Patent Signaling, Entrepreneurial Performance, and Venture Capital Financing*

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This version: October, 2010

* The authors thank Ola Bengtsson, Thomas Chemmanur, Rebel Cole, Scott Hsu, Josh Lerner, Yang Lu, Ron Masulis, Sean Nicholson, Jeffrey Pontiff, Meijun Qian, Jay Ritter, David Robinson, Morten Sorensen, Xuan Tian, and participants at the Financial Management Association Meeting and the Singapore Management University Finance Summer Camp for their valuable comments and suggestions.

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Abstract

This work draws on comprehensive patent data for VC-backed firms in the U.S. from 1976 through 2005 to empirically examine the signaling effect of start-up firms' patents on entrepreneurial performance and financing patterns of venture capitalists (VCs). Start-up firms that successfully file patents before receiving any VC investment are more likely to complete IPOs (initial public offerings) and less likely to fail or be acquired. Such prior patenting helps VC investees to receive substantially more VC funding, attract a larger number of more prominent VCs, and experience a longer incubation period. The propensity of patenting is related to information asymmetry in the market: start-up firms tend to file patents when the degree of information asymmetry in the public market is higher. These results are robust to instrumental regressions that use public firms' patenting choices as the instrument. Our empirical evidence therefore suggests that patenting serves as an effective signaling device for mitigating the asymmetric information problem between entrepreneurs and VCs.

Keywords: Venture capital; innovation; patents; entrepreneur; signaling; controlling rights; financing

JEL classification: G24; O34

I. INTRODUCTION

Because start-up firms are often characterized by large intangible assets, negative cash flow, great technological uncertainty, and low liquidation value, entrepreneurs depend primarily on venture capitalists (VCs) for outside financing and endorsement. However, VC investment by itself is plagued by information asymmetry between VCs as outside investors and entrepreneurs as insiders (Leland and Pyle, 1977; Amit, Glosten, and Muller, 1990; Fried and Hisrich, 1994). Although the literature has long recognized the asymmetric information problem between VCs and entrepreneurs, most extant studies focus on how VCs mitigate such a problem through various financing strategies.[1] In actuality, because reducing asymmetric information and associated agency costs is a critical issue for entrepreneurial firms, especially high-tech and early-stage firms (Gompers and Lerner, 1996),[2] one of the most effective signaling tools for mitigating this information asymmetry may be patenting,[3] whose role nonetheless remains underexplored in the literature. To throw light on this issue, this study empirically addresses three research questions: How effective is patent signaling in predicting entrepreneurial performance? How does patent signaling affect VC financing patterns? How do VCs encourage their investees' innovation?

As regards our first research question, Hsu and Ziedonis (2007), in a recent study of 370 semiconductor start-up firms funded by VCs between 1980 and 2005, find that these firms' patenting records both work as effective signals and explain the likelihood of initial public

[1] Examples include staged capital infusion (Sahlman, 1990; Gompers, 1995), convertible bonds (Gompers, 1996), and the combining of convertible preferred securities and staged capital infusion (Cornelli and Yosha, 2003).

[2] The theoretical premise is that information asymmetry governs the relationship between start-up firms and VCs, and high-quality start-up firms have the incentive to separate themselves from other firms in the market. A large body of literature examines the impact of information asymmetry in markets and the role of signals as mechanisms that lead to a separating equilibrium between different types of firms (e.g., Spence, 1973; Kreps, 1990).

[3] Bhattacharya and Ritter (1983) suggest that entrepreneurs use patenting as a credible signal to communicate with outside financiers. As a signaling tool, patenting should incur nontrivial costs if a separating equilibrium is to be sustained. Lemley (2000) estimates the direct monetary costs associated with the patenting process at roughly $25,000 per patent.

offering (IPO). Nonetheless, although the literature suggests that public market investors take patents as important indicators in IPO pricing (e.g., Stuart, Hoang, and Hybels, 1999; Heeley, Matusik, and Jain, 2007), relatively few studies examine the economic role of patenting in mitigating information asymmetry in the private market. Kaplan, Sensoy, and Stromberg (2009), however, do establish that intellectual property, including patents, is more important than physical capital in start-up firms' IPO success. Our first hypothesis thus states that patenting start-up firms are more likely to issue IPOs and less likely to go bankrupt than other start-up firms.

Prior studies have documented that start-up firms' patenting activities work as an important factor in VCs' valuation process.[4] For instance, Hellmann and Puri (2000) and Hall and Ziedonis (2001) suggest that innovative entrepreneurs are more likely to attract VC funds. On the other hand, survey research by Hellmann and Puri (2000) suggests that it takes innovative start-up firms longer than imitative ones to bring products to market. It is therefore noteworthy that, in addition to signaling quality, start-up firm patents also reflect the innovativeness of the founding entrepreneurs. VCs, however, are concerned about the potential risk associated with innovative entrepreneurs,[5] and thus have the incentive to syndicate with more VCs to diversify the risk. Based on these arguments, our second hypothesis proposes that patenting start-up firms receive higher investment amounts from more VCs and experience a longer incubation period.

Understanding how VC investment affects innovation is another important issue as yet underexplored in the VC literature (Gompers and Lerner, 2001). However, Kortum and Lerner (2000) show that the industry level VC investment spurs patents, while Chemmanur, Krishnan,

[4] Some may wonder whether VCs need signals. In answer, it should be noted that, unlike angle investors, VCs serve as agents whose investment decisions require approval from and are monitored by their own investors (Gilson, 2009). Hence, even if they know the entrepreneurial firm's capabilities, VCs still prefer credible signals before they initiate investment decisions.

[5] Gompers (1995) and Gompers and Lerner (2001) suggest that innovative entrepreneurial founders, being perhaps more interested in their own interests, may be obsessed with their inventions or academic reputations and be willing to take higher risks, because for them payoffs are the same as call options.

and Nandy (2008) document that at the firm level VC monitoring raises the total factor productivity (TFP) of investees. Hsu (2010) also finds that the patent numbers of VC-backed IPOs increase with VC-incubation period. Nevertheless, some international studies present conflicting evidence. For example, researchers report a negative relation between VC investment and start-up firm patent numbers in German and Italian firms (e.g., Engel and Keilbach, 2007; Caselli, Gatti, and Perrini, 2009). These authors argue that VCs may focus more on capitalizing innovations than on creating them. To provide new insights into this question, we use a sample of both public and private VC-back firms to investigate how VC investment actually affects investees' patenting activities.

We take our comprehensive list of U.S. VC-backed firms from the Thomson VentureXpert database for the 1976–2005 period. These firms can be matched to the 1976–2006 U.S. patent records in the updated NBER patent dataset using GVKEY and CUSIP identifiers. For VC investees without identifiers, we collect their patent data by manually searching the company names in the Patent Full-Text and Image Database (PatFT) of the USPTO (U.S. Patent and Trademark Office). The resulting sample contains comprehensive financial and patent information for VC-backed firms that either proceeded to IPO or remained private throughout the sample period. Such a dataset allows us to provide new and comprehensive empirical firm-level evidence for the entrepreneur-VC-innovation nexus.[6]

We find that VC investees with at least one successful patent application prior to receiving any VC investment have a significantly higher probability of completing IPO and a significantly lower probability of failure than VC investees without prior patents. Specifically, 67.39% of patenting VC investees successfully completed the IPO process, whereas only 14.81% of VC investees without patents did so. On the other hand, only 3.47% of patent-filing VC

[6] We recognize that our sample of start-up firms includes only the VC-backed firms reported in the Thomson VentureXpert database. However, we do not think that the data limitation affects the validity of our statistical inferences, as the empirical analyses we adopt are not subject to the selection bias from VC-financing.

investees filed bankruptcy, in sharp contrast to the 10.12% of VC investees without patents who did so. We formally test such outperformance using probit regressions with a patent indicator (equals one if the firm has at least one successful patent application over the five-year period prior to receiving first-round VC investment) and several control variables, including the number of successful patent applications (i.e., patent counts), number of VC rounds, number of VC investors, VC financing amount, average duration, VC incubation period, firm age, VC age, and year and industry dummies. Our results remain robust to different industries and financing stages, suggesting that entrepreneurial firm patenting serves as a credible signal to VCs of start-up firm quality. The patent counts, however, do not significantly explain VC-backed firms' IPO or failure, consistent with our argument that it is patenting rather than patent counts that is informative.

Although good quality firms do tend to have patents, it is also widely recognized that unobserved factors like firm quality may affect both VC investees' final success and their patenting choices. To overcome the potential endogeneity issue, we propose two instrumental variables (IVs): public firms' patent ownership and patent counts at the industry level. These two IVs, although found to be closely related to the dummy variable for VC-investee patent, do not directly affect these firms' final success or failure, except through patenting choices. We use multivariate probit regressions to take these IVs into account and find consistent support for our first hypothesis that patenting start-up firms are more likely to IPO and less likely to go bankrupt than other start-up firms.

Similarly, using both ordinary least squares (OLS) regressions and two-stage least squares (2SLS) regressions that contain the IVs, we show that VC investees' patenting records significantly affect the way that VCs finance them. That is, patenting VC investees receive significantly higher investment amounts from more VCs and experience significantly longer

incubation periods than VC investees without patent records. Specifically, if a firm has filed any successful patent applications before receiving VC money, it receives over 7 million USD more in total VC investment, experiences 1.8 years longer of incubation period, and receives funding from 0.35 more VC investors. Patent counts, on the other hand, seemingly have no explanatory capacity for VC financing patterns. These findings are not attributable to any other causes, such as firm vintage, VC vintage and size, growth options, R&D intensity, industry characteristics, or business cycles.

To further justify the patent signaling argument, we examine the relation between information asymmetry and patenting activities in recognition that the importance of signaling rises with market information asymmetry (Leland and Pyle, 1977; Amit, Glosten, and Muller, 1990). We find that industry-wide information asymmetry, measured with the volatility of the daily return residuals from the CAPM and the Fama-French (1993) three-factor model (Blackwell, Marr, and Spivey, 1990; Clarke, Fee, and Thomas, 2004), correlates positively with VC investees' patenting activities. This evidence suggests that start-up firms tend to file more patents when such signaling is made more valuable by a higher degree of information asymmetry. At the industry level, information asymmetry decreases the IPO likelihood of VC investees.

In addressing the third research question, we find not only that first-round VC investment tends to coincide with the slow-down (but not cessation) of patenting activities but that the extent of the slow-down increases with first-round VC investment amount and VC vintage. Rather than contradicting the literature, however, these findings suggest that, given VCs' tendency to avoid the high risk associated with early stage innovation, VC-backed firms make a rational choice to shift focus. For their part, experienced VCs tend not to overemphasize innovation but rather,

once they invest in a firm, try to shift its focus from invention to production and marketing in order to capitalize the innovation.

The remainder of this paper is organized as follows. Section II describes the data and reports the test results for the effect of patent signaling on entrepreneurial performance and VC financing patterns. Section III examines the relation between information asymmetry and VC-backed firms' patenting activities. Section IV analyzes the effect of VC investment on subsequent innovation, and Section V concludes the paper.

II. DATA AND EMPIRICAL RESULTS

A. Data

We retrieve the data on all VC-backed companies in US from the Thomson VentureXpert database for the sample period 1976 to 2005, a total of 27,837 start-up companies. Thomson VentureXpert covers comprehensive information on buyout and venture capital firms and their investment. We then collect the patent data from the updated NBER patent dataset and match them to the VC-backed companies using GVKEY and CUSIP identifiers.[7] This patent dataset contains information about all patents granted by the USPTO and their assignees (signaled by identifiers) in the 1976–2006 period. To ensure data quality and prevent selection bias, we focus our empirical analysis on only those VC-backed firms that have CUSIP information (38% of the Thomson VentureXpert database), for a total of 10,572 VC-backed firms with 71,894 patent counts. It is also worth noting that, following Kortum and Lerner (2000) and Hirukawa and Ueda (2008), we date all patents by their application dates.[8]

[7] For VC-backed firms without identifiers, we collect patent data by manually searching their company names in the USPTO Patent Full-Text and Image Database (PatFT) and conduct robustness analysis in Section II F.

[8] As argued in Hall, Jaffe, and Trajtenberg (2001) and many other studies, application dates are the most appropriate time placer for patents because inventions begin entering real economies once they appear.

Table 1 presents an annual summary of VC investment and the patenting activities of all VC-backed companies with CUSIP information by year from 1976 to 2005. These summary statistics show two to three up-and-down cycles in the number of total VC-backed firms, which hit one peak in 1987 and another in 2000. The average number of VC rounds and the average years in the incubation period show countercyclical moves, whereas the average number of syndicated VCs and first-round investment amounts present procyclical moves. These time series suggest that VCs time the market in both investment and IPO. As regards the patenting activities of sample firms, other than a sharp drop in the patent application process during 2004 and 2005 because of the application-grant lag (i.e., it takes about two years for the USPTO to grant a valid patent application), we observe an escalation in total patenting activities by VC-backed firms. The percentage of VC-backed firms that successfully applied for at least one successful patent application (see the rightmost column) indicates two to three up-and-down cycles with peaks in 1976, 1993, and 2005. The stationary time series of patent ownership percentages reveals no permanent uptrend, which could be interpreted to mean that expensive patenting signals prevent a pooling equilibrium in which both good and bad ventures own patents. More detailed investigations in the following sections further justify the relation between patenting and entrepreneurial performance.

B. Patenting, entrepreneurial performance, and VC financing: Descriptive statistics

As a preliminary analysis, Table 2 compares the entrepreneurial performance and VC financing patterns of two groups of sample firms: the first group includes VC-backed firms that filed at least one successful patent application in a designated period, while the second group

includes all other VC-backed firms in the same period.[9] Panel A includes a "Yes" group of 1,466 sample firms that succeeded in patenting within the five-year window before the first round of VC investment and a "No" group of another 8,295 firms that did not. The comparison shows that VC investees with patent records received more rounds of VC investment, received funds from more VCs, experienced longer duration and incubation periods, and received significantly more VC funds in the first round and in total than VC investees without patent records. These findings do indeed suggest that VCs treat these two groups of firms differently.

More important, we find that VC investees with patents have a significantly higher probability of IPO and a lower probability of either failure or acquisition.[10] Most notably, whereas 67.39% of patent-filing firms successfully completed the IPO process, only 14.81% of firms without patents did so. On the other hand, only 26.93% of patent-filing firms were acquired or liquidated versus 63.99% of firms without patents. These findings not only strongly support our first hypothesis that firm patenting performance predicts final success but provide empirical evidence on the effectiveness of patenting as a signaling device.

Additionally, when we examine investee and VC characteristics, we find that the patenting group is significantly more mature and is invested in by more mature and larger VCs. These observations lend further support to our signaling argument because, if start-up firm patenting serves as an important signal, then it should attract more prominent VCs in the first round, those characterized by longer vintage and larger asset management. Our earlier result also indicates that patenting start-ups can attract a greater number of VC investors.

Column B presents another grouping in which all VC-backed firms are divided into two groups according to whether or not they filed successful patent applications within a 10-year

[9] Since IPOs usually provide the highest returns for VCs (Gompers, 1995), we use IPO ratios to measure the success of VC investment.

[10] As in Lerner, Sorensen, and Stromberg (2010), such grouping provides an initial measure of the innovativeness of start-up firms.

window (five years before and five years after the year of receiving first-round VC investment). All the interesting differences in summary statistics reported for Column A also hold for this grouping, suggesting that the difference between patenting firms and nonpatenting firms is robust to the grouping method.

We then implement an industry-level analysis for the effect of patenting activities on entrepreneurial performance and VC financing patterns. Table 3 categorizes all the firms into six major industry groups (biotech, communications and media, computer-related, medical/health/life sciences, semiconductor, and non-high tech). The firms within each industry are then again divided into "Yes" and "No" groups according to whether they filed any successful patent applications in the five-year window prior to the year of first-round VC financing. Again, VC investees with patent records received more rounds of VC investment, received funds from more VCs, experienced longer duration and incubation periods, and received higher VC funds for the first round and in total than the VC investees without patent records.[11] Without exception, VC-backed firms with patent-filing records have a significantly higher probability of successfully completing IPOs and a lower probability of acquisition or failure. Overall, the differences in VC financing patterns and entrepreneurial performance are largely consistent with Table 2 and cannot simply be attributed to industry effect.

We also perform similar comparative analysis for different VC financing stages and obtain consistent results (see Section II F). All our findings hence suggest a positive relation between patenting performance and IPO success that is persistent across various industries and financing stages, and lends further support to our patent-based signaling argument.

[11] The exceptions are VC investment duration in the communications/media industry and VC funds for the first round in the semiconductor/other electronics industry.

C. Patenting and entrepreneurial performance

We conduct regression analyses to formally test the signaling effect of patenting on VC-backed start-up firms' success chances while controlling other relevant control factors and endogeneity issue. First, we employ probit regressions to examine the effect of start-up firms' patent filings (prior to the first round of VC funds) on their future performance as measured with a dummy variable representing IPO, being acquired, or being liquidated. We have two explanatory variables of interest: a patent dummy for start-up firms that filed at least one successful patent application (the patent dummy) and the number of successful patent applications filed by the start-up firms over the past five years (prior patent counts). The regressions also take into account various control variables, including the number of VC rounds, number of VC investors, VC financing amount for the first round (in log), average duration, total years of VC incubation, firm age, VC age, and year and industry dummies.

Panel A of Table 4 strongly supports our proposition. First, the patent dummy significantly and positively predicts the likelihood of IPO (Model 1) and significantly and negatively predicts the likelihood of acquisition or bankruptcy (Models 2 and 3). Second, and most noteworthy, the estimated coefficients of prior patent counts indicate that if start-up firms have prior patent records, their IPO likelihood increases by over 50% while their acquisition and bankruptcy likelihood drop by over 70% and 40%, respectively. We also find that prior patent counts have a positive (negative) effect on the likelihood of IPO (bankruptcy/acquisition), although not as strong as the patent dummy in terms of statistical significance. In fact, the coefficients indicate that each patent raises the IPO probability by 0.03% and lowers the acquisition probability and bankruptcy probability by 0.6% and 0.2%, respectively. The negative relation between start-up firms' failure and their patent counts confirms Eisdorfer and Hsu's (2009) finding for public firms. More important, the observation that the patent dummy plays a

much greater role than patent counts suggests that a firm's ability to succeed in patenting is more informative than how many patents it receives, meaning that patenting is more like a signaling tool than a quality measure.

Interestingly, we find that the number of VC investment rounds, the number of VCs involved, and the first-round VC investment amount are significantly negatively related to start-up firms' IPO probability, whereas this latter is positively related to the total VC incubation period. The negative coefficient associated with the number of VC investment rounds may reflect either of two explanations: firms with less monitoring have a better chance of success or they are already in good enough condition not to need many rounds of cash infusion. The negative coefficient associated with the number of involved VCs may reflect the negative impact of over-monitoring or the fact that VCs prefer to join forces in riskier deals. The negative coefficient associated with the first-round VC investment amount, however, is somehow puzzling and from an ex post perspective suggests inefficient VC investment in the first round. Lastly, the positive effect of the total VC incubation period on IPO probability supports the value of VC incubation for new ventures, which also accords with the argument of Hochberg, Ljungqvist, and Lu (2007) that attracting (prestigious) VCs on board is a pivotal event. Model 2 of Panel A shows that acquisition event is related to lower first-round VC investment amount, shorter average duration and incubation period, and young investee, while Model 3 shows that bankruptcy event is related to more VC investment rounds, shorter incubation period, and young investee.

To investigate whether the relation reported in Panel A is due to start-up firms' endogenous choice in patenting, we implement multivariate probit regressions, in which the

patent dummy is the endogenous explanatory variable dependent on two IVs:[12] public firms' patent ownership and public firms' patent counts. We argue that these two variables are closely related to the patent dummy as they reflect general preference for patenting, but do not directly affect entrepreneurial performance. To compute the first IV we categorize all public firms into each of six industries and then, for each industry, we compute the fraction of public firms that receives at least one patent in each year. We then take the ten-year average of each industry's fraction as a descriptor for the prevalence of public firms' patent ownership in each industry, which should be informative about new ventures' patenting decision. The second IV, public firms' patent counts, is the ten-year average of patents owned by public firms in each industry in each year. This variable describes the intensity of patent activities among public firms within one industry. Higher public firms' patent counts indicate a competitive environment that may affect new ventures' patenting choices. We justify the validity of the proposed two IVs in two ways: Conceptually, these IVs reflect only public firms' patenting activities and have no direct influence on new ventures' IPOs or failures, except through patenting choices. Statistically, we find that these IVs are uncorrelated with the errors from the probit regressions of Panel A.

Panel B of Table 4 reports the multivariate probit regression results that confirm the signaling effect of patenting. The patent dummy reveals a significantly positive effect on the likelihood of IPO and a significantly negative effect on the likelihood of acquisition or bankruptcy. The coefficients associated with prior patent counts and other control variables are largely the same as in Panel A. The bottom part of Panel B indicates that public firms' patent ownership does positively affect the patent dummy, indicating that both start-up firms and public firms are exposed to common technological cycles or policy regulations. Public firms' patent

[12] Another explanatory variable, prior patent counts, is not set as an endogenous explanatory variable due to its insignificant role in Panel A. The use of a multivariate probit program to handle endogeneity problems with a binary dependent variable and a binary endogenous independent variable has been adopted by Loureiro, Sanz-de-Galdeano, and Vuri (2006), Koedel (2008), and Monfardini and Radice (2008). Cumming (2008), on the other hand, uses binomial logit models for binary endogenous independent and dependent variables.

counts, on the other hand, affect the patent dummy negatively. This observation can be attributed to exclusive patent rights and limited patentable opportunities: once a firm patented a specific technology, its competitors are excluded from using that technology. The likelihood ratio (LR) test results reported in the bottom indicate an insignificant correlation between the errors of the two regressions, actually suggesting the exogeneity of the patent dummy (e.g., Monfardini and Radice, 2008).

D. Patenting and VC financing patterns

We then use OLS regressions and 2SLS regressions to explore whether VC-backed start-up firms' patenting activities affect VC financing patterns. Table 5 reports the results of the OLS regressions, which take into account three logarithmic dependent variables: the total VC funding amount, the VC incubation period, and the number of involved VCs. The main independent variables are the patent dummy and prior patent counts. The other control variables are firm age, VC age, VC fund size (capital under management) in logarithm, the market-to-book ratio and R&D-to-asset ratio of the industry to which the firm belongs, and year and industry dummies.[13] As pointed out in Chemmanur and Fulghieri (1999) and Maksimovic and Pichler (2001), industrial technological uncertainty affects the timing and financing choices of new ventures. Controlling for the industrial market-to-book ratio, R&D-to-asset ratio, and industry dummies therefore ensures that our test results are not driven by industrial technological uncertainty.

We find that, once all other factors are controlled for, start-up firms' patenting activities significantly explain VC financing patterns. Specifically, for total VC funding amount, the coefficients associated with the patent dummy range from 0.108 to 0.456, with statistical significance. In untabulated results based on the OLS regressions without logarithmic dependent

[13] It should be noted that, because we lack detailed firm-level measures for all start-up firms, we use the industrial market-to-book ratio as a proxy for the start-up firm's growth options and asset intangibility, and the industrial R&D-to-asset ratio as a proxy for the start-up firm's R&D intensity (see Gompers, 1995).

variables, we find that if a firm filed any successful patent applications before receiving VC funds, it is likely to have received over 7 million USD more in total from VCs, experienced 1.8 years longer of incubation period, and received funds from 0.35 more VCs. These results, combined with those in Tables 2 and 3, reveal an interesting phenomenon: patenting firms are patient about receiving VC funds, and both patenting firms and VCs are patient about IPO progress. This observation is consistent with our signaling argument in that both entrepreneurs and VCs must have good reasons for engaging in such costly waiting. In explanation, we suggest that strong, innovative firms, such as Google, are healthy enough that both the entrepreneurs and VCs are willing to wait for either better timing or higher prices. The additional finding that patenting firms have more VC investors may be attributable to two factors: First, the entrepreneurs may have greater bargaining power against the VCs and have the incentive to invite more VCs to dilute each other's influence. Second, VCs are concerned about the potential risk associated with innovative entrepreneurs and thus have the incentive to syndicate with more VCs to diversify this risk (Gompers, 1995; Gompers and Lerner, 2001).

We also find that the number of patents has a significant (positive) effect only on the length of the VC incubation period. Such a positive relation is fairly intriguing: why must firms with more patents wait longer for IPOs? One possible reason is that they are timing the market. Moreover, the relatively unimportant role of VC investee's patents is consistent with Table 4 and corroborates that a start-up firm's *ability* to patent is more important than how many patents it obtains. An alternative explanation is that the effect of earning one more patent on VC financing characteristics varies in different industries and cannot be presented in a pooled regression setting.

Among the control variables, we find that total VC investment amount increases with VC age, VC size, and industrial R&D-to- asset ratio. Thus, larger and more experienced VCs tend to

invest in larger start-up firms, and start-up firms in R&D-intensive industries receive more VC funds. In Model 2, VC incubation years increase with investee age or VC age, while decrease with industrial market-to-book ratio or R&D-to-asset ratio. This finding suggests that it takes longer for VCs to incubate start-up firms with high growth options and high R&D intensity. Model 3 indicates that the number of involved VC investors decreases with firm age and industrial market-to-book ratio, meaning that younger start-up firms with lower growth options attract fewer VCs.

Overall, the inclusion of all these control variables and industry and year dummies in the OLS regressions ensures that the explanatory power of the patent dummy is not due to firm characteristics, VC characteristics, industry characteristics, or business cycles. Nonetheless, we recognize the potential endogeneity issue in the results reported in Panel A of Table 5 and hence conduct 2SLS using the same two IVs (public firms' patent ownership and patent counts). The second stage regression suggests that the patent dummy still significantly raises total VC investment amount, VC incubation years, and VC investors. In the bottom of Panel B, we find that the patent dummy is positively affected by public firms' patent ownership but negatively affected by their patent counts, consistent with Table 4. We also report Hansen J-statistics for the validity of the proposed IVs and the chi-square statistics for the endogeneity of the patent dummy (Hansen, 1982; Baum, Schaffer, and Stillman, 2003, 2007). J-statistics do not reject the null hypothesis, indicating that the two IVs are valid because they are statistically uncorrelated with the error process. On the other hand, the rejection of the null hypothesis in the chi-square statistics suggests that the patent dummy can be treated as an exogenous explanatory variable. Thus, there could be no endogeneity issue for the relation between start-up firm patenting and VC financing patterns.

E. Competing explanations

We recognize that our main findings—that patenting firms have a higher probability of success and VCs finance patenting firms differently—could also be (partially) interpreted based on competing explanations. The first of these is the "unobserved firm/industry characteristics" explanation, which argues that some unobserved characteristics lead to a positive relation between the patenting decision and entrepreneurial success or different VC financing patterns. In our view, this explanation is unconvincing for several reasons: First, we observe similar patterns across different industries and financing stages. Second, our regression analyses control not only for important firm and VC characteristics but also for industry and year dummies. Most important, we propose two valid IVs to correct for the potential effect from unobserved factors, if any, and still find consistent statistically significant results.

The second competing explanation, which we name "smart VCs," argues that some VCs are smarter or have better information access than others. On the one hand, they prefer the patenting start-up firms; on the other hand, they adopt different investment strategies that result in different financing patterns. One approach to disentangling the smart VCs explanation from our signaling argument is to consider the explanatory power of VC age and size for all the differences identified, because vintage and money under management presumably reflect how smart a VC is. In our empirical tests, we do consider VC age (Table 4) and VC age and size (Table 5) and find that their existence does not eliminate the role of the patent dummy. In addition, since start-up firms have strong incentive to disclose their patenting success to all potential VC investors, it is unclear why some smart VCs snap up all the good opportunities in a competitive market.

It is also worth mentioning that these two alternative explanations are not entirely different from our signaling explanation in that even smart VCs and outstanding entrepreneurs

still need effective signals to make their decisions. That is, although all entrepreneurs have the incentive to signal their quality to a greater number of VCs, "smart" entrepreneurs in particular do so because they want better deals and less control from "smart" VCs. This assumption is supported by Tables 2 and 3. On the other hand, as investor-monitored financial intermediaries, VCs must defend their decisions to their investors based on solid indicators, among which patenting is certainly one of the most credible. Hence, in equilibrium, these incentives result in different VC financing patterns.

F. Robustness checks

Although our main results are based on GVKEY/CUSIP mapping, we recognize a potential selection problem: most firms without identifiers never proceeded to IPO. However, for robustness purposes, it is worth investigating whether their performance also depends on patenting activities. For this analysis, we use the patent data collected manually from the PatFT database for 15,554 such firms. As reported in Panel A of Table 6, 9.07% or 1,441 start-up firms filed at least one successful patent application within five years before receiving first-round VC investment. Consistent with Table 2, the patenting activities of firms without identifiers are still informative about their performance. That is, start-up firms with successful patent filing prior to VC financing are more likely to go public and less likely to be acquired or fail than those without successful patent filing. In terms of VC financing, start-up firms with patent filing receive more rounds of investment from more VCs, experience longer duration and incubation periods, and receive more money in both first-round and total VC investment. Similar results are reported in Panel B, which divides all start-up firms without identifiers into two groups based on whether they filed at least one successful patent application within five years before or five years after

receiving the first VC investment round. This table therefore suggests that our findings thus far cannot be simply attributed to the selection bias in the coverage of the NBER patent database.

In Table 7, we examine whether the earlier findings are robust to different financing stages by categorizing all VC-backed firms with available financing stage records into four subsamples: start-up/seed, early stage, expansion stage, and later stage. These subsamples are then again separated into "Yes" and "No" groups based on patent records in the five-year window prior to first-round VC financing. We find that, in general, VC investees with patent records receive more funds (per round and in total) from more VCs with longer duration and incubation periods.[14] Again, VC-backed firms with patent records have a significantly higher successful probability of completing IPOs and a lower probability of being acquired or failing. In addition, the patterns of investee age and VC age and size, albeit weaker, are similar to those in Tables 2 and 3. Table 7 thus corroborates that firm patenting effectively explains the likelihood of success and VC financing patterns.

III. PATENT SIGNALING AND INFORMATION ASYMMETRY

Our next step is to examine the relation between patent signaling and information asymmetry. As shown in Leland and Pyle (1977) and Amit, Glosten, and Muller (1990), the importance of entrepreneurs' signaling rises with market information asymmetry. If information is direct and costless, there is no need for start-up firms to signal their quality. To empirically test whether the extent of information asymmetry leads to patent signaling, we use the volatility of the daily return residuals from the CAPM and the Fama-French (1993) three-factor model as proxies of information asymmetry (Blackwell, Marr, and Spivey, 1990; Clarke, Fee, and

[14] We recognize that patent-filing investees in the start-up stage receive lower investment in the first round and involve fewer VCs, whereas patent-filing investees in the early stage receive lower investment in the first round. However, these exceptions may be due to the relatively smaller sample size of patent-filing investees (33 in the start-up stage and 82 in the early stage).

Thomas, 2004).[15] For every year, we regress each public stock's daily excess return on daily market excess returns (and the daily small-minus-big factor and value-minus-growth factor), and estimate daily return residuals. Then, for each one of six industries, we compute the variance of daily return residuals of all firms in that industry in that year as the return residual volatility.

As Table 8 shows, at the industry level, both proxies correlate positively with VC-backed start-up firms' patent choices, as measured by (1) the percentage of start-up firms in each industry with successful patent applications and (2) the total patents received by start-up firms in each industry, given the inclusion of such control variables as the patent counts of VC-backed firms in the prior year, industrial VC investment in the prior year, and industrial market-to-book ratio and R&D-to-asset ratio in the prior year. The positive relation between information asymmetry and patent choice cannot therefore be attributed simply to existing patents, VC funding, growth options, or R&D-intensity.

The role of information asymmetry in entrepreneurial performance is also worth investigation. The probit regression results in Table 9 indicate that the return residual volatility from the Fama-French three-factor model negatively affects IPO likelihood but positively affects the probability of being acquired. This finding is intuitive: when market information asymmetry rises, both entrepreneurs and VCs have incentives to slow down the IPO process because public investors become reluctant to chase IPO deals.[16] On the other hand, higher information asymmetry gives some firms information advantages over public investors and makes the former more aggressive in acquisition. We also note the negative (but insignificant) effect of information asymmetry on bankruptcy probability. One possible explanation is that higher information asymmetry makes it easier for incapable entrepreneurs to hide their poor

[15] In unreported tables, we use the dispersion in analysts' earnings forecasts as an alternative proxy of information asymmetry (e.g., Krishnaswami and Subramaniam, 1999; Diether, Malloy, and Scherbina, 2002) and obtain consistent results.

[16] Pastor, Taylor, and Veronesi (2009) argue that, when start-up firms' profitability becomes volatile, the market raises the threshold for expected profitability, which leads to fewer IPOs.

performance and avoid being forced into bankruptcy. This table therefore substantiates the influence of information asymmetry on entrepreneurial performance and, together with Table 8, justifies the necessity and effectiveness of patent signaling.

IV. VC FINANCING AND SUBSEQUENT PATENTING ACTIVITIES

Finally, we use our comprehensive patent data to explore how VC financing patterns affect start-up firm innovations at the firm level, a question that remains controversial in the literature (Gompers and Lerner, 2001).[17] Figure 1 reflects our initial probing of this question. First, Panel A shows the average total patent number of all VC-backed firms for an 11-year window centered on the year of receiving first-round VC investment. Perhaps not surprisingly, we observe a steep uptrend in the average total number of patents from year -5 (five years before the VC funding) to year 1 (one year after the VC funding) and then a less steep uptrend from year 1 to year 5. This finding suggests that VCs tend to wait for the right timing to invest in firms or to invest in firms whose innovation is already half complete, a rational assumption given that the VCs do not then need to incur too much research risk and can focus on marketing the innovation.

We further inspect the effect by restricting the sample to include only firms with patent records before first-round VC financing (Panel B), and find that the innovation uptrend (measured by the average number of patents) slows down in year -1. Such an observation lends further support to the argument that patenting works as a signaling device. VCs know about these innovations and focus on capitalizing the growth options. Once the entrepreneurs have proven that they can invent, the VCs are more concerned about whether these inventors will take on too

[17] Recent studies by Kortum and Lerner (2000), Lerner, Sorensen, and Stromberg (2010), and Hsu (2010) provide explorative investigation into this relation.

much risk in future research and/or do too little about financial performance. As a result, the VCs try harder to persuade the managing team to switch from innovation to production and marketing, which results in a slow-down in innovation.

It is also noteworthy that the results given in Figure 1 reconcile some different findings reported in the literature, especially the industry-level findings of Hirukawa and Ueda (2008). Most particularly, based on these outcomes, we argue that VCs do spur innovation but focus primarily on financial profits.

Table 10 presents the results of the OLS regressions examining how VC financing affects VC-backed start-up firms' subsequent innovation performance, which is measured with start-up firms' patent counts in the five-year window after first-round VC financing (year 1 to year 5) minus its patent counts in the five-year window before first-round VC financing (year -5 to year -1). Several important VC financing characteristics are considered on the right hand side of the regressions: first-round VC investment amount, the number of VC investors in first round, firm age, leading VC age and size, a dummy equals one if the firm has no patent record before, patent counts in the five year window prior to first-round VC investment, and year and industry dummies. It should be noted that the first two control variables are included to help remove any trends in the dependent variable.

Panel A reveals several interesting patterns. First, first-round VC investment has a negative effect on start-up firms' subsequent innovations, indicating that VCs tend to "play safe" when they have more money at stake. Second, VC vintage has a similar negative effect, implying that more experienced VCs are more sophisticated and do not easily become overconfident at investees' innovation. These two findings accord with our earlier conjecture that VCs focus primarily on capitalizing their investment and actually persuade entrepreneurs to do the same. Finally, we find that start-up firms tend to slow down innovation when more VCs are involved,

possibly because of syndicated VC power. Hence, although entrepreneurs may want more VCs involved in order to dilute the power of each, they may feel substantial pressure to shift their focus from innovation to operations and markets because of second opinions from the more conservative VCs. Similar results are reported in Panel B, in which we scale the difference by firm size, and suggest a robust effect of VC financing patterns on their investees' innovation performance

V. CONCLUSIONS

Using comprehensive patent data of VC-backed start-up firms, this research explores several important issues of patenting and entrepreneurial financing. Not only does patenting play an important signaling role between VCs and entrepreneurs, but our results show that start-up companies' patenting prior to any VC investment is credible by leading to higher IPO success rates. Accordingly, entrepreneurs tend to wait for patent filing before asking for VC money and tend to file more patents when the degree of information asymmetry is higher. Consequently, patenting start-up firms not only attract larger and more experienced VCs in first VC financing round, but also receive significantly larger amounts in first rounds or all rounds of investment, and experience longer investment incubation periods. All these findings are consistent with the signaling role of patents in equilibrium. Patent filing also helps to enhance entrepreneurs' control in start-ups: new ventures with prior patents are significantly less likely to be acquired in trade sale than those without patents. One concern is that these results are driven by the endogeneity reason: high-quality entrepreneurs are more likely to have patents. We control this problem with the instrumental variable regressions that use public firms' patent percentages of all patents or patents counts of public firms as the instruments. Our findings are robust to such endogeneity.

This research, however, does leave several issues unresolved that call for further investigations. First, our examination of VC involvement with their portfolio firms could be expanded using more detailed characterization of their investment decisions and contracts with entrepreneurs. Such a focus could also increase understanding of the consequences of these connections, whose investigation is limited in this present study by data availability. Second, future work might build upon our findings to throw light on how patenting affects stock prices in VC firm's valuation process, as well as specific contracting terms. Third, although this present analysis focuses exclusively on ex post performance measures like IPOs, liquidation, or acquisition, it would intuitively seem worthwhile to examine whether patenting as a signal also impacts the operating performance of start-up firms.

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Table 1: Summary of Year Distribution for the Full Sample

The sample includes all sample firms with CUSIP information that received VC investment between 1976 and 2005. For each year, the table reports the number of sample firms and summary statistics for the venture capital financing patterns, such as the number of investment rounds, number of syndicated venture capitalists, VC incubation years, and first-round VC investment amounts. The last two columns report sample firms' patent counts and percentages of any successful patent application within the 5-year window before the first round of VC investment.

Year	Number of VC-backed firms	Average number of VC investment rounds	Average number of VC investors per round	VC incubation years from the first to the last round	Aggregate first-round VC investment (mill. $)	Aggregate patent counts by VC-backed firms at [-5, -1] year around first VC round	Percentage of VC-backed firms file patent at [-5, -1] year from first VC round
1976	31	3.26	1.70	4.73	32.34	446	12.81%
1977	44	2.67	1.82	4.36	31.17	429	12.80%
1978	67	2.71	1.78	3.56	109.94	471	11.84%
1979	69	2.35	2.10	3.20	109.82	373	10.65%
1980	82	2.21	2.26	2.99	117.36	368	9.66%
1981	135	1.70	2.35	1.38	290.58	346	8.80%
1982	165	1.79	2.25	1.90	214.65	488	8.54%
1983	222	1.92	2.67	1.40	570.27	596	8.15%
1984	225	2.39	2.61	1.65	445.52	624	8.81%
1985	267	2.67	2.33	1.80	903.29	661	9.34%
1986	289	2.73	2.66	2.00	878.25	773	9.43%
1987	420	3.29	2.35	2.97	3872.15	1003	9.43%
1988	311	2.86	2.30	2.18	1826.36	1119	9.30%
1989	387	3.25	2.23	2.88	2328.33	970	9.09%
1990	283	3.84	2.12	3.11	794.62	1127	9.13%
1991	209	4.10	1.92	2.97	442.15	1299	10.11%
1992	321	4.21	1.92	3.43	1053.61	1748	9.90%
1993	331	4.72	2.03	3.64	1403.79	1924	10.96%
1994	304	4.11	1.93	3.15	1303.44	2375	10.85%
1995	391	3.67	1.86	2.91	2596.43	4352	9.98%
1996	521	3.51	1.90	3.00	3794.84	4548	9.29%
1997	740	3.06	1.79	2.13	4318.00	6534	9.27%
1998	750	3.21	1.82	3.79	6419.14	7096	8.37%
1999	756	3.54	2.24	2.62	14391.29	7663	7.57%
2000	936	3.21	2.31	2.26	24503.62	8004	7.74%
2001	661	3.82	2.26	3.01	8888.86	7526	7.59%
2002	449	3.81	2.28	3.41	7256.82	5147	6.89%
2003	395	4.24	2.17	4.08	11265.68	3244	8.13%
2004	436	4.56	2.11	4.91	9560.81	828	9.86%
2005	375	3.26	2.01	4.73	12288.91	237	10.65%

Table 2: Summary Statistics for VC Financing Patterns and Entrepreneurial Performance Based on Patenting Activities

The sample includes all sample firms with CUSIP information that received VC investment between 1976 and 2005. The table reports summary statistics for VC financing patterns, including the number of investment rounds, number of syndicated VCs, VC duration in years from the first round to the next, VC incubation years (from first round to last round), first-round VC investment, total VC investment for all rounds, percentage of companies going public, probability of a company being acquired, and probability of failure (becoming defunct or bankruptcy). Column A reports the information on the firms with and without patent filing within the 5-year window before the first round of VC investment. Column B reports the information on the firms with and without patent filing within the11-year window centered in the year receiving the first round of VC investment.

	A. Patent filing in the 5 yrs before first VC investment		B. Patent filing in the 5 yrs before & 5 yrs after the first VC investment	
	Yes	No	Yes	No
Number of VC investment rounds	4.44	3.39	4.12	3.40
Number of VC investors	2.74	2.29	2.61	2.28
VC duration (years to next funding)	1.59	1.22	1.54	1.22
VC incubation years from first round to last	5.68	2.79	4.79	2.61
First-round investment ($ mill.)	15.93	11.21	17.17	12.28
Total VC investment ($ mill.)	153.36	101.46	129.12	88.01
Probability of going public (%)	67.39	14.81	68.15	14.54
Probability of being acquired (%)	23.46	53.87	21.66	52.23
Probability of bankruptcy (%)	3.47	10.12	3.22	9.50
Firm age	10.84	7.90	10.02	7.82
VC age	15.72	14.62	15.23	14.59
VC size ($ mill.)	2765.36	2217.83	2787.85	2731.52
Observations	1466	8295	1501	8601

Table 3: Summary Statistics for VC Financing Patterns and Entrepreneurial Performance Based on Patenting Activities: By Industry Group

The sample includes all sample firms with CUSIP information that received VC investment between 1976 and 2005. The table reports summary statistics for VC financing patterns, including the number of investment rounds, number of syndicated VCs, VC duration in years from the first round to the next, VC incubation years (from first round to last round), first-round VC investment, total VC investment for all rounds, percentage of firms going public, probability of firms being acquired, and probability of failure (defunct or bankruptcy). We group all sample firms into six industries: biotech, communications and media, computer-related, medical/health/life sciences, semiconductor, and non-high tech. For each industry group, we divide sample firms into firms with and without patent filings within the 5-year window before the first round of VC investment

	Biotechnology		Communications /media		Computer related		Medical /health /life science		Semiconductors /other electronic		Non-high-technology	
Patent filing 5 years before VC investment	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Number of VC investment rounds	5.66	4.23	4.54	3.70	4.49	3.68	4.42	3.74	4.44	3.95	2.83	2.38
Number of VC investors	2.89	2.53	2.92	2.35	2.88	2.43	2.67	2.33	2.76	2.53	2.15	1.95
VC duration (years to next funding)	1.33	1.30	1.09	1.46	1.31	1.13	1.44	1.30	1.78	1.32	2.61	1.53
VC incubation years from first round to last	6.64	3.75	4.95	2.82	5.22	2.83	5.46	3.06	6.46	3.70	4.67	1.91
First-round VC investment ($ mill.)	13.23	9.65	21.33	16.74	15.23	9.16	10.86	8.47	8.35	13.72	56.48	13.55
Total VC investment amount ($ mill.)	202.51	149.59	232.41	186.23	136.35	104.87	133.31	83.25	111.09	105.13	122.16	44.01
Probability of going public (%)	7.82	6.98	14.11	5.31	14.69	3.51	15.57	7.00	17.78	5.52	19.59	7.77
Probability of being acquired (%)	23.25	44.31	28.83	54.43	21.67	58.42	21.69	46.35	17.22	55.68	29.72	39.83
Probability of bankruptcy (%)	2.32	4.76	4.91	9.92	5.94	8.07	2.35	7.99	1.11	8.93	2.03	10.06
Firm age	9.33	5.97	8.24	5.97	9.41	5.98	9.26	7.03	12.01	7.23	19.60	12.59
VC age	16.51	14.68	16.89	15.09	14.92	15.09	15.98	14.45	16.21	14.55	14.03	14.93
VC size ($ mill.)	2014.8	1630.3	2988.3	2068.2	2779.6	2066.8	1809.7	2381.8	4082.8	2482.9	3053.2	2496.5
Observations	172	422	163	1143	286	3446	212	1014	180	616	148	2504

Table 4: Impact of Innovation on Entrepreneurial Performance

The sample includes all sample firms with CUSIP information that received VC investment between 1976 and 2005. We use probit regressions in which the dependent variable is a dummy. In (1) and (4), the dummy is one if an IPO occurs, zero otherwise; in (2) and (5), the dummy is one if the firm is acquired, zero otherwise; and in (3) and (6), the dummy is one if the firm goes into bankruptcy, zero otherwise. The independent variables include a dummy equal to one if a company has patent filings within the 5-year window before the first round of VC investment, as well as the total number of patent filings prior to VC investment, number of VC rounds or VC investors, first-round VC financing, average round duration, total VC incubation years (from first VC round to last), firm age, and VC age. We control year and industry fixed effects and report heteroscedastically robust *t*-statistics in parentheses. In Panel B, we implement multinomial probit regressions with two instrumental variables, public firms' patent owning rate and public firms' patent counts, to control for endogeneity issue. We also report the likelihood ratio test (*p*-values in brackets) with the null hypothesis of uncorrelated errors in two equations.

	A. Probit			B. Multivariate probit		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent	IPO dummy	Acquired dummy	Bankrupt dummy	IPO dummy	Acquired dummy	Bankrupt dummy
Patent dummy (for patents prior to VC investment)	0.547***	-0.709***	-0.476***	0.561***	-0.823***	-0.528***
	(7.20)	(11.25)	(4.94)	(4.38)	(6.55)	(3.97)
Patents in the 5 years prior to first VC investment	0.000	-0.006**	-0.002	0.000	-0.006*	-0.001
	(0.95)	(1.96)	(1.04)	(1.24)	(1.75)	(0.56)
Number of VC investment rounds	-0.072***	-0.002	0.076***	-0.078***	0.003	0.081***
	(4.66)	(0.24)	(6.39)	(4.91)	(0.38)	(6.57)
Number of VC investors	-0.031**	0.011	0.016	-0.029*	0.012	0.013
	(2.03)	(1.16)	(1.30)	(1.89)	(1.34)	(1.06)
First-round VC investment amount	-0.040**	-0.036***	-0.009	-0.041***	-0.036***	-0.009
	(2.56)	(3.58)	(0.60)	(2.61)	(3.50)	(0.60)
Average round duration	-0.009	-0.030*	0.008	-0.007	-0.033*	0.019
	(0.33)	(1.77)	(0.28)	(0.25)	(1.95)	(0.65)
Total VC incubation period	0.019	-0.018**	-0.022*	0.021*	-0.015*	-0.028**
	(1.57)	(2.29)	(1.75)	(1.69)	(1.88)	(2.10)
Firm age	0.003	-0.011***	-0.007	0.003	-0.010***	-0.007
	(0.75)	(3.81)	(1.60)	(0.77)	(3.75)	(1.52)
VC age	-0.004	0.001	-0.002	-0.004	0.001	-0.002
	(1.33)	(0.48)	(0.85)	(1.37)	(0.54)	(0.85)
Constant	-2.165***	-0.909***	-2.532***	-0.871***	0.430*	-1.510***
	(8.27)	(7.75)	(9.17)	(2.86)	(1.80)	(4.85)
Fixed industry effect	Yes	Yes	Yes	Yes	Yes	Yes
Fixed year effect	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.15	0.09	0.06			
Dependent (endogenous regressor)				Patent dummy	Patent dummy	Patent dummy
Public firms' patent ownership				3.220***	3.239***	3.220***
				(9.51)	(9.52)	(9.51)
Public firms' patent counts				-0.129***	-0.131***	-0.129***
				(4.48)	(4.52)	(4.48)
LR test for uncorrelated errors				0.001	0.880	0.001
				[0.973]	[0.348]	[0.974]
Observations	5067	5839	5313	5810	5810	5810

Table 5: Impact of Innovation on VC Financing Patterns

The sample includes all firms with CUSIP information that received VC investment between 1976 and 2005. We use OLS regressions in which the dependent variable is the logarithmic number of (1) total VC funding amount of all rounds, (2) VC incubation years, and (3) the number of VC investors. The independent variables include a dummy equal to one if a firm has patent filings for 5 years prior to receiving the first VC investment, as well as the total number of patent counts, firm age, VC age, VC firm's average fund size in log, industrial market-to-book ratio and R&D-to-asset ratio. We control year and industry fixed effects and report heteroscedastically robust *t*-statistics in parentheses. In Panel B, we implement two-stage least squares regressions with two instrumental variables, public firms' patent owning rate and public firms' patent counts, to control for endogeneity issue. We also report the Hansen J-statistics for the validity of instrumental variables and the Chi-square test for the endogeneity of the patent dummy. *p*-values are reported in brackets.

	A. OLS			B. 2SLS		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent	Log of total VC funding amount (millions)	Log of VC incubation years	Log of investing VC number	Log of total VC funding amount (millions)	Log of VC incubation years	Log of investing VC number
Patent dummy (for patents prior to VC investment)	0.456*** (8.80)	0.356*** (10.71)	0.108*** (4.17)	2.189** (1.96)	3.152*** (3.25)	1.340** (2.06)
Patents in the 5 years prior to first VC investment	-0.000 (0.67)	0.001*** (2.99)	0.000 (0.36)	-0.002 (1.41)	-0.003 (1.53)	-0.001 (1.51)
Firm age	0.001 (0.36)	0.012*** (8.48)	-0.005*** (6.91)	-0.004 (0.99)	0.004 (1.18)	-0.008*** (3.90)
VC age	0.006*** (4.54)	0.002** (2.50)	0.000 (0.78)	0.005*** (3.34)	0.001 (0.84)	0.000 (0.01)
Log(VC size)	0.123*** (12.90)	-0.002 (0.42)	0.011*** (2.73)	0.113*** (9.16)	-0.021** (2.12)	0.003 (0.50)
Industrial market-to-book ratio	-0.006 (0.20)	-0.075**** (3.95)	-0.034** (2.09)	0.059 (1.11)	0.026 (0.57)	0.008 (0.28)
Industrial R&D/total assets	3.083*** (3.25)	-2.078*** (3.62)	0.726 (1.46)	4.226*** (3.33)	-0.423 (0.38)	1.356* (1.92)
Constant	-0.350 (1.19)	1.605*** (7.09)	0.649*** (4.88)	2.770*** (20.57)	1.284*** (11.58)	0.581*** (9.80)
Fixed industry effect	Yes	Yes	Yes	Yes	Yes	Yes
Fixed year effect	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.33	0.16	0.05			
Dependent (endogenous regressor)				Patent dummy	Patent dummy	Patent dummy
Public firms' patent ownership				0.460*** (2.86)	0.421*** (2.67)	0.394** (2.52)
Public firms' patent counts				-0.020*** (2.48)	-0.021*** (2.66)	-0.020** (2.54)
Hansen J-stat. for IVs				0.000 [0.990]	0.474 [0.491]	1.643 [0.200]
Chi-sq test for endogenous patent dummy				2.849* [0.092]	21.652*** [0.000]	5.500** [0.019]
Observations	6726	6980	6965	6670	6918	6903

Table 6: VC Financing Patterns and Entrepreneurial Performance of VC-backed Firms without CUSIP

The sample includes all firms without CUSIP information that received VC investment between 1976 and 2005. The table reports summary statistics for VC financing patterns, including the number of investment rounds, number of syndicated VCs, VC duration in years from the first round to the next, VC incubation years (from first round to last), average investment in the first round, total VC investment for all rounds, percentage of firms going public, probability of firms being acquired, and probability of failure (becoming defunct or bankruptcy). Column A reports the information on the firms with and without patent filing within the 5-year window before the first round of VC investment. Column B reports the information on the firms with and without patent filing within the11-year window centered in the year receiving the first round of VC investment.

	A. Patent filing from -5 to -1 years from the first VC investment		B. Patent filing from -5 to +5 years around the first VC investment	
	Yes	No	Yes	No
Number of VC investment rounds	1.14	1.11	1.13	1.10
Number of VC investors	2.78	2.45	2.54	2.22
VC duration (years to next funding)	1.88	1.54	2.54	1.42
VC incubation years from first round to last	2.63	2.26	2.74	1.48
First-round investment amount ($ mill.)	2.16	1.66	2.57	1.48
Total VC investment amount ($ mill.)	10.45	8.14	6.76	6.52
Probability of company going public (%)	2.57	1.61	1.78	1.70
Probability of company being acquired (%)	8.11	11.02	8.98	12.53
Probability of company subsequently fails (%)	9.50	18.35	11.98	20.93
Firm age	6.05	4.20	3.60	4.34
VC age	14.88	14.76	14.19	13.62
VC size ($ mill.)	1067.69	1234.38	1052.38	1147.61
Observations	1441	14113	2911	11396

Table 7: Summary Statistics for VC Financing Patterns and Entrepreneurial Performance Based on Patenting Activities: By Financing Stage

The sample includes all firms with CUSIP information that received VC investment between 1976 and 2005. The table reports summary statistics for VC financing patterns, including the number of VC investment rounds, number of syndicated VCs, VC duration in years from first round to next, total incubation years, first-round VC investment, total VC investment for all rounds, percentage of firms going public, probability of firms being acquired, and probability of failure (defunct or bankruptcy). We group all sample firms into four financing stages: start-up/seed, early stage, expansion stage, and later stage. For each stage group, we divide sample firms into firms with and without patent filings within the 5-year window before the first round of VC investment.

	Start-up/seed		Early stage		Expansion		Later	
Patent filing 5 years before VC investment	Yes	No	Yes	No	Yes	No	Yes	No
Number of VC investment rounds	2.75	1.75	3.11	2.03	4.06	3.61	5.15	4.66
Number of VC investors	1.81	2.14	2.16	2.05	2.58	2.40	2.98	2.64
VC duration (years to next funding)	1.44	0.90	1.09	1.08	1.38	1.14	1.44	1.21
VC incubation years (from first round to last)	3.44	1.23	2.75	1.38	5.51	3.29	5.17	4.13
First-round investment ($ mill.)	2.26	2.54	4.86	5.60	11.36	8.67	10.32	10.04
Total VC investment amount ($ mill.)	50.65	12.90	37.39	32.10	152.83	109.04	214.31	183.46
Probability of company going public (%)	61.29	10.34	79.29	9.71	73.32	11.51	79.04	19.13
Probability of company being acquired (%)	22.58	51.72	12.19	62.22	19.69	58.77	14.66	53.71
Probability of company failure (%)	3.32	12.58	4.88	8.06	2.19	10.07	3.14	10.05
Firm age	4.07	2.86	5.20	4.26	9.07	7.24	6.65	7.42
VC age	7.69	12.65	15.23	12.77	15.97	15.02	15.10	15.38
VC size ($ mill.)	2527.45	1869.45	2991.18	1635.43	1688.50	1978.73	1720.35	2193.84
Observations	33	493	82	1154	320	3466	191	1333

Table 8: Information Asymmetry and Patenting Activities

The sample includes all firms with CUSIP information that received VC investment between 1976 and 2005. We use OLS regressions in which the dependent variables are the percentage of VC-backed start-up firms with patent records in each industry for (1) and (2) and the logarithmic number of patent counts of VC-backed start-up firms in each industry. The independent variables include the return residual volatility from the CAPM and the Fama-French three-factor model, the logarithmic number of patent counts of VC-backed start-up firms in each industry in the prior year, industrial VC investment in the prior year, industrial market-to-book ratio, and industrial R&D-to-asset ratio. We report heteroscedastically robust *t*-statistics in parentheses.

Dependent	A. Percentage of VC-backed start-up firms with patent records at the industry level		B. Log (1 + the number of patents of VC-backed start-up firms at the industry level)	
	(1)	(2)	(3)	(4)
Volatility of daily return residuals from CAPM	8.45***		35.19*	
	(5.22)		(1.88)	
Volatility of daily return residuals from Fama-French three-factor model		9.17***		24.30*
		(5.63)		(1.76)
Log(1+The number of patents filed by VC-backed start-up firms at the industry level in the prior year)	0.02***	0.02***	0.54***	0.55***
	(5.01)	(5.51)	(7.34)	(7.76)
Prior industrial VC investment	-0.02***	-0.02***	0.15***	0.144***
	(6.16)	(6.40)	(2.35)	(6.74)
Prior industry market to book ratio of industry	-0.01*	-0.01**	-0.06	-0.05
	(1.77)	(2.13)	(0.54)	(0.47)
Prior industrial RD/total assets	0.42***	0.35***	1.89	1.92
	(3.79)	(2.67)	(1.00)	(0.99)
Constant	0.11	0.13	2.19	2.25
	(6.65)	(7.27)	(6.21)	(6.78)
R^2	0.49	0.49	0.54	0.57
Observations	154	154	154	154

Table 9: Impact of Innovation and Information Asymmetry on Entrepreneurial Performance

The sample includes all firms with CUSIP information that received VC investment between 1976 and 2005. We use probit regressions in which the dependent variable is a dummy for IPO, being acquired, or bankruptcy. The independent variables include information asymmetry (industry portfolio's prior residual volatility from the Fama-French three-factor model), a dummy equal to one if a firm has patent filings for 5 years prior to receiving the first VC investment, as well as the total number of patent counts, and other control variables. We also report heteroscedastically robust *t*-statistics in parentheses. In Panel B, we implement multinomial probit regressions with two instrumental variables, public firms' patent owning rate and public firms' patent counts, to control for endogeneity issue. We also report the likelihood ratio test (*p*-values in brackets) with the null hypothesis of uncorrelated errors in two equations.

	A. Probit			B. Multivariate probit		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent	IPO dummy	Acquired dummy	Bankrupt dummy	IPO dummy	Acquired dummy	Bankrupt dummy
Information asymmetry	-46.856*	40.177***	-34.641	-49.060*	40.253***	-34.091
	(1.65)	(2.79)	(1.15)	(1.65)	(2.79)	(1.13)
Patent dummy (for patents prior to VC investment)	0.555***	-0.715***	-0.473***	0.545***	-0.619***	-0.515***
	(7.33)	(11.35)	(4.91)	(4.30)	(4.37)	(3.70)
Patents in the 5 years prior to first VC investment	0.000	-0.006*	-0.002	0.000	-0.006*	-0.001
	(0.83)	(1.92)	(1.05)	(1.28)	(1.75)	(0.57)
Number of VC investment rounds	-0.071***	-0.003	0.076***	-0.077***	-0.003	0.081***
	(4.60)	(0.34)	(6.43)	(4.85)	(0.36)	(6.60)
Number of VC investors	-0.031**	0.010	0.016	-0.028*	0.010	0.013
	(2.10)	(1.13)	(1.31)	(1.85)	(1.08)	(1.06)
First-round VC investment amount	-0.041**	-0.036***	-0.009	-0.041***	-0.036***	-0.009
	(2.47)	(3.54)	(0.60)	(2.61)	(3.57)	(0.60)
Average round duration	-0.008	-0.032*	0.010	-0.005	-0.035**	0.021
	(0.33)	(1.87)	(0.34)	(0.20)	(2.06)	(0.70)
Total VC incubation period	0.018	-0.017**	-0.022*	0.021*	-0.018**	-0.028**
	(1.61)	(2.17)	(1.78)	(1.67)	(2.20)	(2.14)
Firm age	0.002	-0.010***	-0.007	0.002	-0.010***	-0.007
	(0.63)	(3.77)	(1.61)	(0.76)	(3.78)	(1.53)
VC age	-0.004	0.001	-0.002	-0.004	0.001	-0.002
	(1.21)	(0.46)	(0.86)	(1.37)	(0.55)	(0.86)
Constant	-1.945***	-0.935***	-2.397***	-0.450	0.087	-1.221***
	(6.00)	(7.95)	(8.23)	(1.16)	(0.33)	(2.98)
Fixed industry effect	Yes	Yes	Yes	Yes	Yes	Yes
Fixed year effect	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.15	0.09	0.06			
Dependent (endogenous regressor)				Patent dummy	Patent dummy	Patent dummy
Public firms' patent ownership				3.220***	3.197***	3.220***
				(9.51)	(9.33)	(9.51)
Public firms' patent counts				-0.129***	-0.128***	-0.130***
				(4.48)	(4.42)	(4.48)
LR test for uncorrelated errors				0.041	0.631	0.005
				[0.840]	[0.427]	[0.944]
Observations	5067	5839	5313	5810	5810	5810

Table 10: Impact of VCs on Patenting after First-Round VC Financing

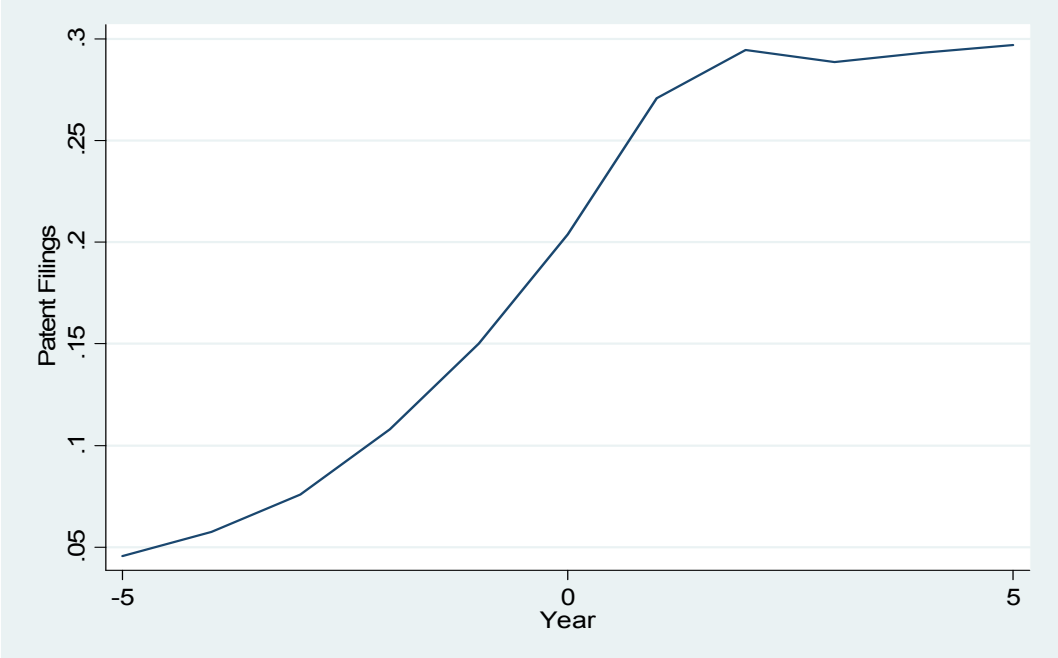
The sample includes all firms with CUSIP information that received VC investment between 1976 and 2005. We implement OLS regressions in which the dependent variable of Panel A is the VC investee's patent counts in the five-year window after first-round VC financing (year 1 to year 5) minus its patent counts in the five-year window before first-round VC financing (year -5 to year -1). The dependent variable in Panel B is the difference scaled by firm size (investee total capital). The independent variables include the first-round VC investment amount, the number of VC investors, firm age, VC age, VC size in log, a dummy equaling one if the firm has no patent record prior to receiving VC investment, and the patent counts for 5 years prior to receiving first-round VC investment. We control year and industry fixed effects and report heteroscedastically robust *t*-statistics in parentheses.

Dependent	A. Increase in patents from 5 years prior (year -5 to -1) to 5 years after receiving first VC investment (year 1 to 5)		B. Increase in patents adjusted by firm size	
	(1)	(2)	(3)	(4)
VC first-round investment amount	-0.067***	-0.159***	-0.029*	-0.051*
	(5.77)	(4.89)	(1.65)	(1.75)
Number of VC investors		-0.602		-1.068
		(1.34)		(1.63)
Firm age	-0.054	-0.038	0.179*	0.220*
	(0.77)	(0.47)	(1.86)	(1.66)
VC age	-0.145***	-0.131	-0.138*	-0.133
	(2.76)	(0.75)	(1.89)	(1.22)
Log(VC size)		-0.000		-0.000
		(1.05)		(0.41)
Dummy (having no patent prior to VC investment)	7.297***	6.308**	-2.228	-2.278
	(3.55)	(2.59)	(0.58)	(0.53)
Number of patents in the 5 years prior to VC investment	1.063***	1.415***	0.481***	0.598***
	(64.32)	(76.13)	(23.17)	(20.06)
Constant	-4.882	15.057	3.531	37.982
	(1.51)	(1.30)	(0.80)	(3.33)
Fixed industry effect	Yes	Yes	Yes	Yes
Fixed year effect	Yes	Yes	Yes	Yes
R^2	0.37	0.86	0.06	0.09
Observations	9051	5867	9051	5867

Figure 1: Year Average of Patent Counts Before and After Receiving First-Round VC Financing

The sample includes all firms (with and without CUSIP information) that received VC investment between 1976 and 2005. Panel A reports the average patent counts from [-5, +5] year centered in the year of receiving first-round VC investment for all VC-backed firms; Panel B reports the average patent counts from [-5, +5] year centered in the year of receiving first-round VC investment for VC-backed firms with patent records prior to VC financing.

Panel A: Full sample



Panel B: Subsample of firms with successful patent application(s) before receiving first-round VC funds