A comparison of the effect of angels and venture capitalists on innovation and value creation[1]

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Abstract: We examine the influence of private equity, in particular angel groups and venture capital (VC) investments, in shaping the innovation of technology ventures and in realizing successful exits. We consider the theoretical and empirical implications of angel group investment and isolate the separate influences of angels and VCs towards a venture's innovation strategy and successful exit, revealing striking insights about their relative contribution. We do so by tracking 350 technology ventures that receive angel group and VC investment. The methodologies employed econometrically control for identification issues in the dynamic multi-stage nature of external capital financing.

1. INTRODUCTION

Entrepreneurs launching technology-based ventures face considerable risks as they innovate while assessing technological feasibility, business model credibility, and product or service viability. These early-stage entrepreneurial risks severely limit capital sources, yet angel investors and venture capitalists fill this need by assuming risk alongside company founders in exchange for an equity stake in the company. Capital infusion is one important way private equity fuels innovation that would not otherwise occur. A second way private equity investors might fuel firm innovation is by actively engaging founders through strategic counsel around development and production, and connecting them to key management talent. Accordingly, private equity is believed to provide more than just money to technology entrepreneurs. In this paper, we investigate whether private equity does, in fact, impact firm-level innovation beyond mere capital infusion. Our emphasis is on assessing whether contributions to innovation due to active engagement differ between angels and venture capitalists (VCs).

Examining the relative impact of angels and VCs on innovation is worthwhile in several respects. Both have a high concentration of their total investment in seed and early-stage ventures, where the risks associated with innovation are highest. In 2013, 91 percent of all angel investment and 35 percent of all venture capital was invested (and 55.6 percent of all deals) in seed and early stage ventures. It seems entrepreneurs increasingly have a choice between sources of private equity, so understanding the relative contribution to innovation has considerable practical importance.[1] Of course, in many cases investment by angels or VCs might be viewed as complements, occurring simultaneously, or sequenced where VCs invest subsequent to angels. In these cases it is also important to distinguish how each contributes to venture innovation, empiricists accounting for one type of private equity without accounting for the other risks misstating the true effect on innovation. This has important implications for how we interpret prior empirical research that has focused exclusively on how venture capital contributes to innovation without considering angel contributions. Finally, there may be theoretical reasons to expect a difference between how angels and VCs contribute to innovation. Dissimilarities on such issues as board involvement, investment structure, exit requirement, and ownership control might inspire varying degrees or effectiveness of active involvement in ventures.

There are a number of empirical challenges to overcome to address our research question. A focus on angels invites consideration of the full spectrum of different types of angel investors, ranging across wealthy individuals, former or existing entrepreneurs, or executives with or without pertinent industry experience, and those organized into angel groups.[2] Unfortunately, there is a lack of data capturing this heterogeneity. Currently, the only data available is that collected by angel associations from angel groups and networks (OECD, 2011). To overcome this limitation, we focus on an available sample of technology ventures funded by angel groups. This focus compromises generalizability of our findings, and may bias the results against finding differences because angel groups are thought to be similar to early stage VCs along several dimensions (OECD, 2011). It has the advantage, however, of a conservative test. Moreover, it is a test worth undertaking because the angel investment sector is not only growing, but is becoming increasingly more formalized and organized through groups (Ibrahim, 2008) to leverage economies in due diligence, investment scale and staging, networks, and capability. These are economies typically enjoyed within venture capital firms. Our analysis compares innovation in early-stage venture capital backed firms with angel-group backed firms.

Another empirical challenge is in measuring the effects on innovation. This challenge has two dimensions. On both dimensions we follow precedent. First, we follow precedent in measuring innovation through patenting rates and patent citations, the latter of which accounts for the importance of the patent. Specifically, Kortum and Lerner (2000) apply patent count and citation per patent measures to examine the impact of venture capital funding on innovation at industry level, and Lerner et al. (2011) use count measure of forward citations to analyze the long run effect of private equity investments on innovation. While our approach is consistent with the prior studies, we recognize that patents may not be a comprehensive measure of innovation, and discuss this limitation later. Patents have the advantage, however, of being covered by virtually every field of innovation. Moreover, they have long been used to construct indicators that serve as proxies for the value of innovation. Therefore, we adopt this practice to distinguish the value of innovation from commercialization, which is one way to exercise value.

The second dimension of the challenge is distinguishing whether innovation effects are due to active contributions by investors through their value-added services to ventures subsequent to investment. We will refer to active contributions as a "treatment" effect and investment as a selection effect. Selection effects might drive the relationship if certain investors are able to pick better ventures. For example, we might observe that VCs contribute more to innovation than angels because VCs conduct more rigorous due diligence. Samila and Sorenson (2011) argue that firm-level studies could overestimate the benefits of VC if it is merely a VC selection issue. Treatment effects might drive the relationship if the investor facilitates the innovation process through endorsement, networks, or governance. We are interested in examining treatment effects, and our theoretical and empirical analysis gives this special consideration. To control for the possibility that VCs or angels may merely fund better-quality firms, which then go on to subsequently innovate more voraciously (in other words, to address any potential endogeneity or selection issues related to private equity backing), we employ two alternative methodologies.[3] The first approach is a difference-in-differences estimation used to measure the changes in venture innovation induced by either angel or VC backing. It enables us to measure the effect of angels and VCs on patents at a given period of time before and after investment, while controlling for firm and calendar year effects. The second approach is a "switching regression" methodology to control for unobservable characteristics that affect both the likelihood of receiving VC investment (selection effect) as well as ventures' innovation outcome. We use the switching regression results to perform a counterfactual analysis that answers the questions: How would VC-backed ventures innovate if they had not received venture capital but had only received angel funding, and how would angel-backed ventures innovate if they have not received angel funding but had received VC funding?

We believe our results have important policy and managerial implications for technical entrepreneurs seeking to understand the relative impact of angels and VCs in catalyzing innovation. In the next section, we discuss the existing research linking private equity and innovation, and present a theoretical rationale for why angel groups and VCs might differentially influence innovation in their ventures.

2. PRIVATE EQUITY AND INNOVATION

A focus on understanding the relative contributions of VCs and angel groups to innovation should be important for entrepreneurs of early-stage technology ventures. Such ventures are notable for the amount of cash they require to move from inception to their early stages, and rely heavily on capital provided by angels and VCs. Traditionally, angel investors were thought to fill the niche between friends and family financing, and formal venture capital investors. Increasingly it is recognized that the investment process is not necessarily as linear as was presumed in the past (OECD, 2011). This is partly because of the growth of angel groups, which tend to invest at a slightly later stage of venture development than traditional angels because they can pool their resources, facilitating the larger investment often required later in a firm's development. It may also be because VCs have dramatically shifted their proportion of investment allocated to early-stage ventures, and the proportion of deals has increased from 19.5 to 55.6 percent between 2002 and 2013.[4] Consequently, angel groups and early stage VCs tend to invest at the same stage of venture development (Ibrahim, 2008).

When entrepreneurs in technology ventures can choose to source capital either from angel groups or early stage VCs, their choice might be guided by the terms of the financial offering, or by the value-added services each may offer. VCs and angel groups are believed to offer a number of value-added services that may spur innovation and commercialization. For example, private equity investors might use their networking skills to recruit professional managerial talent and advisory board members. Klausner and Litvak (2001) report that eBay was a profitable start-up that did not require outside funding, yet it sought capital from venture capital firm Benchmark Partners to leverage its connections to secure a seasoned CEO and other executives. Private equity investors are also thought to create value by providing decision-making expertise, facilitated by the fact that most have successful experiences in industry as scientists, engineers, physicians, or entrepreneurs. Sometimes, investors are granted a seat on the board of directors, enabling them direct involvement in venture decisions around recruiting, product development, and production. Even if the actions of investors do not affect venture innovation, it may be that their investment provides an indirect benefit by signaling venture quality, enabling the venture to better attract partners or managerial talent.

The expectation that private equity investors contribute to venture innovation has inspired researchers to investigate, and these efforts have several features. First, they focus exclusively on how VCs contribute to innovation, at the exclusion of angels or angel groups. Second, they differ on whether they provide evidence at the industry or firm level. Finally, they differ in the extent to which they disentangle whether innovation effects are tied to the value-added services of private equity investors (the treatment effect), or the investment decision (the selection effect).

Several studies report higher innovation rates in industries or regions corresponding to higher VC investment. For example, Kortum and Lerner (2000) show that in the US, an industry's aggregate VC investment level is tied to its patenting rate, after controlling for technological opportunity.[5] Popov and Roosenboom (2012) use a similar approach to study patenting rates in European industries and regions, and conclude there is a weak link with VC investment.[6] Samila and Sorenson (2011) demonstrate that aggregate regional VC investment influences patenting rates in US metropolitan areas.[7]

There has been much research at the firm level of analysis, investigating whether VC involvement is tied specifically to a venture's innovation. For example, Kortum and Lerner (2000) confirm a correlation with VC investment and patenting rates in 530 Middlesex County ventures, although this effort did not attempt to distinguish between treatment and selection effects. Engel and Keilbach (2007) confirm a weak relationship between VC investment and higher patenting rates in German ventures, believing their results suggest a treatment affect (of value-added services) because they control for selection effects by matching VC-backed ventures to non-VC-backed ventures identical on certain observable attributes (i.e., industry, patent count prior to investment, and location) using semi-parametric estimation of the nearest neighbor match. It is worth noting, however, that a serious limitation of the semi-parametric matching estimation is that it does not account for any unobservable heterogeneity that may influence VC investment. VCs consider multiple factors (some of them are tacit) before making investment decisions and therefore a matching technique based on some observable factors may not suffice as an effective control for VC selection effect. A recent work by Lerner et al. (2011) provide evidence that private equity backed leveraged buyouts (LBOs) pursue more influential innovations as measured by the number of patent citations received in the years after private equity investment.

Despite the lack of firm level analysis on the link between private equity and venture innovation, there is some research pointing toward significant effects of value-added services on other dimensions of venture success. Again, this evidence is more abundant for VCs than angels. Below we outline this evidence, first for VCs and then angels, and outline a theory to explain why we should expect significant treatment effects on innovation, before we test whether the treatment effects are significantly different from one another.

2.1 VENTURE CAPITALISTS AND VALUE-ADDED SERVICES

The literature highlights three broad streams of research that explain how VCs may augment innovation or enhance the likelihood of commercialization.

VC's role as a quality signal and information intermediary. VCs are active investors with an extended network providing industry information and contacts that are critical for early stage ventures to establish a foothold in the industry (Sorenson and Stuart 2001). This stream argues that the involvement of VCs serve as a quality signal, which increases venture visibility and reduces the cost to search for potential partners. Scholars have found that the endorsement effects of VCs make VC-backed ventures better able to attract research and commercial partners (Hsu, 2006) and human capital (Hellmann and Puri, 2002) than non-VC-backed ventures. Moreover, there is some evidence that endorsement effects are more pronounced when ventures are in earlier stages (Stuart et al., 1999), where innovation is critical. In addition, VCs also act as information intermediaries, providing privileged information access to ventures seeking appropriate resource partners (Gans et al., 2002). In a similar vein, Burt (1992) and Lindsey (2002) suggests that the information advantage obtained from VC backing provides access to potential partners that allow ventures to form more strategic alliances. VC-backed ventures' ability to garner enhanced cooperation from potential partners and increased visibility suggests that VC-backed ventures may develop higher quality innovations that are cited more frequently and thus have a higher economic value. Shan et al. (1994) and Baum et al. (2000) find evidence that cooperative alliances are linked to ventures' innovation output.

VC's role in governance. A second stream emphasizes VCs role in governing their ventures through efficient contract covenants and board membership, which facilitates the establishment of a formal structure and monitoring of firm activities (Sahlman, 1990). Since VCs possess strong business acumen and actively participate in a range of functions that span industrial segments, they are more likely than founders or internal directors of the venture to be aware of potential threats and opportunities in the business environment (Hsu, 2006). The impact of VC governance is profound when ventures are in their early stages where perceived risk is high. Sapienza (1992) provides empirical support showing that VCs intensify their governance effort by increasing their interactions with founders in the early stages of development. Similarly, Giot and Schwienbacher (2007) show that location proximity between the VC and the ventures helps VCs to better assist and monitor the venture. Baum and Silverman (2004) suggest that while VCs consider factors like patenting rates, alliance formation, and human capital to make investment decisions, they also provide mentorship to enhance ventures' intellectual capital and overall performance. Implementation of an efficient governance mechanism by securing board membership and enforcing control right covenants bestows significant decision making rights to

VCs that influence the ventures' economic value, for example the timing of commercialization and the mode of commercialization through IPO or acquisitions. To this effect, empirical evidence shows VC-backed ventures have faster growth (Chemmanur et al., 2011) and a higher likelihood of commercialization through an IPO (Hsu, 2006; Shane and Stuart, 2002).

VC's as financial intermediary. A final way in which VCs may affect innovation and commercialization is through the incentives to exit in a stipulated time frame (Berglöf, 1994), which may expedite the development process. VCs are structured as financial intermediaries who have to generate returns from their fund and exit within a stipulated time frame. While the time-oriented nature of the VC market may make them less tolerant towards early innovation failures (e.g., Tian and Wang, 2013), the disciplined approach to exit in a timely fashion may spur innovation intensity and shorten the commercialization duration of VC-backed ventures. Hellmann and Puri (2000) found empirical evidence that VC financing is associated with a significant reduction in the time taken to bring a product to market.

2.2 ANGELS AND ADDED-VALUE TO VENTURE INNOVATION

Unfortunately, there exists no evidence at the industry or firm level about whether angels influence venture innovation. However, Kerr et al. (2011) examine ventures soliciting funds from two angel groups, and find that funded ventures have a higher likelihood of survival compared to those unable to secure angel investment.[8] Below, we develop theoretical arguments about the relative contributions of angels and VCs to innovation.

Angel's role as a quality signal and information intermediary: Similar to VCs, angel backing may provide an early endorsement of quality that alleviates uncertainty around the initial stages of technology development (OECD, 2011; Elitzur and Gavious, 2003). Evidence from field interviews and surveys reveals that similar to VCs, angel-group members are active investors with industry networks that facilitate the recruitment of human capital (Politis, 2008). Shane and Stuart (2002) argue entrepreneurs' network that includes angels and VCs enhance their ability to acquire support from resource holders that can have a significant effect on venture performance.[9]

Angel's role in governance: In contrast to VCs, angels generally have a flexible control mechanism and prefer to adopt an informal hands-on approach instead of board membership (Ibrahim, 2008). Active angels possess strong industry knowledge about the technology, the commercialization process, and their prior entrepreneurial experience provides valuable guidance to shape venture development (Shane, 2008; Politis, 2008). While both angels and VCs offer mentorship roles in venture development, the flexible control mechanism adopted by angels may create an environment where entrepreneurs work alongside angels that may eventually increase venture innovation. Studies reveal that the stringent control rights imposed by VCs may create a conflicting environment between VCs and entrepreneurs, and it occurs frequently in technology-intensive ventures (Sapienza, 1992). However, a flexible control mechanism may also provide challenges to the establishment of an efficient governance structure, affecting the type of innovation pursued by technology ventures and the likelihood of commercialization.

Angels as direct investors: Angels employ their own capital in funding ventures, unlike VCs, and do not have the time-oriented performance-based compensation (i.e., 2% management fees and 20% carried interest) omnipresent in the VC market. This basic economic distinction in the funding structure suggests that there may be differences in the incentives for and challenges to direct angel funding and indirect VC funding, which in turn may create differences in how angels and VCs nurture innovation. Unlike VCs, angels have the flexibility to extend investment cycles (Freear et al., 1994), which might enhance ventures' long-term innovation. While this may allow angels to show higher tolerance for early innovation failures compared to VCs, it may increase the time and effort required by angels to develop and commercialize ventures' innovation.

Similarities and differences between angels and VCs bear on their relative contributions to venture innovation, and ultimately whether these differences influence the time and likelihood of commercialization. The theoretical arguments suggest that the relative ability of angels and VCs to nurture innovation may be complementary or substitutive and warrants an empirical justification of the question.

3. DATA, METHODS, AND VARIABLES

3.1 DATA

Ascertaining whether angels and VCs differentially influence venture innovation is challenging on a number of dimensions. First, it requires observing innovation for each venture over time, which we accomplish by matching venture names to patent data.[10] Second, it requires a longitudinal sample of three types of private equity backed ventures: (a) those receiving angel funding; (b) those receiving VC funding; and (c) those receiving both angel and VC funding. To our knowledge, no such sample exists. The data collection effort is described below.

Angel-group-backed ventures. The sample of angel-group-backed ventures originates from the *Angel Investment Performance Project* (AIPP) survey (Wiltbank and Boeker, 2007), the largest available data on angel group investors in North America, funded by the Ewing Marion Kauffman Foundation. It was collected in 2007 from 539 investors representing 86 angel groups and 1,137 exits from their investments.[11] Data were collected online through a questionnaire that asked for information regarding the investor's experience, the ventures in which they had invested, and details about their investment in and exit from those ventures. 276 angel groups were originally contacted and asked to distribute a survey to their members. Eighty-six of these groups (31 percent) participated, and thirteen percent of the members of the eighty-six groups completed the survey. Although the AIPP data is collected at the investor level, we use the survey to obtain venture-level data. Since the ventures are anonymous in the publicly available data, we obtained them directly from the authors. 433 separate ventures were listed in the AIPP survey, but we focused only on the 218 technology-based ventures, as indicated by their presence in one of the following SIC Codes: drugs (SIC 283), industrial machinery and equipment (SIC 35), electronic and electrical equipment (SIC 36), scientific instruments (SIC 38), and computer programming, data processing, and other computer related services (SIC 7371, 7372, 7373). This set of industries is similar to the study by Hsu (2006), which focused on VC-backed ventures. The sample was further reduced to 137 after deleting ventures that were based in Canada, spin-offs, or otherwise had incomplete information.[12]

We compared the list of 137 angel-group-backed ventures with Thomson One VentureXpert and found that 58 ventures also received VC investment in the seed/early stage of the venture. The information from the AIPP Kauffman survey and VentureXpert helps us to identify the timing of each investment. Out of the 58 ventures, 39 ventures received the VC investment in the same year they received angel-group investment, 14 ventures received VC investment in the year following the angel-group investment, and 5 ventures received VC investment within 2-3 years after the angel-group investment.

VC-backed ventures. Using the 137 angel-group-backed ventures as a starting point, we sought to develop a representative sample of pure VC-backed ventures from the Thomson One *VentureXpert* database that received the VC funding in their seed/early stage and were comparable to angel-group-backed ventures along a number of dimensions. We adopted the matching hierarchy technique employed by Hsu (2006), wherein ventures were matched by industry 3-digit SIC, year of initial funding, and the founding year. If no match was found using all three criteria, the founding year criterion was dropped. The funding year and SIC industry match was always retained, otherwise, no match was declared. This enables us to control for heterogeneity due to industry effects, time effects, and venture development cycle effects. We adopted an iterative search process to ensure that the ventures sampled are only VC-backed, without angel-group involvement, leading to the identification of 213 pure VC-backed ventures.[13]

The sample selection and the identification process yielded a dataset of 350 ventures - 137 angel group backed ventures out which 58 ventures also received VC funding in the seed/early stage, and 213 pure VC-backed ventures. The sources used to isolate these ventures included information about financing amounts and investment year. To obtain other venture level information we matched venture names to patent data, and other sources yielding information about founding year, exits (IPOs, acquisitions, or bankruptcy), and venture location, which were used to generate control variables, defined in the Appendix.[14] From this information we created an unbalanced panel dataset with observations for each venture running from the founding year through 2010 or until venture termination. Since the most recent founding year is 2006, we are able to construct a risk set for patents filed until 2010.

3.2 DEPENDENT VARIABLES

Venture Innovation. We identify all patents associated with ventures. The innovation measures are based on patent application year (i.e. the year in which the patent application is filed) since it is closer to the time of the actual innovation (e.g., Griliches et al., 1987). *Patent count* is measured as the number of patent applications filed (and subsequently granted) by the venture in a particular year. To capture the importance of each patent, we construct two measures of innovation quality based on forward-citation counts. Following Hall et al. (2001, 2005), the citation truncation problem is corrected using citation-lag distribution. Consistent with the literature, we use two variables, (1) *citation per patent* defined as average number of forward citations each patent receives in subsequent years, and (2) *forward 4-year citation* defined as the number of forward citations within four years of filing for all patents filed in a given year. The forward 4-year citation measure is constrained for patents filed before December 2008, to observe forward citations received until 2012. Natural log transformation is used to counter the right-skewness of the variables. For our sample of 350 firms we observe 2107 patents.

Exit and time to exit. Two types of exits are observed: IPOs and acquisition. *Success* is coded as "1" for the year in which the venture exits either through IPO or acquisition, and "0" otherwise. We also distinguished between exits by *IPO* and exits by *Acquisition*.

Summary statistics and univariate analysis. Table I, panel-A provides the summary statistics of the ventures. The average angel-group-backed venture was founded in year 2001 and received its first funding 19 months later. The average VC-backed venture was also founded in year 2001 and received its first investment 17 months later. The industrial representation of the ventures in the sample is fairly typical of the broader set of industries funded by VCs. Of the sampled firms, ventures in computer programming and software had a higher proportion of representation.[15]

Table I, panel-B reports the means of our variables across different types of private equity backed ventures. Columns 2-4 report means for ventures backed by angel groups, both angel groups and VCs, and VCs only, respectively. Columns 5 and 6 report significant differences across these different types of ventures. While angel-group-backed ventures have significantly lower values for *patent count*, *citation per patent*, and *forward 4-year citation* compared to ventures backed by both angel group and VCs, there is no significant difference in innovation measures between VC-backed ventures and ventures backed by both angel group and VCs. We next implement multivariate tests to control for unobserved heterogeneity, and to assure that attempts to isolate an investor's ability to impact (or treat) venture innovation and survival are not confounded with an investor's ability to select ventures.

[Insert Table I, panel A and B about here]

3.3 MULTIVARIATE METHODS AND RESULTS

We exploit the data with two different methodologies commonly used to disentangle selection effects from treatment effects and the specification includes firm and year fixed effects.

3.31 Difference-in-differences estimation. We document the dynamic pattern of venture innovation changes from four years prior to the VC investment year and five years after the VC investment year, benchmarked against ventures without VC investment (but receiving angel group investment), and attempt to distinguish between the impact on innovation arising from selection effects prior to funding and that arising due to the treatment effects of VCs subsequent to funding. We implement this approach through the following regression specification:

$$Ln\left(Y_{i,t}\right) = \alpha + \beta_k \sum_{k-1}^{4} Before_{i,t}^{k} + \eta_k \sum_{k-1}^{5} After_{i,t}^{k} + \gamma_{i,t} Ln\left(cumm.\, dollar\ inflow_{i,t}\right) + \mu_t\left(Year(t)\right) + \delta_i\left(Firm(i)\right) + \varepsilon_{i,t} \quad (1)$$

where *i* indexes ventures and *t* indexes time. $Ln(Y_{i,t})$ is the natural log of the dependent variable (venture innovation). $Ln(cumm.\ dollar\ inflow_{i,t})$ is the natural log of the cumulative dollar ($Mn) investment received by the venture until year *t*. *Year(t)* and *Firm(i)* captures year and firm fixed effects. The independent variables include the event-time dummies around the year of first VC investment that capture residual changes in innovation around the first VC investment year (base year). The variable $Before^{k}_{i,t}$ takes the value of '1' if the venture receives VC investment and the observation is *k* years prior to the first VC investment year (*k* = 1, 2, 3, or 4), and '0' otherwise.

Similarly, $After^{k}_{i,t}$ is equal to '1' if the venture receives VC investment and the observation is k years after the first VC investment year (k = 1, 2, 3, 4, or 5), and '0' otherwise. The benchmark, or control sample, consists of angel-group-backed ventures where $Before^{k}_{i,t}$ and $After^{k}_{i,t}$ is always 0. Standard errors are clustered at the firm level.[16]

The specification controls for fixed differences between VC-backed and angel-group-backed ventures via the firm fixed effects. The coefficient estimates of the event-time dummies reflect the difference in innovation between VC-backed and angel-group-backed ventures with respect to the first VC investment year (base year). If it is the VC treatment effect that enhances the innovation of the ventures, we should observe that VC-backed and angel-group-backed ventures exhibit a similar innovation trend prior to the first VC investment year (the parallel trends assumption) and a significant jump in innovation for VC-backed ventures after the first VC investment year. If, however, VCs only have superior abilities in selecting more innovative ventures instead of being better able to catalyze innovation, VC-backed ventures should show a higher level of innovation compared to angel-group-backed ventures, even before the first investment year and should not exhibit a significant jump in venture innovation compared to angel-group-backed ventures after the first VC investment year. Therefore, the difference-in-differences estimation effectively separates selection from treatment effects.

3.32 Difference-in-differences analysis. In Table II, the dependent variables (columns 1 – 3) are natural logs of patent count, forward 4-year citation, and citation per patent. The coefficient estimates of the before year dummies (*Before (k)*) are not significant in all three columns, suggesting that angel group and VC-backed firms do not exhibit substantial differences in innovation outcome before the first VC (angel group) investment year. It also supports the parallel trends assumption of the differences-in-differences identification estimation. Analyzing the after year dummies (*After (k)*), we find that for patent count, the influence of VCs appears significant for the first and second year post VC investment, but remains insignificant thereafter. However, the citation-based measures show a significant jump in the post-investment period and continue to remain significant in the first investment year. The results suggest that VCs and angel groups have a similar impact on patent counts, but the relative impact on patent citation measures is significantly higher for VC-backed ventures.[17]

[Insert Table II about here]

3.33 Switching regression estimation. In applying the switching regression, we are interested in analyzing how the potential innovation outcomes would shape if the venture that received VC investment did not have such an investment. Specifically, the analysis aims to answer two questions. First, what would the innovation outcome of a venture receiving VC investment have been had it not received VC financing? Second, what would the innovation outcome of a venture that did not receive VC investment (but receives angel investment) have been had it received VC financing?

We adopt a generalized version of the traditional Heckman model (Heckman, 1979) that accounts for the effect of unobservable heterogeneity by using the inverse Mills ratio.[18] In the two-step analysis, the first stage dynamic probit regression predicts the probability of VC investment that reflects the VC selection equation and calculates the inverse Mills ratios for ventures that receive VC investment and for ventures that do not receive VC investment. The inverse Mills ratio captures unobservable factors that VCs may use to select better-quality firms.

In the second stage, we regress venture innovation on the inverse Mills ratio and control variables separately for VC-backed and angel-group-backed ventures. Because we are interested in the difference in innovation between VC-backed and angel-group-backed ventures, the expected value of venture innovation is conditional on receiving VC investment. Therefore, we should assess the estimates' properties for VC-backed and angel-group-backed ventures separately.[19]

Finally, the predicted values from the second stage regression for VC-backed and angel-group-backed ventures are used through a hypothetical (counterfactual) analysis to answer the questions highlighted above. We compute the hypothetical innovation for VC-backed ventures had they not received VC investment and the hypothetical innovation for angel-group-backed ventures had they received VC investment. Multiplying the coefficient estimates obtained from the second stage analysis of VC-backed ventures with the vector of venture attributes for the subsample of VC-backed ventures provides the predicted venture innovation. To assess the hypothetical venture innovation of VC-backed ventures had they not received VC investment, we multiply the coefficient estimates obtained from the second stage analysis of angel-group-backed ventures by the vector of venture attributes for the subsample of VC-backed ventures. Likewise, we calculate the predicted venture innovation of angel-group-backed ventures and the hypothetical venture innovation of angel-group-backed ventures had they received VC investment.

In the empirical specification, we control for variables related to the venture and to the VC investment market that could affect VC-firm matching such as venture age, cumulative patents filed by the venture before VC investment, venture location, industry, and time dummy capturing the internet bubble period. In addition, we include exogenous variables that influence the supply and demand of VC investments in the economy in a given year but are independent of the future innovation outcome of a venture: a) *pension fund* is the size of local and state pension fund alternative investments assets lagged by one year and adjusted for USD 2013 dollar terms.[20]

State pension funds are a major source for raising VC capital and therefore it captures the aggregate variation in the supply of VC funding available to the ventures in a given state and in a given year (Mollica and Zingales, 2007); and b) *prior VC funds raised* is the average number of VC funds raised over the five year period prior to the VC investment year in the venture.

3.34 Switching regression analysis. Table III (panel A), column 1 reports the results for the first stage probit estimation. The dependent variable is VC year dummy that is equal to '1' for VC investment year and '0' otherwise.[21] Cumulative patents filed prior to VC investment and the bubble period variables are positive and significant determinants of receiving VC investment. With regard to exogenous variables that affect the demand and supply in the VC market, we find that the coefficients of pension fund and prior VC funds raised are both positive and significant, suggesting that the availability of funds to VCs is an important factor for VC investment (Gompers and Lerner, 1998). Columns 2-7 report the second-stage regressions for VC-backed and angel-group-backed ventures with the inverse Mills ratio calculated from the first stage. The second-stage results show that while the inverse Mills ratio is mostly positive and significant for VC-backed ventures, it remains insignificant for angel-group-backed ventures for all three measures of venture innovation. This suggests that relative to angel groups, VCs may also use some unobservable factors to select ventures, and the unobservable factors also positively affect the future innovation of ventures receiving a VC investment. Therefore, proper control for this unobservable selection effect enables us to attribute the residual innovation of VC-backed ventures to the treatment effect of VCs.

[Insert Table III, panel A and B about here]

Table III (panel B) reports the results for the counterfactual analysis for VC-backed versus angel-group-backed ventures. Interestingly, the patent count results suggest that, on average, VC-backed ventures achieve a 14.2% lower patent count compared to what the same venture could have achieved had they not received VC investment, suggesting that VCs in fact have a negative effect on patent count and therefore do not nurture venture innovation by increasing the patent rate. Similarly, angel-group-backed ventures, on average, achieve a 5.3% higher patent count compared to what they could have achieved had they received VC investment. However, results based on patent citation measures reveal that on average, VC-backed ventures achieve a significantly higher citation compared to what the same venture could have achieved had they not received VC investment, suggesting that VCs have a strong positive effect in enhancing the quality of innovations by increasing patent citations. The counterfactual analysis of angel-group-backed ventures also shows that the same venture could have generated significantly higher patent citations had they received VC investment. The increase in patent citations attributed to the VC catalyzing effect is consistent with our earlier results presented in Table 2. In summary, the results overall emphasize that the nurturing effect of VCs compared to angel-groups drives ventures' innovation quality rather than the innovation rate.

3.35 Effect on innovation commercialization – Hazard rate estimation. Finally, we equate venture performance with successful exit. The timing of exit through an IPO and the timing of exit through an acquisition are two common performance measures for technology ventures. While external investments from VCs and angel groups nurture innovation in different ways, as highlighted in our results, the economic objective of private equity investment is to earn returns by commercializing the innovation and exiting either through an IPO or acquisition. We therefore examine differences in the time-to-exit for VC-backed and angel-group-backed ventures by employing a parametric accelerated time-to-exit model with log-normal distribution (a hazard model with log time as dependent variable), similar to Hochberg et al. (2007).[22]

Although our results are robust for alternative distributions (exponential, Weibull), the advantage of log normal distribution is that the hazard rate is not monotonic and does not consider a constant hazard rate. Time-to-exit of ventures yet to exit successfully by the close of 2010 is right censored at the end of calendar year 2010 to allow for the possibility that they may exit successfully after the end of our sample period. We relate the log time-to-exit to the type of private equity investment received by the venture, controlling for venture attributes (patent count, cumulative dollar inflow, venture location, and industry), funding year effects, and conditions in the IPO and M&A exit markets. To measure exit market conditions, we use the quarterly log number of IPOs and the quarterly log number of M&A deals prior to venture exit (lagged by a quarter). The model allows for time-varying covariates.

3.36 Parametric hazard rate analysis. Table IV presents the accelerated time-to-exit parametric hazard (duration) analysis where log time is the dependent variable. Positive (negative) coefficients indicate that the covariate increases (decreases) the time a venture takes to exit via an IPO or an acquisition transaction. The key variables of interest are the dummy variables *Pure Angel-backed Venture* and *Pure VC-backed Venture*, and are compared against the missing category where a venture received funding from both types of sources. Column 1 suggests that pure angel-group-backed ventures take longer to achieve a successful exit than ventures receiving funding purely from VCs and both VCs and angel groups. T-tests also confirm that angel-group-backed ventures are slower to exit than pure VC-backed ventures. When we differentiate between types of exit in columns 2 and 3, it appears that these results seem particularly suitable for acquisition events. Pure angel-group-backed ventures take longer to achieve IPO compared to ventures backed by both angels and VCs. In summary, the findings suggest that VCs strong incentives to exit ensures that VC-backed ventures take a relatively shorter time to realize an exit event compared to angel-backed ventures.

[Insert Table IV about here]

5. DISCUSSION AND CONCLUSION

This study examines the influence of private equity investments on venture innovation and commercialization, and is the first to distinguish between types of private equity investor. It does so by considering the different theoretical implications of angels and venture capital firms and empirically isolating their separate influences. We have argued that simultaneous consideration of both is important because early-stage venture capitalists and angel groups are structurally different, and this may have dissimilar consequences in catalyzing venture innovation. Moreover, focusing on angel investment may be critical because a sole focus on venture capital's effects may be spurious, as angel investments may be endogenous to venture capital investments. To decouple the influence of angel and venture capital investment, we assembled a novel dataset of ventures backed by angel groups and early-stage venture capital representing five technology-intensive SIC industries. Several results are worth highlighting.

Researchers studying venture capitalists will be interested in the reported findings because it has significant implications for how we interpret the true effect of venture capital investment in nurturing innovation by taking into account other potential sources of private equity investment. It seems that in some cases, ignoring angel investments is not a fatal flaw when studying the impact of venture capital at the firm level. When studying innovation quality or performance through successful exit, our results demonstrate that venture capital influence is significantly higher compared to angel influence. The same conclusion cannot be drawn when studying innovation rates, a common strategy in our field. Venture capitalist influence almost disappears in the presence of prior angel influence.

Researchers studying angels will be interested in our findings because it provides insight into their contribution relative to venture capitalists. The findings suggest that venture capitalists provide a critical complement to angels by facilitating greater innovation quality in their portfolio firms and a faster realization of returns. Scholars may also be interested in investigating the extent that ventures receiving angel funding have advantages over those that do not. While there is some evidence that they survive longer (Kerr et al., 2011), future research might consider the full spectrum of ventures both with and without private equity funding, and compare them along the full set of performance metrics. One critical challenge in studying angel investors is the fact that their investments are difficult to observe. We overcome this problem by focusing on angel groups. Angel groups are considered a very structured form of angel investment, closely resembling early stage VC investments. While our results are not necessarily generalizable to all angel investor types, future research might also seek evidence in this regard.

The interpretation of the higher innovation quality produced under venture capital influence has a number of possible explanations. It may be possible that innovation quality is not improved, but that the forward citation measures capture social network effects tied to venture capital. For example, it may be that a venture capitalist's established ties, including its other portfolio firms, are prone to citing the focal venture's patents. It may also be that venture capital investment tends to have better media coverage that sends a strong VC endorsement signal to the market (Stuart et al., 1999; Hsu, 2006) and enhance a venture's visibility. To gain some insight on this aspect, we calculated the unique number of times a venture appeared in Factiva news after VC investment. The Factiva news count shows a significant correlation (ρ=0.21) with the citation measure, indicating that there may be some credence to the visibility explanation, though more research is required to test this possibility. An alternative interpretation to the link between venture capital investment and innovation quality is that venture capitalists tend to "swing for the fence" in their portfolio ventures, seeking to build businesses of considerable importance. We find some evidence of this by looking at standard deviations of citation measures across ventures receiving either angel or venture capital investment. Venture capital-backed ventures have much higher standard deviations in their citation measures, and future research should investigate why venture capital backed ventures have higher innovation quality than angel-backed ventures.

Although patents play a central role in empirical research on innovation, there is a great deal of heterogeneity across industries and firms in the way in which innovation is pursued. Since firms strategically choose whether or not to pursue patents, patent acquisition is endogenous to the firm's decision, and causality claims linking patents to innovation should be viewed more conservatively. We attempt to alleviate this concern by sampling technology industries where innovation expressed through patents is prevalent.

Very little work has examined the impact of angel investors on venture innovation and development, and it is natural to question whether they contribute in a meaningful way to a venture's success. Our work is the first to formally compare the relative contribution of angels with venture capitalists. It provides initial evidence detailing where angels might substitute for venture capitalists and where they may contribute in complementary ways to the venture. It also speaks to researchers studying venture capital influence, and establishes future protocol for empirical research in that context. It is worthwhile for future researchers to compare the long term effect of venture capital and angel investment on innovation given the time sensitive nature of venture capital investments that makes them less tolerant to early innovation failures. As a practical implication of our research, it is important for the technology entrepreneur to understand the relative contribution of different types of private equity investors and what value they might bring to the venture.

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Table I.
SAMPLE OVERVIEW AND SUMMARY STATISTICS

Panel A: Descriptive statistics		
Venture characteristics	Investment by Angels	Investment by VCs
Average year venture founded	2001.0	2001.0
Average year of first investment	2002.6	2002.4
Drugs (SIC 283)	0.17	0.14
Industrial machinery and equipment (SIC 35)	0.02	0.01
Electronic and electrical equipment (SIC 36)	0.17	0.12
Scientific instruments (SIC 38)	0.15	0.13
Computer programming and software (SIC 7371, 7372, 7373)	0.46	0.60
Rounds of investment		
≤ 2	0.67	0.41
3 – 4	0.20	0.40
≥ 4	0.13	0.19
East coast location	0.35	0.32
West coast location	0.39	0.64
Success (IPO or Acquisition)	0.47	0.60
IPO	0.06	0.07
Acquisition	0.41	0.53
Observations (N)	137	271

Note: Panel-A reports the descriptive statistics for the sample of ventures backed by angel groups and VCs.

Panel-B. Univariate analysis by type of investment					
Variables	Angel group-backed (2)	Angel group & VC-backed (3)	VC-backed (4)	Diff between (2) and (3) (5)	Diff between (3) and (4) (6)
Innovation measures					
Patent count (as of 12/31/2010)	4.54	7.25	6.10	*	--
Forward 4-year citation	16.95	55.83	54.60	**	--
Citation per patent	3.88	9.62	12.25	**	--
Venture characteristics					
Venture age (at first investment)	1.73	1.21	1.34	**	--
Patent dummy	0.70	0.82	0.70	--	--
Prefunding patent	1.20	1.36	1.40	--	--
Observations (N)	79	58	213		

Note: Panel-B reports the difference of means for angel-group-backed, both angel groups and VC backed, and VC-backed only ventures. The entire sample of 350 ventures consists of 79 angel-group-backed ventures, 58 angel-group and VC-backed ventures, and 213 matched VC-backed ventures. ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.

Table II.
DIFFERENCE-IN-DIFFERENCES APPROACH

Dependent variable	*Natural log of patent count*	*Natural log of forward 4-year citation*	*Natural log of citation per patent*
	(1)	(2)	(3)
Before (4) years	-0.062 (0.110)	-0.155 (0.257)	-0.197 (0.234)
Before (3) years	0.005 (0.084)	0.023 (0.192)	0.078 (0.211)
Before (2) years	0.046 (0.072)	0.168 (0.167)	0.116 (0.163)
Before (1) years	0.042 (0.059)	0.074 (0.134)	0.033 (0.133)
After (1) years	0.123*** (0.039)	0.376*** (0.079)	0.352*** (0.076)
After (2) years	0.140*** (0.046)	0.458*** (0.091)	0.398*** (0.084)
After (3) years	-0.009 (0.039)	0.220*** (0.084)	0.193** (0.080)
After (4) years	0.030 (0.045)	0.230*** (0.091)	0.214** (0.087)
After (5) years	-0.036 (0.042)	0.158* (0.086)	0.129* (0.073)
Log Cumulative dollar inflow	0.067*** (0.024)	-0.061 (0.051)	-0.127** (0.055)
Year fixed effects	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
Location fixed effects	Yes	Yes	Yes
Observations (N)	2641	2641	2641
R^2	0.03	0.04	0.05

Note: This table reports the regression results of the difference-in-differences estimation. The dependent variables are natural logs of patent count, forward 4-year citation, and citation per patent. The main independent variables include before VC investment four year dummies (Before (k) where k= 1, 2, 3, 4) and after VC investment five year dummies (After (k) where k= 1, 2, 3, 4, 5). The base year is the VC investment year. Robust clustered errors at the firm level are reported in parenthesis. The unit of observation is firm-year. ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.

Table III.
SWITCHING REGRESSION

Panel A: Stage 1 & 2							
	First stage	Second stage					
Dependent variable	*VC year dummy*	*Log patent count*		*Log forward 4-year citation*		*Log citation per patent*	
		VC-backed	Angel-group-backed	VC-backed	Angel-group-backed	VC-backed	Angel-group-backed
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log Cumulative patent	0.221** (0.089)	0.286*** (0.038)	0.478*** (0.039)	0.233** (0.105)	0.270*** (0.082)	0.226** (0.096)	0.179* (0.108)
Log Venture age	-0.918*** (0.078)	0.281* (0.160)	-0.104* (0.057)	0.774** (0.398)	-0.251 (0.106)	0.069 (0.480)	-0.275* (0.156)
Bubble period	0.367*** (0.014)	-0.029 (0.067)	0.022 (0.065)	-0.094 (0.164)	-0.008 (0.117)	0.129 (0.190)	0.073 (0.159)
Log Prior VC funds raised	0.260* (0.143)						
Log Pension fund	0.103** (0.050)						
Log Cumulative dollar inflow		-0.092*** (0.013)	-0.112 (0.086)	-0.205*** (0.031)	-0.120 (0.114)	-0.191*** (0.035)	-0.152 (0.106)
Inverse Mills ratio		0.483** (0.220)	0.338 (0.295)	1.360** (0.554)	0.018 (0.537)	0.308 (0.663)	-0.136 (0.524)
Location effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Venture fixed effects		Yes	Yes	Yes	Yes	Yes	Yes
Observations (N)	1200	2040	601	2040	601	2040	601
Chi^2 / Adj. R^2	177.38***	0.39	0.34	0.19	0.14	0.16	0.10

Note: Stage 1 dependent variable (VC year dummy) is a dummy variable that indicates whether or not a venture gets VC investment in a given year. The time series for each VC-backed venture in stage 1 analysis is until the year of receiving the first VC investment. The dependent variables in stage 2 are venture innovation variables (log of patent count, log of forward 4-year citation, and log of citation per patent). The independent variable in stage 2 includes the inverse Mills ratio obtained from stage 1. Heteroskedasticity-robust standard errors clustered at the firm level are reported in parenthesis for stage 1 and bootstrapped standard errors clustered at the firm level are reported in parenthesis for stage 2. ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.

Table III (continued).
SWITCHING REGRESSION

Panel-B: Counterfactual analysis						
	Predicted value of VC-backed venture (actual)	Predicted value of VC-backed venture if they had not received VC investment (counterfactual)	Difference between (1) and (2)	Predicted value of angel-group-backed venture (actual)	Predicted value of angel-group-backed venture if they had received VC investment (counterfactual)	Difference between (4) and (5)
	(1)	(2)	(3)	(4)	(5)	(6)
Log patent count	0.269	0.411	-0.142***	0.319	0.266	0.053**
Log forward 4-year citation	0.569	0.379	0.190***	0.313	0.402	-0.089***
Log citation per patent	0.689	0.261	0.428***	0.282	1.478	-1.196***

Note: This table reports the counterfactual analysis based on the results of the second stage switching regression. Columns 1, 2, and 3 present the means of the predicted innovation measures for VC-backed ventures (obtained from cols. 2, 4, and 6 from table 3, panel-A), the means of the counterfactual (hypothetical) innovation measures of VC-backed ventures if they had not received VC investment (obtained from cols. 3, 5, and 7 from table 3, panel-A) and the difference between the means. Columns 4, 5, and 6 present the means of the predicted innovation measures for angel-group-backed ventures (obtained from cols. 3, 5, and 7 from table 3, panel-A), the means of the counterfactual (hypothetical) innovation measures of angel-group-backed if they had received VC investment (obtained from cols. 2, 4, and 6 from table 3, panel-A) and the difference between the means. ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively for t-test of mean difference.

Table IV.
PARAMETRIC HAZARD ANALYSIS

Dependent variable	*Log of time to exit*		
	(1)	(2)	(3)
Hazard type	*Success* (Dummy =1 for IPO or acquisition)	*Acquisition* (Dummy =1 for acquisition)	*IPO* (Dummy =1 for IPO)
Pure VC-backed venture [a]	-0.274** (0.122)	-0.349*** (0.133)	0.272 (0.256)
Pure Angel-backed venture [a]	0.301** (0.150)	0.278* (0.158)	0.769** (0.390)
Log Venture age	-0.132* (0.075)	-0.118 (0.078)	-0.171 (0.221)
Log cumulative patent count (time varying)	0.024 (0.048)	0.037 (0.050)	-0.040 (0.116)
Log Cumulative dollar inflow (time varying)	0.106** (0.046)	0.140*** (0.051)	-0.098 (0.129)
Log number of IPOs (time varying)	-0.747*** (0.113)	-0.695*** (0.118)	-1.252*** (0.274)
Log number of Acquisitions (time varying)	0.074 (0.258)	0.046 (0.271)	0.631 (0.640)
Location controls	Yes	Yes	Yes
Industry controls	Yes	Yes	Yes
Funding year controls	Yes	Yes	Yes
Log likelihood	-270.34	-269.36	-36.15
Observations (N)	350	350	350
Number of exit events	193	173	20

Note: This table reports the influence of angel investment and VC investment on the time to exit. All models are accelerated time to exit parametric hazard models where log time is assumed to be normally distributed. Positive (negative) coefficients indicate that the covariate increases (decreases) the time a venture takes to exit via an IPO or an M&A transaction. Time to exit of ventures yet to exit successfully by end of 2010 is right censored at the end of calendar year 2010 (to allow for the possibility that they may yet exit successfully after the end of our sample period), and the likelihood function is modified accordingly. The models allow for time-varying covariates. Market conditions (*log of number of IPOs* and *log of number of Acquisitions*) are time varying. *Log Cumulative Patent count* and *Log Cumulative dollar inflow* are also treated as time varying covariates and all other variables are treated as time invariant. Intercepts are not shown. The key independent covariates are *Pure VC-backed venture* is a dummy variable equal to one for ventures backed by only VCs and *Pure Angel-backed venture* is a dummy variable equal to one for ventures backed by only angels. Values are regression coefficient (clustered robust standard errors at the firm level); ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively. [a] Relative to ventures that received both angel group and VC funding.

APPENDIX TABLE A.1

VARIABLE DEFINITIONS

VARIABLE	DEFINITION
Innovation success variables	
Patent count	Patents applications filed by venture *j* in year *t*.
Forward 4-year citation	Total forward patent citations to venture *j*'s flow of patents within 4 years of patent application date in year *t*.
Citation per patent	Total forward patent citations to venture *j*'s flow of patents divided by the total patents filed by venture *j* in year *t*.
Exit event variables	
Success	Dummy = 1 if venture *j* exits through IPO or acquisition.
IPO	Dummy = 1 if venture *j* exits through IPO.
Acquisition	Dummy = 1 if venture *j* exits through acquisition.
Investment and time variables	
VC-backed dummy	Dummy= 1 for venture *j* that received VC investment.
Before (t)	Dummy=1 for the time window 1 to 4 years prior to VC investment.
After (t)	Dummy=1 for the time window 1 to 5 years post VC investment.
VC year dummy	Dummy=1 for the year of first VC investment.
After VC years	Dummy=1 for all the years after the first VC investment.
Time to exit	Calendar time between first funding event and exit date.
Control variables	
Venture age	Age in years of venture *j* at the time of the first funding event.
Patent dummy	Dummy = 1 if venture *j* has filed for at least one patent.
Cumulative patent	Cumulative patents filed by venture *j* before year *t*.
Cumulative dollar inflow	Cumulative dollar inflows received by venture *j* in year *t* ($Mn)
Number of IPOs	Log of lagged quarterly avg. no. of IPOs prior to venture exit.
Number of Acquisitions	Log of lagged quarterly avg. no. of M&As prior to venture exit.
East Coast location	Dummy=1 for ventures headquartered in east coast.
West Coast location	Dummy=1 for ventures headquartered in west coast.
Other location	Dummy=1 for ventures not headquartered in east / west coast.
VC supply and demand variables	
Pension fund	Size of local and state pension fund assets lagged by one year and adjusted for US 2010 dollar terms ($Bn).
NSF applied grant	Log of the moving average change over five years (in real terms) of NSF applied research grant.

[1] Statistics for angel investment were gathered from The Center for Venture Research at University of New Hampshire, which, at the time the manuscript was written, reported investment by stage of investment for the first two quarters of 2013 (https://paulcollege.unh.edu/research/center-venture-research/cvr-analysis-reports). Statistics for venture capital was gathered from PricewaterhouseCoopers MoneyTree report. Compared to venture capital, the proportion of angel investment in seed and early stage was considerably more stable, at 44 percent in 2002.

[2] The Angel Capital Association defines an angel investor as a high net worth individual who invests directly into promising entrepreneurial businesses in return for stock in the companies. Many are entrepreneurs themselves, as well as corporate leaders and business professionals. While definitions of angel investors can vary, it is generally understood that angel investment excludes investments made by family and friends.

[3] These same two approaches were used by Chemmanur et al. (2010), who used difference-in-differences to measure changes in firm employment, and capital expenditure around the IPO event, and Chemmanur et al. (2011) who used switching regression to measure a firm's change in total factor productivity subsequent to receiving venture capital.

[4] Source: PriceWaterhouseCoopers MoneyTree Report.

[5] They note that increases in patent production at the industry level and increases in venture funding at the industry level may be due to unobserved factors that influence technological opportunities and, therefore, simply regressing an industry's patent production on venture funding may overstate the influence of VCs. They control for these factors using the instrument of U.S. Department of Labor's 1979 clarification of the "prudent man" rule.

[6] They use investments made by independent funds in the past five years as an instrument to address the endogeneity of VC investment and advent of technological opportunities.

[7] They employ instrument variable operationalized using the count of limited partners in each region over the past three years to address the endogeneity that VCs might allocate resources to regions rich in promising technologies.

[8] The higher survival rates of angel-group funded ventures may be due to the fact that angel groups effectively nurture and motivate entrepreneurs, two qualities necessary for the innovation process (Manso, 2011), particularly germane in early-stage innovation efforts rife with unpredictability and failure.

[9] The authors do not account for angel effect separately and consider the combined effect of external investment.

[10] The *IQSS Patent Network database* (see Lai et al., 2011 for a description), the *USPTO database*, and *Google patents* databases are used to match patent information for each venture at a firm-year level from its founding year to 2010 (or earlier, if the firm exited through IPO, acquisition or went bankrupt).

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[11] See http://sites.kauffman.org/aipp/about.cfm for more information on the AIPP survey.

[12] The distribution of returns of the final sample of 137 ventures is similar to the distribution of the AIPP dataset. The average investor return reported in the AIPP dataset is 27 percent, approximately equivalent to other surveys conducted on angel investments (e.g., Mason and Harrison, 2002; Center of Venture Research Report, 2007), and the distribution of returns is also similar to other surveys, skewed to the left with close to fifty percent of the investments having negative or zero return. Also, the average return reported in the AIPP data compares favorably with the returns of venture capital investment, reported at 26.9 percent in 2004 for a ten-year period (NVCA report). Further, a comparative analysis of VC investment and angel investment conducted by Kerr et al. (2011) and Mason and Harrison (2002) show no significant difference in investment returns.

One natural concern is whether the AIPP dataset comprises accredited angel investors who have had positive investment experiences and tend to share the information. Wiltbank and Boeker (2007) compared the returns reported by high response rate angel groups (seven groups with more than 60 percent response) with low response rate angel groups and found no significant difference. This suggests that the 31% of angel-groups that responded to the AIPP survey is not a biased sample containing only high-performing angel-groups.

[13] We eliminated ventures that had 'undisclosed investor' in any investment round. The 'undisclosed investor' category in VentureXpert may represent angel groups or individual investors. Next, we gathered information (investment portfolio, principal partners, capital under management) of the VC firms involved in each investment round to ascertain whether they fall under the traditional VC category. Finally, we conducted an exhaustive search on Google, Factiva, Lexis-Nexis, and also employed a customized web-crawler search for each VC-backed venture to ascertain whether the venture had any affiliation with US-based angel groups listed in the Angel Capital Association directory. A web crawler is a software program that runs an automated iterative algorithm to search web URLs and hyperlinks. A web crawler-based search is considered more efficient than a human agent coordinated internet search because it interprets the words before and after the keyword to determine whether the information is useful.

[14] Information on founding year and current status (IPO, acquisition, privately held, bankrupt) was collected from news article searches in *Factiva*, *Lexis-Nexis*, *Bloomberg Businessweek*, *CrunchBase*, *CB Insights*, and company websites combined with data from *VentureXpert* and *SEC filings*. *VentureXpert*, the *AIPP survey,* and *SEC filings*

were consulted for VC and angel group financing amounts and investment year. Information on venture location and SIC codes was obtained from *Corptech Directory of Technology Companies* (1995 – 2006) and *Lexis-Nexis*.

[15] To ensure the sampled VC-backed ventures in our analysis is representative of early stage VC investments, we compared the 271 (213+58) VC-backed ventures to the universe of VC-backed technology ventures (7517) founded between 1995 and 2006 that received their first VC investment in the seed/early stage of development. No significant differences were observed in average venture age at the time of first investment, average cumulative VC investment, and percentage of IPOs and acquisition exits. The analysis is available upon request.

[16] A similar difference-in-differences estimation strategy has been adopted by Bertrand and Mullainathan (2003) and Chemmanur et al. (2010) to study firm performance around different events.

[17] We also implemented fixed effects negative binomial regression with patent count and forward 4-year citation as count dependent variables. The results are essentially similar to Table 2.

[18] A similar approach was adopted by Shaver (1998) in analyzing the impact of acquisition versus green field entry on firm survival, and by Chemmanur et al. (2011) in analyzing the impact of VC on total factor productivity of the firm. For a detailed discussion on switching regression, see Heckman (1979), and Maddala (1983).

[19] Venture that received both angel group and VC investment are treated as VC-backed for the years after the venture receives VC investment.

[20] Information sourced from Annual Survey of Public Pensions: State and Local Data.

[21] VC year dummy is set to '0' for all the years for ventures that did not receive any VC investment (but received angel-group investment). For VC-backed ventures, VC year dummy is '0' in all years prior to VC investment, and it equals '1' in the year the venture receives VC investment. It is set to missing in the following years after VC investment. Therefore in the first stage, VC-backed ventures effectively drop out of the sample for all years subsequent to the year of VC investment.

[22] Our results are qualitatively similar to the semi-parametric Cox hazard model and are available upon request.