist's incentive to take an initial equity stake in a particular portfolio company to gain access to growth opportunities. Hence, this logic leads to the following hypothesis:

Hypothesis 2. The negative effect of market uncertainty on the initiation of a venture capital project will be weaker in industries with higher growth potential.

Second, competition among venture capitalists in the target industry can adversely affect the value of growth options. Using a wait-and-see strategy by holding the deferral option to deal with market uncertainty may become less valuable to the venture capitalist when other venture capitalists are actively investing in the industry. Delaying investment in such an industry may incur substantial opportunity costs. First of all, there is a possibility that other active venture capitalists may invest in the venture first and preempt the focal venture capitalist. Secondly, even if other venture capitalists do not preempt the focal venture capitalist from investing in the focal venture, they can invest in *other* ventures in the industry for similar growth opportunities, e.g., for the same cutting-edge technology. Such investment can strengthen the competitive position of other ventures in the industry and effectively drive down the value of the focal firm's growth options. For both reasons, the venture capitalist adopting a wait-and-see strategy may lose underlying growth opportunities to (preemptive) competitors if other venture capitalists are actively investing in the industry (Smit and Ankum, 1993).

Therefore, in an industry characterized by intense competition among venture capitalists, the focal venture capitalist needs to give more attention to the strategic actions of competitors in making their investment decisions, which will make the venture capitalist less worried about the adverse impact of market uncertainty on its initial commitment to a project. On the other hand, in an industry with lower competition among venture capitalists, the venture capitalist will be less concerned about potential losses to competitors and instead the venture capitalist needs to be more responsive to market uncertainty in determining the timing of its new project. The above argument suggests that the delay effect of uncertainty on initial investments will be less salient in industries with a high level of competition among venture capitalists. We thus hypothesize that:

Hypothesis 3. The negative effect of market uncertainty on the initiation of a venture capital project will be weaker in industries with higher competition among venture capitalists.

4. Methods

4.1. Data and sample

Our study examines the timing of new venture capital projects. We collect data from Venture Economics' VentureXpert. VentureXpert is a fairly comprehensive database that contains most VC investments and missing investments tend to be less significant ones (Gompers and Lerner, 2002; Kaplan et al., 2002). This database has been used extensively in existing research (Barry et al., 1990; Cumming et al., 2009; Hochberg et al., 2007; Shane and Stuart, 2002; Sorenson and Stuart, 2001).

We construct our dataset as follows. First, we collect raw data from VentureXpert that meet the following conditions: (1) the investment represents the initiation of a venture capital project in the U.S. with founding year information available for portfolio companies; (2) the investment is made by venture capital funds, as explicitly defined so by VentureXpert; and (3) the investment is made between 1980 and 2007. This procedure results in 22,164 unique ventures.

Second, we focus on the decision of the lead investor. While a venture capital project is usually undertaken by a syndicate of investors, the lead investor is responsible for initiating the deal and for bringing other investors into the deal. The lead investor typically has larger equity stakes (Wright and Lockett, 2003). We determine the lead investor as the firm that participated in the first round and made the largest total investment in the company across all rounds of funding (see also, Nahata, 2008).[4] We lose 1818 ventures due to unidentified investors or missing information on investment amount.

Third, among the remaining 20,346 portfolio companies, 18,699 have single lead investors; 1647 have received investments from a total of 3919 *co-lead investors*. Co-lead investors are the ones that invest in the first round and invest the same largest amount in a portfolio company. In order to avoid biased estimates, we randomly sample one of the co-lead investors for each of the 1647 companies. Including all the co-lead investors does not alter the empirical results reported below.

Finally, the effective sample for estimation reduces to 18,678 observations, due to missing values for the Market volatility measures. Because we have lost observations in constructing our sample, we compare our sample observations with the original 22,164 observations. We find that the sample is very similar to the population in terms of their composition by year, industry, syndicate size for the first round, and lead investor type.

[4] This procedure differs slightly from the usual procedure that identifies the lead investor as the one with the largest total investment in the portfolio company across all rounds of financing (Barry et al., 1990; Megginson and Weiss, 1991; Sorensen, 2007). The latter procedure disregards when the venture capitalist started its association with the portfolio company. Since later funding rounds usually involve larger amounts based on higher company valuations, a venture capitalist that participated only in the last round of financing but invested the largest amount could be identified as the lead investor. This would not be a meaningful classification.

Portfolio companies are distributed across a wide range of industries. According to the Venture Economics Industry Classification (VEIC), portfolio companies can be grouped into as many as 550 industries, but as few as three broad industry classes (i.e., information technology, medical/health/life science, and non-high technology). We would like to have an industry classification that addresses the following concerns: (1) the classification should reflect new developments in the U.S. economy, including the emergence of the computer hardware, computer software and Internet service industries. A mere copy of the 1987 SIC codes does not serve us well in this regard; (2) the classification should enable us to capture developments in the public market, since our study examines how the venture capitalist responds to market information in determining the timing of new projects. Relying solely on the VEIC codes does not serve this purpose well; and (3) the classification should sort the companies into similar lines of business based on shared technological and managerial principles.

With these considerations, we re-classify the portfolio companies into 43 industries by considering the VEIC, the NAICS and the Fama and French (1993) industry classification (http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/). Existing venture capital research has used a similar industry classification (Brav and Gompers, 1997). All the industry-level variables are measured with this classification, unless otherwise indicated.

Table 1 reports the composition of sample by industries, as well as the median time to initial funding of new venture capital projects. As expected, new venture capital projects are concentrated in the information technology (e.g., computer software and Internet, electronics, communications and computer hardware) and life sciences sectors (e.g., pharmaceutical products and medical equipment). Further, these industries display significant heterogeneity in terms of the time to initial funding.

4.2. Dependent variable

Table 2 presents the definitions of dependent and independent variables. Because we are interested in when a venture capital project is initiated, our dependent variable is the time in years from when the investment opportunity emerges to when the venture capitalist makes the first investment in the portfolio company. The venture capitalist observes the investment opportunity only if the firm exists at the time the portfolio company is founded. Thus, the dependent variable is either the time since the founding of the portfolio company for an existing venture capitalist or, in fewer cases, the time since the founding of the venture capitalist for an existing portfolio company. Note that the venture capitalist's fund can be established before or after the founding of the portfolio company.

4.3. Independent variables

4.3.1. Uncertainty

Uncertainty refers to the randomness of the external environment that cannot be altered by the actions of individual firms. Real options models typically consider uncertainty about prices or profits (Caballero and Pindyck, 1996; Dixit and Pindyck, 1994). Thus, we use the volatility of market returns to measure the target industry's uncertainty. Such market-based measures are reasonable since returns of venture capital funds are correlated with market returns (Cochrane, 2005; Kaplan and Schoar, 2005).

Table 1
New venture capital projects by industry.

Industry	Frequency	Percent	Median time to initial funding	Industry	Frequency	Percent	Median time to initial funding
Computer Software and Internet	7270	38.92	1.58	Insurance	90	0.48	1.75
Communication	1893	10.13	1.33	Construction Materials	85	0.46	2.88
Pharmaceutical Products	1439	7.70	1.31	Automobiles and Trucks	82	0.44	3.06
Electronic Equipment	1362	7.29	1.52	Apparel	65	0.35	4.25
Medical Equipment	1321	7.07	1.64	Real Estate	61	0.33	1.50
Computer Hardware	1002	5.36	1.41	Measuring and Control Equipment	54	0.29	1.75
Business Services	515	2.76	2.72	Shipping Containers	53	0.28	2.50
Healthcare	435	2.33	1.50	Rubber and Plastic Products	52	0.28	2.29
Petroleum and Natural Gas	319	1.71	1.67	Fabricated Products	48	0.26	1.49
Banking	270	1.45	2.04	Agriculture	35	0.19	1.32
Retail	265	1.42	2.08	Financial Trading	27	0.14	3.64
Entertainment	244	1.31	2.92	Candy and Soda	26	0.14	2.33
Electrical Equipment	198	1.06	2.54	Textiles	25	0.13	3.58
Machinery	195	1.04	2.63	Utilities	25	0.13	3.76
Food Products	186	1.00	3.05	Beer and Liquor	17	0.09	1.83
Consumer Goods	182	0.97	1.67	Construction	17	0.09	3.78
Chemicals	175	0.94	2.08	Aircraft	14	0.07	5.29
Personal Services	153	0.82	2.39	Coal	10	0.05	1.36
Business Supplies	121	0.65	3.30	Non-Metallic and Industrial Metal Mining	5	0.03	2.08
Transportation	116	0.62	2.27	Recreation	4	0.02	1.92
Printing and Publishing	110	0.59	2.25	Shipbuilding and Railroad Equipment	4	0.02	8.84
Restaurants, Hotels, Motels	108	0.58	3.68	*Total*	*18,678*	*100.00*	*1.60*

Note: This table breaks down the 18,678 observations by the 43 industries. The time to initial funding (in years) is either the time since the founding of the portfolio company for an existing venture capitalist or the time since the founding of the venture capitalist for an existing portfolio company.

Table 2
Variable definitions.

Variables	Description
Dependent variable	
Time to initial funding	The time in years since the founding of the portfolio company for an existing venture capitalist, or the time since the founding of the venture capitalist for an existing portfolio company.
Explanatory variables	
Market volatility — standard error	The standard error of the regression of excess market returns on the three Fama–French factors. We collect the market return data from COMPUSTAT and CRSP.
Market volatility — conditional variance	The conditional variance of the regression of excess market returns on the three Fama–French factors, where the conditional variance is assumed to follow a GARCH (1,1) process. We annualize the conditional variance for the past year and take its log.
Sales growth	The median sales growth of the industry for the current year. We collect the firm-level sales data from COMPUSTAT.
HHI	The Herfindahl–Hirschman index of the investment size of venture capitalists in an industry. We collect the investment data from VentureXpert (in thousand USD).
Total initial investment venture received	The log of the total first-round investments (in thousand USD) in a portfolio company by all venture capitalists.
Staged financing	Dummy variable that takes the value 1 if, *ex post* the initial funding, the portfolio company receives at least another round of financing from the same venture capitalist.
R&D intensity	The median R&D expenditure over sales for an industry. It is lagged one year.
Tangibility	The median tangible-to-total assets ratio for an industry, where tangible is the total assets from COMPUSTAT less current assets, investments and advances, intangible assets, and other assets (Rajan and Zingales, 1995). It is lagged one year.
Industry dummies	Set of mutually exclusive dummy variables that take the value 1 if the portfolio company operates in one of the 43 industries reported in Table 1.
VC portfolio size	The log of the total number of active investments that the venture capitalist has maintained in the last five years.
VC syndicate size	The total number of venture capitalists joining the lead investor in a portfolio company's initial financing round.
VC fund age	The time in years from the founding of the venture capitalist's fund to the initial financing of the portfolio company by the fund.
Independent VC	Dummy variable that takes the value 1 if the venture capitalist is an independent venture capitalist; 0 otherwise.
Early-stage venture	Dummy variable that takes the value 1 if the portfolio company is at the *Startup/Seed* or *Early stage* according to VentureXpert's classification.
Same region	Dummy variable that takes the value 1 if the portfolio company is located in the same geographic region as the venture capitalist. We adapt the VentureXpert classification and define the following 15 geographic regions: Alaska, Great Lakes, Great Plains, Hawaii, Mid-Atlantic, Northern California, New England, New York Tri-State, Northwest, Ohio Valley, Rocky Mountains, Southern California, South, Southeast, and Southwest.
Venture state dummies	Set of dummy variables that take the value 1 if the portfolio company is located in one of the 50 U.S. states or the District of Columbia.
No. IPO issues	The total number of new IPO issues in the U.S. in the previous year. We take the log of this measure.
Year dummies	Set of dummy variables each of which takes the value 1 if the initial funding took place in 1980, 1981, …, 2007 (respectively).

We perform the following procedures to generate the uncertainty measure. We first compute the monthly value-weighted market returns for each industry using information from COMPUSTAT and CRSP. We then specify the following model to forecast monthly industry returns recursively from 1950–2007:

$$R_t - RF_t = a + b^*MKTRF_t + s^*SMB_t + h^*HML_t + e_t. \quad (1)$$

R_t is the return on the stock portfolio in an industry. RF_t is the risk-free return rate. $R_t - RF_t$ is the excess return on the stock portfolio. $MKTRF_t$ is the excess market return over the risk-free return rate where the market return is the value-weighted return on all stocks. SMB_t is the difference between small-firm return and big-firm return. HML_t is the difference between high book-to-market equity return and low book-to-market equity return. The average adjusted R-square for all the regressions based on Eq. (1) is 0.58, suggesting that the forecasting model indeed captures a significant fraction of the variation in stock returns (Fama and French, 1993).

Last, we take the standard error of the regression as the uncertainty measure (*market volatility — standard error*). The forecasting equation filters out the systematic component and the standard error of the regression represents what is volatile and unpredictable. This volatility measure is consistent with suggestions from the theoretical real options work (Dixit and Pindyck, 1994) and with previous empirical real options work (Bulan, 2005; Campa and Chang, 1995; Driver and Moreton, 1991; Ghosal and Loungani, 1996, 2000).

The advantage of this market volatility measure is that it captures the total uncertainty in a single variable. Pindyck (1991) maintains that increased volatility in the product markets is translated into increased volatility in the stock market. If markets are (semi-strong) efficient, (public) information about asset fundamentals and growth prospects are priced by the market. Hence, the volatility of stock returns should provide an adequate measure of the total uncertainty that is relevant for firm-level investment decisions.

Our focus on industry-level uncertainty is also justified in the real options framework because industry-level uncertainty is particularly important for firm-level investment decisions. The irreversibility of investment is more pronounced at the industry level when capital is industry-specific (Dixit and Pindyck, 1994). The predictions of real options theory thus have greater relevance for uncertainty that is industry-wide (Pindyck, 1991). In the empirical analysis below, we include portfolio company-level variables to control for project-specific uncertainty.

4.3.2. Growth

Industry growth should increase the value of growth options relative to deferral options, and firms targeting higher growth industries should capture more valuable growth options (Folta and O'Brien, 2004). Field research studies indicate that venture capitalists explicitly consider whether portfolio companies are in growing markets (Kaplan and Stromberg, 2004). We focus on growth in the output market, and calculate a *sales growth* measure to capture the growth rate of an industry (Sharfman and Dean, 1991). We obtain the firm-level sales data from COMPUSTAT and group them into the 43 industries. We then calculate the sales growth for each firm for the current year, and take the median sales growth for all the firms in the industry as our measure. When we use a lagged sales growth measure, we obtain similar results.

4.3.3. Competition among venture capitalists

The current study focuses on how competition among venture capitalists in an industry affects their investment behavior. While competition can be measured as the number of firms in the industry (see also Folta, 1998), we must consider the possibility that an industry has a large number of investors but is dominated by a few large ones. We thus employ a standard Herfindahl–Hirschman index (HHI) (Hirschman, 1964) and adjust for the investment size of each venture capitalist in the industry. Specifically, for a given industry in a given year, we compute the HHI as follows:

$$HHI = \sum_{j=1}^{m} \left[I_j / \sum_{j=1}^{m} I_j \right]^2 \tag{2}$$

Where $j = 1,\ldots,m$ is the number of venture capitalists in the industry, and I is the dollar amount of investment in the industry by each venture capitalist (in thousand USD). A higher value of HHI indicates higher concentration and thus lower level of competition among venture capitalists in the industry.

4.4. Control variables

The timing decision is likely influenced by other industry-level factors, venture capitalist characteristics, portfolio company characteristics, and general market conditions.

4.4.1. Total initial investment amount venture received

Since portfolio companies lack substantial operating income or liquid secondary equity markets, the initial investment will largely be sunk costs. If venture capital investments are completely reversible, the venture capitalist can always recover the invested capital completely as soon as it finds that it has made the investment at a wrong time. The initial investment amount should have no impact on the time to initial funding of new venture capital projects controlling for industry differences. On the other hand, if venture capital investments are at least partially irreversible, the initial investment amount required should have a negative impact on the time to initial funding of the new project.

4.4.2. Staged financing

A venture capital project is more likely to be initiated if the investment is to be staged. First, since staged financing provides the investing firm with an option to abandon in mid-stream (Chi and Nystrom, 1995), the venture capitalist can effectively reduce the downside risk through staging. Second, staging also provides the venture capitalist with an opportunity to learn about the effort of the entrepreneur or the quality of the portfolio company. Such learning will not take place without investing. The dummy variable, *Staged financing*, takes the value one if, *ex post* the initial funding, the portfolio company receives at least another round of financing from the same investor. The empirical results remain unaltered when we have a more conservative definition of staged financing; for example, we have also considered an investment *staged* only if the portfolio company has received another two or three rounds of financing by December 2008.

4.4.3. Target industry characteristics

Venture capital investments are subject to information asymmetry and agency problems (Amit et al., 1998). Such problems differ from market uncertainty in two aspects. First, venture capitalists usually are less informed about the project quality and entrepreneurial effort than entrepreneurs themselves (Kaplan and Stromberg, 2003). Second, uncertainty about the project quality and the entrepreneurial effort can partly be resolved through learning by investing. Thus, the venture capitalist may initiate an investment project sooner to learn about the entrepreneur and the portfolio company.

Information asymmetry and agency problems tend to be severe in industries with high R&D intensity or asset intangibility (Gompers, 1995). First, investments in industry-specific assets are subject to greater discretion by entrepreneurs and R&D intensity is associated with the specificity of assets in an industry (Bradley et al., 1984; Titman, 1984). We therefore control for industry R&D intensity by including the lagged industry median R&D expenditures over sales (Pisano, 1989). Second, the value of intangible assets is more difficult to evaluate than that of tangible assets, and intangible assets would be associated with higher agency costs. It follows from the agency perspective that projects in industries with lower *R&D intensity* or higher *Tangibility* will more likely be delayed.

In addition, venture capital investment decisions may be influenced by unobservable industry-specific factors. We include *Industry dummies* in our estimation to account for such industry fixed effects.

4.4.4. Venture capitalist characteristics

We control for three venture capitalist characteristics. First, venture capitalists usually maintain a portfolio of projects. Since it takes years to grow a portfolio company until a successful exit, the venture capitalist may have to defer or avoid making any new investment as its existing portfolio increases. We thus control for *venture capitalist portfolio size*. Second, venture capitalists typically syndicate their investments to improve project selection and learning, spread risk and increase value-creating services for portfolio companies (Brander et al., 2002; Lerner, 1994). For these reasons, *VC syndicate size* may increase a venture capitalist's incentive to invest in a portfolio company.

Third, venture capital funds are organized as limited partnerships, which raise funds from outside investors, dissolve after 7–10 years, and return the proceeds to those outside investors. To achieve their goal, venture capitalists usually invest the raised capital under management within the first 2–4 years. As such, venture capitalists do not have the privilege of deferring investment indefinitely, and older funds may not have the opportunity to initiate any new projects. We control for the age of venture capital funds (*VC fund age*). If the venture capitalist has multiple funds investing in the portfolio company simultaneously, we select the oldest fund. Random selection of a fund in case of multiple funds does not change the empirical results below. Fourth, as compared with captive investors that are bank-, corporate-, or government-owned, independent investors are more active in recruiting managers and directors, helping with fund-raising, and interacting with their portfolio companies (Bottazzi et al., 2008). We include a dummy variable, *Independent VC*, in our estimation to see whether independent investors also are more active in initiating venture capital projects.

4.4.5. Portfolio company characteristics

We include three portfolio company-level controls. First, portfolio companies are at different stages of development when they start to receive venture capital. We include a dummy, *Early-stage venture*, which equals one if the portfolio company is at the Startup/Seed or Early stage in Venture Economics' classification. Investment in an early-stage company tends to entail higher project-specific uncertainty concerning the costs and benefits of the project. Second, as existing research suggests (Sorenson and Stuart, 2001), venture capitalists tend to invest in ventures with close geographic proximity. We include a dummy variable, *Same region*, to indicate if the venture is located in the same geographic region as the VC fund financing the venture. Third, we include *Venture state dummies* to control for unobservable state fixed effects.

4.4.6. General market characteristics

We control for IPO market conditions by including the log of the number of new issues in the U.S. in the previous year (*No. IPO issues*). Finally, we include *Year dummies* in our estimation to account for unobservable time-varying effects on venture capital investment decisions.

4.5. Estimation model

We estimate the timing of new projects with accelerated-failure-time models (Hougaard, 1997). Let T denote the duration of time that passes before the venture capitalist initiates the investment in a portfolio company, then

$$lnT_j = \beta_0 + x_j\beta_x + \varepsilon_j \quad (3)$$

where the dependent variable is the natural logarithm of the duration T (Cameron and Trivedi, 2005), and x is the vector of explanatory variables. We assume that the error term ε_j follows a standard normal distribution with mean 0 and standard deviation σ. A graph comparing the kernel density estimate and the normal density shows that it is reasonable to assume a normal distribution. This assumption also has the advantage that the hazard rate of initial investment first increases and then decreases over time. Other distributions imply either a constant hazard rate (e.g., exponential) or hazards that increase (or decrease) monotonically over time (e.g., Weibull or Gompertz). In the context of venture capital investments, monotonic hazard functions are implausible. It is not reasonable to assume that the portfolio company is never more likely to be funded later on than when the venture capitalist first identifies the investment opportunity (a monotonically decreasing hazard function). Nor is it reasonable to assume that the portfolio company becomes ever more likely to be funded the longer they have remained unfunded (a monotonically increasing hazard function).

The survival function for the lognormal distribution (S) yields the probability that the spell T lasts at least to time $t: S(t_j|x_j) = 1-\Phi\left[\frac{\ln T_j-(\beta_0 + x_j\beta_x)}{\sigma}\right]$, where Φ is the standard normal distribution. From the survival function, we derive the hazard function:

$$h(t|x_j) = lim\frac{P(t\leq T < t + \Delta t|T\geq t)}{\Delta t} = \frac{-\frac{d}{dt}S(t|x_j)}{S(t|x_j)}. \tag{4}$$

This hazard function specifies the hazard that the portfolio company receives the initial funding, conditional on the fact that it has not through time t. The coefficients for the lognormal regression model can be interpreted as follows: The larger the coefficient of an explanatory variable, the longer the duration of time before the venture capitalist makes the initial investment in the portfolio company, and the lower the hazard of the venture capital project being initiated.

To avoid specifying a particular probability distribution, we can also use a semi-parametric Cox model (Cameron and Trivedi, 2005). We obtain highly consistent results with the alternative Cox specification as well as with several other parametric specifications including Weibull and (piecewise) exponential.

5. Results

Table 3 presents descriptive statistics and correlations between variables. The uncertainty, growth and competition measures are significantly correlated with one another. We take two steps to test whether our estimation suffers from multi-collinearity problems. First, all the measures, including the interaction terms between Market volatility, Sales growth and HHI, have variance inflation factors (VIF) less than 2, which is substantially below the threshold value of 10 for potential multi-collinearity (Chatterjee et al., 2000). Second, the sign and statistical significance of the Market volatility measures remain consistent in our estimation with or without Sales growth, HHI, R&D intensity and Tangibility. Therefore, we are confident that the results reported below are robust to multi-collinearity.

Table 4 reports the estimation results. Model 1 is the baseline model with only constant and controls. Modes 2–4 examine the effects of the variables of our interest. Model 5 is the full model. Models 6–11 are for robustness checks. Wald (chi square) tests indicate that all the models are statistically significant ($p<0.001$). The predicted median time to initial funding of new venture capital projects from Model 5 is 1.54 years, which is close to the sample median of 1.60 years. Also, the largest increase in the median time depending on the changes in the parameter estimates of the model has never exceeded four years. This result indicates that the venture capitalist cannot indefinitely defer investing because of the limited lifespan of its fund.

Model 1 reveals several noteworthy empirical findings about the control variables. First, the coefficient of *Total initial investment venture received* is positive and significant ($p<0.001$), suggesting that the venture capitalist tends to defer investing in a portfolio company that requires larger initial commitment. Second, the venture capitalist will accelerate its initial investment in a portfolio company that receives staged financing *ex post*. Taken together, the two results indicate that although staging reduces the downside risk and increases a venture capitalist's incentive to initiate the project, the investor is still concerned about the upfront sunk cost investment that has a delay effect for larger projects. These empirical results are consistent with our assertion that venture capital investments are at least partially irreversible despite the presence of staging and other contractual features. Third, *R&D intensity* does not have any statistically significant effect across the models; *Tangibility* has the expected positive effect on the time to initial funding of new venture capital projects, albeit only significant in Models 9–11. It appears that the informational and agency concerns as reflected by the two variables have more pronounced effects on the timing of subsequent investments (see Gompers, 1995) than on the timing of initial investments.

Fourth, among venture capitalist-level controls, an increase in the *venture capitalist portfolio size* decreases a venture capitalist's incentive to initiate a new project. This empirical result is consistent with the finding that the number of cumulative investments has a negative impact on a firm's propensity to take patents in a new technical area (McGrath and Nerkar, 2004). Also, when the lead investor is joined by an increasing number of syndicate partners, its propensity to make a new investment increases. When the venture capital fund has been around for a long time, the venture capitalist is less likely to initiate a new project, a result that corroborates industry expert observations.[5] Independent venture capitalists are more active than captive investors in initiating venture capital projects. Fifth, among portfolio company-level controls, *earlier-stage* ventures receive venture capital financing sooner. Also, portfolio companies that are located in the same geographic region as investors have a higher likelihood of getting venture capital funding. Finally, we do not find a statistically significant effect of the IPO market on the timing of new investments. Since it takes years to grow a portfolio company, the IPO market probably does not have an immediate impact. In addition, when the IPO market is doing well, the venture capitalist will probably set priority on pushing later-stage ventures in its existing portfolio to IPO (Cumming et al., 2005).

Let us turn to our hypotheses. Hypothesis 1 predicts a negative effect of uncertainty on a venture capitalist's decision to initiate a project. Consistent with this hypothesis, the parameter estimate of *Market volatility* in Model 2 of Table 4 is positive and significant ($p<0.001$), indicating that market volatility increases a venture capitalist's propensity to defer and decreases the hazard of a project being initiated. The likelihood ratio test suggests that adding the uncertainty measure significantly improves the explanatory power of Model 2 over Model 1 (LR = 36.61, $p<0.001$). Holding the value of all other variables at their median

[5] See, for example, Jens Lapinski. "VC Fund Raising Manual". http://jenslapinski.wordpress.com/2008/06/20/vc-fund-raising-manual.

Table 3
Descriptive statistics and correlations.

No.	Variables	Mean	S.D.	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1)	Market volatility — standard error	5.71	3.02	1.87	11.70	1.00														
(2)	Market volatility — conditional variance	2.78	0.74	0.25	5.36	0.60	1.00													
(3)	Sales growth	0.16	0.11	−0.33	0.58	0.45	0.33	1.00												
(4)	HHI	0.05	0.11	0.0030	1.00	−0.30	−0.18	−0.26	1.00											
(5)	Total initial investment venture received	7.82	1.50	0.69	15.50	0.05	0.14	0.07	0.03	1.00										
(6)	Staged financing	0.62	0.48	0.00	1.00	0.06	0.04	0.06	−0.13	−0.01	1.00									
(7)	R&D intensity	0.14	0.13	0.00	3.73	0.21	0.12	0.09	−0.29	0.03	0.09	1.00								
(8)	Tangibility	0.24	0.15	0.08	0.79	−0.55	−0.27	−0.26	0.38	−0.05	−0.08	−0.49	1.00							
(9)	VC portfolio size	2.89	1.49	0.00	6.48	0.01	−0.02	−0.05	−0.03	0.16	0.18	0.01	−0.01	1.00						
(10)	Independent VC	0.75	0.43	0.00	1.00	0.06	0.02	0.03	−0.05	0.05	0.18	0.03	−0.05	0.13	1.00					
(11)	VC syndicate size	2.48	1.73	1.00	21.00	−0.04	0.02	0.01	−0.06	0.33	0.12	0.01	0.01	0.12	0.01	1.00				
(12)	VC fund age	4.73	6.53	−11.00	44.00	−0.02	−0.06	−0.03	0.02	0.07	−0.04	−0.00	0.02	0.27	−0.11	0.03	1.00			
(13)	Early-stage venture	0.64	0.48	0.00	1.00	0.11	0.12	0.11	−0.20	−0.16	0.26	0.15	−0.17	0.05	0.08	0.05	−0.06	1.00		
(14)	Same region	0.44	0.50	0.00	1.00	0.06	0.02	−0.02	−0.04	−0.16	0.07	0.05	−0.09	−0.07	0.06	−0.06	−0.02	0.13	1.00	
(15)	No. IPO issues	6.75	0.35	5.48	7.32	0.12	0.09	0.37	−0.08	0.10	0.02	−0.01	−0.09	−0.04	0.03	−0.05	−0.02	0.02	−0.03	1.00

Note: This table provides descriptive statistics for dependent and independent variables. Variables are defined in Table 2. $N = 18{,}438$ for Conditional variance; $N = 18{,}678$ for all other variables. Correlations with absolute values larger than 0.02 are significant at $p < 0.01$.

level, when market volatility increases from the 25th to 85th percentile, the hazard decreases from 0.32 to 0.14; the median time to initial funding increases from 2.12 to 4.37 years.

Hypothesis 2 suggests that the delay effect of uncertainty will be attenuated by industry growth potential. The empirical implication is that the positive relationship between market volatility and the time to initial funding of new venture capital projects weakens at higher levels of industry sales growth. Model 3 shows that the coefficient of the interaction term between Market volatility and Sales growth is negative and significant ($p<0.001$), suggesting that the marginal negative effect of uncertainty on the time to initial funding decreases with an increase in industry sales growth. Holding the value of other variables at their median level, when sales growth increases from its 25th to 85th percentile, the interaction effect (or the difference of differences) for a similar increase in market volatility is an increase of 0.150 in the hazard of initial funding and a decrease of 0.137 years in the median time to initial funding.

Hypothesis 3 posits that the positive relationship between uncertainty and the time to initial funding of new venture capital projects becomes weaker at higher levels of competition among venture capitalists. Empirically, we expect a positive interaction between Market volatility and HHI, since higher HHI indicates lower level of competition among venture capitalists. The coefficient of the interaction term between the two variables in Model 4 is indeed positive and significant ($p<0.05$). The likelihood ratio test suggests that Model 4 with the interaction term increases the explanatory power significantly over Model 2. Holding the value of other variables at their median level, when HHI increases from its 25th to 85th percentile, the interaction effect for a similar increase in market volatility is a decrease of 0.136 in the hazard of initial funding and an increase of 0.128 years in the median time to initial funding. This result is consistent with the finding that competition reduces the negative impact of uncertainty on the *investment level* (Bulan, 2005; Guiso and Parigi, 1999).

5.1. Robustness tests

We perform a number of analyses to examine the robustness of the empirical results. First, we test the sensitivity of the results to an alternative measure of Market volatility. We specify a GARCH (1,1) process to estimate the conditional variance of the error term in Eq. (1) (Price, 1996). We annualize this measure, take its log and lag the measure by one year (Folta et al., 2006). Table 3 shows that this lagged conditional variance measure is highly correlated with the standard error measure at 0.60. Models 9–11 of Table 4 report the results with this conditional variance measure. The main effect of Market volatility in Model 9 is still positive and significant ($p<0.001$), a result consistent with that in Model 2. The interaction effects with Sales growth and HHI in Model 10 are also significant and qualitatively similar to those in Model 5.

Second, we test whether the delay effect of Market volatility is driven by several dominant industries in our sample. We single out all the industries that are represented by more than 5% of the sample observations. These industries include *Computer Software and Internet*, *Computer Hardware*, *Communication*, *Electronic Equipment*, *Pharmaceutical Products*, and *Medical Equipment*. We re-estimate Model 2 of Table 4 for each subsample, and for the pool of remaining industries ("*Remaining sample*"). Table 5 reports the results for the effect of uncertainty. Two points are worth noting. First, the coefficient estimates of Market volatility for all the six dominant industries in Models 1–6 are positive and statistically significant. This result indicates that the delay effect indeed holds up for different subsets of the industries. Secondly, the coefficient estimate for the remaining sample in Model 7 remains statistically significant and has the same positive sign as for the six dominant industries and the full sample (reproduced in Column 8 of Table 5). Therefore, our results are not driven by the dominant industries.

We further test whether the coefficient estimates of Market volatility are statistically equal for all the seven subsamples. We perform seemingly unrelated estimations for this purpose. An overall Wald test rejects the null hypothesis that the coefficients are statistically equal across the industries ($\chi^2(6)=18.52$, $p<0.005$). By comparing the *remaining sample* with the six dominant industries, however, we find that the coefficient for the *remaining sample* is statistically similar to those for *Computer Hardware*, *Computer Software and Internet*, and the *full sample*, but different from others. We suspect that while the delay effect of uncertainty holds for different subsets of industries, the magnitude may differ.

Finally, we test whether uncertainty has any second-order effect. Since portfolio companies typically have insufficient earnings and cash flows at the time of initial investment, the value of venture capital projects depends primarily on expected growth opportunities (Gompers and Xuan, 2006; Triantis, 2001). Uncertainty increases the value of growth options as well, and may increase it even more than the value of a deferral option (e.g., Folta and O'Brien, 2004; Kulatilaka and Perotti, 1998).

First, relative to delayed investment, immediate investment may result in a larger market share and higher profits, thus bringing about first-mover advantages and creating greater upside potential (Kulatilaka and Perotti, 1998; Lin and Kulatilaka, 2007; Wernerfelt and Karnani, 1987). Second, the value of the deferral option is bounded, while the value of the growth option is not (Folta and O'Brien, 2004). Although the deferral option value is monotonically increasing in uncertainty, it is also asymptotic to the total sunk costs required to invest in the portfolio company. In contrast, the growth option has no such upper bound on its value. As the uncertainty about future market conditions increases, so does the potential economic value of gaining a competitive advantage in that market. Consequently, higher uncertainty may lower investment thresholds for venture capital projects with substantial growth options, inducing a positive effect of uncertainty on investment.

To test whether uncertainty has a non-monotonic effect on the investment timing decision, we include *Market volatility squared* in Models 6 and 7. This term is negative and statistically significant. However, this empirical result does not hold for the conditional variance measure of Market volatility in Model 11. The likelihood ratio test also suggests no improvement in the explanatory power of Model 11 when *Market volatility squared* is included. In addition, we test for the impact of the interaction

Table 4
Initial funding of venture capital projects: results from survival analysis.

Model	1	2	3	4	5	6	7	8	9	10	11
Market volatility		0.118***	0.125***	0.117***	0.124***	0.195***	0.227***	0.232***	0.0586***	0.0532***	0.0576***
		(0.0196)	(0.0196)	(0.0196)	(0.0197)	(0.0413)	(0.0425)	(0.0432)	(0.0157)	(0.0161)	(0.0157)
Market volatility × Sales growth			−0.113***		−0.107***		−0.124***	−0.117*		−0.363**	
			(0.0291)		(0.0292)		(0.0299)	(0.0548)		(0.138)	
Market volatility × HHI				0.266*	0.231*		0.202+	0.287+		0.200+	
				(0.110)	(0.111)		(0.111)	(0.168)		(0.115)	
Market volatility squared						−0.0122*	−0.0163**	−0.0157**			0.0123
						(0.00581)	(0.00595)	(0.00605)			(0.0140)
Market volatility squared × Sales growth								−0.00423			
								(0.0322)			
Market volatility squared × HHI								0.0281			
								(0.0427)			
Sales growth	−0.882***	−0.888***	−0.765***	−0.884***	−0.767***	−0.892***	−0.753***	−0.716*	−0.704***	−0.476***	−0.717***
	(0.0920)	(0.0920)	(0.0973)	(0.0920)	(0.0973)	(0.0920)	(0.0974)	(0.282)	(0.0983)	(0.126)	(0.0994)
HHI	0.0228	−0.00288	0.00663	0.581*	0.514+	−0.0109	0.442+	0.469+	−0.0120	0.0504	−0.0139
	(0.104)	(0.104)	(0.104)	(0.264)	(0.264)	(0.104)	(0.266)	(0.269)	(0.103)	(0.108)	(0.103)
Total initial investment venture received	0.0269***	0.0277***	0.0278***	0.0276***	0.0277***	0.0278***	0.0278***	0.0279***	0.0273***	0.0275***	0.0274***
	(0.00598)	(0.00597)	(0.00597)	(0.00597)	(0.00597)	(0.00597)	(0.00597)	(0.00597)	(0.00590)	(0.00590)	(0.00590)
Staged financing	−0.188***	−0.189***	−0.190***	−0.190***	−0.191***	−0.190***	−0.192***	−0.192***	−0.197***	−0.199***	−0.197***
	(0.0161)	(0.0161)	(0.0161)	(0.0161)	(0.0161)	(0.0161)	(0.0161)	(0.0161)	(0.0159)	(0.0159)	(0.0159)
R&D intensity	0.132	0.123	0.114	0.126	0.116	0.113	0.101	0.102	0.00145	0.000465	0.0100
	(0.0814)	(0.0813)	(0.0813)	(0.0813)	(0.0813)	(0.0814)	(0.0815)	(0.0815)	(0.0812)	(0.0812)	(0.0818)
Tangibility	0.229	0.119	0.230	0.0991	0.207	0.173	0.297	0.304	0.529*	0.607**	0.540*
	(0.210)	(0.211)	(0.213)	(0.211)	(0.213)	(0.212)	(0.216)	(0.220)	(0.216)	(0.219)	(0.216)
VC portfolio size	0.0772***	0.0770***	0.0764***	0.0772***	0.0766***	0.0768***	0.0763***	0.0763***	0.0739***	0.0741***	0.0740***
	(0.00533)	(0.00533)	(0.00533)	(0.00533)	(0.00533)	(0.00533)	(0.00533)	(0.00533)	(0.00529)	(0.00529)	(0.00529)
VC syndicate size	−0.0302***	−0.0308***	−0.0306***	−0.0308***	−0.0306***	−0.0306***	−0.0303***	−0.0303***	−0.0283***	−0.0280***	−0.0283***
	(0.00466)	(0.00466)	(0.00466)	(0.00466)	(0.00466)	(0.00466)	(0.00466)	(0.00466)	(0.00459)	(0.00459)	(0.00459)
VC fund age	0.0121***	0.0122***	0.0122***	0.0122***	0.0121***	0.0121***	0.0121***	0.0121***	0.0108***	0.0108***	0.0108***
	(0.00117)	(0.00117)	(0.00117)	(0.00117)	(0.00117)	(0.00117)	(0.00117)	(0.00117)	(0.00115)	(0.00115)	(0.00115)
Independent VC	−0.0582***	−0.0589***	−0.0590***	−0.0592***	−0.0593***	−0.0591***	−0.0594***	−0.0596***	−0.0619***	−0.0626***	−0.0619***
	(0.0174)	(0.0173)	(0.0173)	(0.0173)	(0.0173)	(0.0173)	(0.0173)	(0.0173)	(0.0171)	(0.0171)	(0.0171)
Early-stage venture	−0.697***	−0.696***	−0.697***	−0.696***	−0.696***	−0.696***	−0.696***	−0.696***	−0.714***	−0.713***	−0.714***
	(0.0168)	(0.0168)	(0.0168)	(0.0168)	(0.0168)	(0.0168)	(0.0168)	(0.0168)	(0.0165)	(0.0165)	(0.0165)
Same region	−0.0910***	−0.0904***	−0.0909***	−0.0900***	−0.0905***	−0.0908***	−0.0912***	−0.0914***	−0.0888***	−0.0887***	−0.0887***
	(0.0152)	(0.0152)	(0.0152)	(0.0152)	(0.0152)	(0.0152)	(0.0152)	(0.0152)	(0.0150)	(0.0150)	(0.0150)
No. IPO issues	−0.00428	−0.000343	0.00496	0.00103	0.00590	−0.00106	0.00558	0.00807	−0.0124	−0.00671	−0.00876
	(0.0257)	(0.0257)	(0.0257)	(0.0257)	(0.0257)	(0.0257)	(0.0257)	(0.0260)	(0.0268)	(0.0270)	(0.0272)
Constant	2.166**	0.165	2.022**	0.359	2.038**	2.033**	2.167**	2.181**	−2.750**	−2.816**	−2.512**
	(0.711)	(0.755)	(0.764)	(0.702)	(0.721)	(0.764)	(0.722)	(0.722)	(0.881)	(0.882)	(0.837)
Industry dummies	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included
Venture state dummies	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included
Observations	18,678	18,678	18,678	18,678	18,678	18,678	18,678	18,678	18,438	18,438	18,438
Wald chi square	4140	4177	4192	4182	4196	4181	4203	4204	4373	4386	4374
log likelihood	−26,168	−26,149	−26,142	−26,146	−26,140	−26,147	−26,136	−26,136	−25,410	−25,403	−25,409
Improvement in log likelihood		36.61***	14.92***	5.82*	19.29***	4.4*	26.74***	0.45	–	12.6**	0.77
Comparison		Model 1	Model 2	Model 2	Model 2	Model 2	Model 2	Model 7		Model 9	Model 9

Notes: This table reports results from lognormal survival models. Dependent variable is the log of time to initial funding for portfolio companies. Variables are defined in Table 2. Models 1–8 report results for the standard error measure of market volatility; Models 9–11 report results for the conditional variance measure of market volatility. The sample reduces to 18,438 observations for Models 9–11 because of missing values for the conditional variance measure. Standard errors appear in parentheses. ***$p<0.001$, **$p<0.01$, $p<0.05$, and +$p<0.10$. All Wald chi square tests are significant at $p<0.001$.

Table 5
Initial funding of venture capital projects: subsample analysis.

Model	1	2	3	4	5	6	7	8
	Computer Software and Internet	Communication	Pharmaceutical Products	Electronic Equipment	Medical Equipment	Computer Hardware	Remaining sample	Full sample
Market volatility	0.261*	1.936**	3.046*	1.003**	1.965*	0.807+	0.254*	0.118***
	(0.124)	(0.650)	(1.422)	(0.367)	(0.930)	(0.479)	(0.111)	(0.0196)
Other variables	Included	Included	Included	Included	Included	Included	Included	Included
Observations	7270	1893	1439	1362	1321	1002	4391	18678
Wald chi square	2034***	395.2***	307.8***	367.4***	406.4***	388.4***	883.8***	4177***
Log likelihood	−9049	−2652	−1924	−1840	−1746	−1181	−6965	−26149
Wald test of equality of coefficients	0.00	6.79**	4.05*	3.95*	3.49+	1.16	–	1.62

Notes: This table reports the coefficient estimates for Market volatility from lognormal survival models. Dependent variable is the log of time to initial funding for portfolio companies. Explanatory variables are the same as in Model 2 of Table 4. Variables are defined in Table 2. Models 1–6 report results for each dominant industry, Model 7 for the remaining sample, and Model 8 for the full sample (reproduced from Model 2 of Table 4). Wald test of equality of coefficients compares the coefficient estimate of Market volatility for the remaining sample with that for each of the other samples. Standard errors appear in parentheses. $^{***}p<0.001$, $^{**}p<0.01$, $^{*}p<0.05$, and $^{+}p<0.10$.

term between *Market volatility squared* and *Sales growth* or *HHI*. We find no statistically significant effect in Model 8. Nor do we find any significant effect for the interaction term between *Conditional variance squared* and *Sales growth* or *HHI*.

6. Discussion and conclusions

The current paper offers a real options view of when a venture capital project is initiated. This study maintains that whether the venture capitalist should invest immediately for gaining access to growth opportunities, or defer investing until the arrival of favorable information depends on the relative value of the deferral and growth options. The empirical results indicate that when market returns are highly volatile in the industry, the venture capitalist tends to defer initiating a project. It appears that venture capitalists highly value the flexibility to act upon updated information under conditions of high uncertainty.

Our analysis also found that in industries with higher sales growth, venture capitalists have greater propensity to initiate new investment projects. Further, the delay effect of market volatility is substantially reduced when the industry experiences great sales growth. Finally, when the industry has higher level of competition among venture capitalists, the dampening effect of market volatility becomes weaker.

The current paper did not find a consistently significant second-order effect of market volatility on the time to initial funding of new venture capital projects. We offer the following possible explanations. First, theoretical research predicts that uncertainty, at its extremely high level, may increase the value of the growth option more than the value of the deferral option when early investment provides strong strategic advantages to preempt competitors (Kulatilaka and Perotti, 1998; Lin and Kulatilaka, 2007; Wernerfelt and Karnani, 1987). The venture capital market has very low barriers to entry (Cochrane, 2005). To our best knowledge, venture capitalists are not known for having significant first-mover advantages of the sort that theoretical research has emphasized (Kulatilaka and Perotti, 1998; Lin and Kulatilaka, 2007).

Second, with the option to invest subsequently, market volatility may primarily enhance the growth potential of the venture capital project provided that two conditions are met: *if* the rights and responsibilities associated with the subsequent round of financing are pre-determined, and *if* the cost of financing stays fixed. However, the rights and responsibilities outlined in contracts are contingent in nature. Equally important, the cost of financing varies from round to round and is highly uncertain for a venture project that typically takes years to complete. Thus, while the growth option value is unbounded theoretically, it is not clear before the start of the investment project that uncertainty will increase the value of the growth option more than the value of the deferral option when both the *future* costs and benefits are uncertain.

It is worth noting that our result about the delay effect of market volatility does not imply that venture capitalists avoid investing in highly uncertain industries. Rather, our study suggests that such an investment will likely be deferred until market volatility reduces. If venture capitalists respond to market information this way, one can anticipate observing cycles of investments that correspond with the public market cycles, a phenomenon that has indeed been observed by extant empirical research (Gompers and Lerner, 2002).

The fact that market information has an important influence on venture capitalists' investment decisions is not surprising. One reason for this relationship between market information and venture capital investment is lack of sufficient information about portfolio companies and venture capital industries. For example, since many venture capital-backed companies do not have meaningful sales for at least 2–3 years after the initial investment, signals from the public market about industry sales growth are important reference points for venture capital investors' initial investment decision. As far as the public market shifts reflect changes in fundamentals, our empirical results corroborate the view that venture capitalists rationally respond to shifts in market fundamentals (Gompers et al., 2008).

The current paper makes several specific contributions to existing research in venture capital and real options. First, this study examines a real options view of venture capital investment decisions. Existing venture capital research has primarily taken an agency perspective (Gompers, 1995), which focuses on how information and agency concerns shape venture capital contract design. The real options approach views venture capital investment opportunities, whether initial or subsequent, as real options. Because real options are valuable under uncertainty, it follows that venture capital investment behavior is influenced by uncertainty. This real options view complements the agency perspective, and together they offer a more complete account for venture capital investment decisions. In addition, the real options lens offers a dynamic, forward-looking view of the investment decision process. In the current study, the initial investment timing decision depends on the relative value of the initial investment opportunity (the deferral option) and future investment opportunities (the growth option).

Second, the current paper fills a research gap by analyzing the timing of initial venture capital funding from a real options perspective. There is a small but growing research literature on venture capital from the real options perspective, but the focus usually is on the valuation and management of venture capital projects. For example, Seppa and Laamanen (2001) observe that a simple binomial options model outperforms the traditional risk-adjusted net present value models in forecasting the economic returns for a sample of portfolio companies. Hurry, Miller, and Bowman (1992) suggest that Japanese venture capitalists follow an 'option' strategy, by which a venture capital project can be viewed as an 'external' investment to create a call option, while the subsequent 'internal' development such as an R&D project can be viewed as exercise of this call option to capitalize on technology opportunities. The current study adds to this stream of research by examining how real options factors, and uncertainty in particular, affect the initial investment timing decision.

Third, the current paper provides further evidence to the "rational response" view about venture capital investments. According to Gompers et al. (2008), some researchers maintain that the volatility of the venture capital industry is a symptom of overreaction by venture capitalists and entrepreneurs to perceived investment opportunities. This asserted overreaction may have its roots in the behavioral biases of venture capitalists irrationally associating past investment successes with future investment opportunities. Or it may stem from venture capitalists who feel compelled to follow the herd out of concern for the potentially negative reputation consequences of being contrarians. Gompers et al. (2008) offer a contrasting view that the volatility of the venture capital industry stems not from such an overreaction, but from the inherent volatility of fundamentals. Gompers et al. (2008) suggest that venture capitalists rationally respond to financially attractive investment opportunities signaled by public market shift. Our study offers further support for this "rational response" view. In our analysis, market volatility has a significant delay effect on venture capitalists' decision to initiate a venture capital project, but industry sales growth has the opposite effect, and further, the delay effect of market volatility is mitigated by sales growth in the target industry and competition among venture capitalists.

There are several opportunities for future research to extend the current study and address some of its limitations. Researchers may further examine the level of venture capital investment from a real options perspective. As compared with discrete large investments, small toehold investments provide greater flexibility to the venture capitalist to adapt to changes in market conditions (Bowman and Hurry, 1993). The investor obtains access to growth opportunities through the initial investment while containing the downside risk to the loss of initial sun cost investment in case of adverse market developments. In addition, it is worthwhile to examine whether venture capitalists that make smaller initial investments followed by larger commitments will outperform those with only discrete small, or large, investments, as implied in real options reasoning (Bowman and Hurry, 1993).

Further research is also needed to address the non-monotonic effect of uncertainty on market entry, investment timing, and investment level. While Folta and O'Brien (2004) find a non-linear effect of uncertainty on market entry, Campa (1993) does not. Our study provides mixed evidence for venture capital investment. Future research may use existing theoretical research to identify possible contexts for an empirical investigation of the non-monotonic effect of uncertainty. For instance, Lin and Kulatilaka (2007) suggest that such non-monotonic effect of uncertainty is likely strong in industries with *strong* growth options such as those industries with strong network effects.

Real options theory promises to be an important and challenging direction for research in the evolving science of management and organizations (Mahoney, 2005). We hope that this study not only fills a gap in the extant research literature, but also proves generative of further theory development and empirical testing in the areas of real options, venture capital and entrepreneurship.

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