UNLEASHING INNOVATION[*]

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ABSTRACT

Using a sample of venture capital (VC)-backed initial public offering (IPO) firms, we study the impact of financial intermediaries' tight leash on entrepreneurs' innovation productivity. We find IPO firms are significantly less innovative when VCs keep a tighter leash on them by interfering with their development more frequently—as measured by a larger number of VC financing rounds. To establish causality, we exploit the plausibly exogenous variation in the frequency of direct flights between VC domiciles and IPO firm headquarters that are due to airline restructuring. Our identification tests suggest a negative, causal effect of VC staging on firm innovation. We further show that staging is more detrimental to firm innovation when innovation is more difficult to achieve, when IPO firms operate in more competitive product markets, and when VCs are less experienced with the industry to which their entrepreneurial firms belong. Our findings suggest that excessive interference by financial intermediaries impedes innovation, and shed light on a previously under-recognized adverse consequence of VC stage financing.

Keywords: Innovation, Stage financing, Venture capital, Short-termism

JEL classification: G24, O31, G34

1. INTRODUCTION

Innovation is vital for a country's economic growth (Solow, 1957) and a firm's competitive advantage (Porter, 1992). Nevertheless, how to effectively motivate and nurture innovation remains challenging for most countries and organizations. Existing literature proposes that a highly developed financial market helps promote innovation through improving capital allocation, reducing the cost of capital, and/or effectively monitoring managers and evaluating innovative projects (e.g., Schumpeter, 1911; Brown, Fazzari, and Petersen, 2009; Hsu, Tian, and Xu, 2013). However, a developed financial market could also give rise to various adverse externalities such as short-termism, rent-seeking, and opportunistic behaviors. In this paper, we focus on the venture capital (VC) market—a key ingredient of the financial market and a main driver of entrepreneurship and technological innovation in the United States—and explore the effect of VCs' staged capital infusions on the innovation output of the initial public offering (IPO) firms they fund.

As a unique feature of VC investment, stage financing refers to the stepwise disbursement of capital from VC investors to entrepreneurial firms. Instead of an upfront, lump sum capital infusion, VC investors split financing into multiple rounds, where the next round investment is contingent upon whether the entrepreneurial firm meets the round performance target pre-specified by the VC. By allowing VC investors to retain the option to abandon the entrepreneur's project if it fails to meet stage targets, staging could lead to more efficient investment decisions and better investment outcomes (e.g., Sahlman, 1990; Admati and Pfleiderer, 1994; Gompers, 1995).

In addition, VC staging can mitigate the hold-up problem by the entrepreneur who undertakes innovation activities. As in the Hart and Moore's (1994) world of incomplete contracting, once the VC has made the investment and the innovation process begins, an entrepreneur who recognizes that the cost is sunk cannot contractually commit to staying with the firm, in which his unique human capital is critical to achieving the venture's full innovation potential. Neher (1999) suggests that VC staging can mitigate this hold-up problem because the gradual embodiment of the entrepreneur's human capital in the venture's physical capital is equivalent to the build-up of collateral, which reduces the entrepreneur's bargaining power and

incentives to leave the firm. Overall, by keeping a tight leash on the entrepreneurs they fund, VC investors can mitigate agency and hold-up problems through stage financing.[1] This "agency hypothesis" implies that VC stage financing promotes innovation.

Alternatively, a tight leash on the entrepreneur, and thus frequent interference through VC staging, may impede firm innovation. Unlike routine operations such as mass production and marketing, innovation involves a long, idiosyncratic process that is full of uncertainty and has a high probability of failure (Holmstrom, 1989). Tolerance for failure in the short run coupled with reward to succeed in the long run is thus necessary for effectively motivating innovation (Manso, 2011; Ferreira, Manso, and Silva, 2013).[2] Any external pressure to meet short-term targets imposed by investors discourages managers from undertaking long-term investment in innovation. While staged capital infusions allow VCs to avoid the hold-up problem, a short-termism problem can arise: due to the pressure to secure the next round of capital infusion from VC investors, the entrepreneur may forgo long-term value creation activities such as investing in innovative projects, and instead, aim for short-term success (i.e., "window dressing"). This "leashing hypothesis" thus argues that VC stage financing impedes innovation by imposing significant pressure on entrepreneurs to meet short-term stage targets and encouraging short-termist investments.[3]

We test the above two competing hypotheses by examining whether VC stage financing promotes or impedes the innovation of their IPO firms. Traditionally, the success of an entrepreneurial firm's investment in intangible assets and research and development (R&D) has been difficult to observe and assess. To capture firms' innovativeness, we make use of an observable innovation output, i.e., the number of patents granted to an IPO firm and the number of future citations received by each patent, which now has become standard in the innovation literature (e.g., Aghion et al., 2013; Nanda and Rhodes-Kropf, 2013; and Seru, 2013).

A naïve ordinary least squares (OLS) regression indicates that VC staging (measured by the number of financing rounds that VCs invest in an entrepreneurial firm before it goes public) does not appear to have an effect on an IPO firm's innovation output. However, this finding is

[1] As Sahlman (1990, p. 506) argued, "The most important mechanism for controlling the venture (by the venture capitalists) is staging the infusion of capital."

[2] Recent empirical research providing supporting evidence for the implications of the failure tolerance theory includes Ederer and Manso (2013), who conduct a controlled laboratory experiment, and Azoulay, Graff Zivin, and Manso (2011), who exploit key differences among funding streams within the academic life science.

[3] Sahlman (1988) describes how the entrepreneur could try to improve short-term performance to ensure that his project will be refinanced in the next round.

likely to be driven by VC stage financing being endogenously determined. Unobservable VC investor or entrepreneurial firm heterogeneity correlated with both VC staging and IPO firm innovation remains in the residual term of the regressions, which makes it difficult to draw correct statistical inferences.

To establish causality, we construct an instrumental variable (IV) for VC staging and undertake the two-stage least squares (2SLS) analysis. Our IV relies on plausibly exogenous variation in VC investors' opportunity costs of staging, captured by the frequency of direct flights between the cities in which the entrepreneurial firm and the VC investor are located. The rationale behind this instrument is that the easier it is for VCs to access their entrepreneurial firms, approximated by more frequent direct flights between VC domiciles and entrepreneurial firm headquarters, the less vital it is for VCs to rely on the costly disciplining mechanism—stage financing.[4]

To further ensure the satisfaction of the exclusion restriction, we make use of the variation in the frequency of direct flights between the locations of VCs and entrepreneurs that is caused by airline restructuring activities such as bankruptcies, mergers and acquisitions, and strategic alliances. These restructuring activities are motivated by the strategic considerations of the airlines themselves rather than by the characteristics of VC investors and entrepreneurial firms located in the cities in which flight services are provided. Therefore, it is reasonable to believe that the number of direct flights between VCs and entrepreneurs affected by airline restructuring is not correlated with the entrepreneurial firms' innovativeness, and therefore the instrument is likely to satisfy the exclusion restriction.

The 2SLS analysis suggests a negative effect of VC staging on the innovation output of the entrepreneurial firms after they go public. One additional round of VC financing leads to a 28.3% reduction in the number of patents per year and a 31% reduction in the number of citations per patent. The results are robust to alternative proxies for innovation output and an alternative specification in which we use the total number of patents and citations generated in the first three years after the firm goes public as the dependent variable. In summary, our findings support the leashing hypothesis but contradict the agency hypothesis.

[4] Tian (2011) argues that potential costs associated with VC stage financing include negotiation and contracting costs associated with each round of financing, forgone economies of scale due to divided capital infusions, underinvestment in early-stage viable ventures, and inducing short-termist behavior on the part of entrepreneurs.

Comparing between the results based on the OLS and IV analyses, it appears that OLS biases the effect of VC staging on firm innovation upward due to endogeneity. This suggests that certain omitted variables simultaneously make firms more innovative and more likely to receive a larger number of VC financing rounds. The entrepreneurial firm's technology complexity could be an example of such an omitted variable. For instance, a new venture at the early stage of developing a new and complex technology is, by nature, difficult for its VC investors to evaluate. Therefore, the venture is likely to receive multiple financing rounds from the VC. Meanwhile, such technology is likely to result in many innovative products and patents. This positive correlation between staging and firm innovation arising from omitted variables thus biases the coefficient estimate upward. Once we use the IV to clean up the correlation between VC staging and the omitted variables, the endogeneity of VC staging is removed and the coefficient estimate decreases, i.e., becomes negative.

To help further identify the possible causal effect of VC staging on IPO firms' innovation output, we examine how VC staging affects IPO firm innovation differently in the cross section in the 2SLS framework. First, if VC staging indeed induces short-termism on entrepreneurs and impedes their innovation, then a natural implication is that VC staging should be particularly detrimental in industries in which innovation is difficult to achieve. Consistent with our conjecture, we find that the negative effect of VC staging on firm innovation is more pronounced in pharmaceutical and electronics industries—where innovation process is long, failure risk is high, and demands for resources are stronger—than in industries where innovation is easier to attain.

Second, short-term pressure imposed upon firms can be exacerbated by product market competition (Aghion, Van Reenen, and Zingales, 2013). To keep competitive advantage over its rival and to survive, a firm is more likely to engage in short-term, less innovative investment that offers faster and more certain returns in a highly competitive market. To the extent that product market competition is an alternative mechanism that imposes short-term pressure on the firm, we expect VC stage financing to adversely affect firm innovation particularly if the entrepreneurial firm operates in a more competitive product market. We find evidence that is consistent with our conjecture.

Finally, we examine how the extent of VC investors' experience in the industry where their portfolio firms operate affects innovation. If VCs have expertise in their portfolio firm's

industry, they should have a better understanding about the business nature of the entrepreneurial firm; their staged capital infusions thus should be less detrimental to firm innovation because the benefit of staging (preventing hold-up and keeping the abandonment option) dominates. Consistent with this conjecture, we show that more intensive staging leads to declining level of innovation only among those IPO firms whose VCs are less experienced with the industry to which the firms belong.

The above cross-sectional tests further lend credence to our causal inferences of a negative effect of VC staging on firm innovation. While it is possible that some omitted variables drive the documented results, it is difficult to conceive of an omitted variable that biases our results equally along all dimensions in firms that are in industries where innovation is difficult or easy to achieve, that operate in more or less competitive product markets, and that are financed by VCs with more or less matched industry expertise. The differential effects of VC staging on firm innovation output along these dimensions alleviate the identification concern to some extent, as our results are unlikely entirely driven by VCs' endogenously selecting to invest fewer rounds in more innovative firms. Instead, it appears to suggest that a treatment effect is at least partially in effect.

The rest of the paper is organized as follows. Section 2 discusses the related literature. Section 3 describes the research design and variable construction. Section 4 discusses sample selection and reports summary statistics. Sections 5 and 6 present the empirical results. Section 7 describes the results from various robustness tests. Section 8 concludes the paper. Variable definitions are in Appendix.

2. RELATION TO THE EXISTING LITERATURE

Our paper contributes to three strands of literature. First, our paper is related to the emerging literature on finance and innovation. Theoretical work from Holmstrom (1989) argues that innovation activities may mix poorly with routine activities in an organization. Aghion and Tirole (1994) suggest the organizational structure of firms matters for innovation. Manso's (2011) model shows that managerial contracts that tolerate failure in the short-run and reward success in the long-run are best suited for motivating innovation. Ferreira, Manso, and Silva (2012) argue that a firm's ownership structure also affects innovation.

Empirical evidence suggests that various economic environment and firm characteristics affect managerial incentives to innovate. Specifically, a larger institutional ownership (Aghion, Van Reenen, and Zingales, 2013), corporate venture capital (Chemmanur, Loutskina, and Tian, 2012), private instead of public equity ownership (Lerner, Sorensen, and Stromberg, 2011), lower stock liquidity (Fang, Tian, and Tice, 2013), and lower analyst coverage (He and Tian, 2013) alter managerial incentives and hence motivate managers to focus more on long-term innovation activities. Other studies examine the effects of venture capital investment, product market competition, bankruptcy laws, general market conditions, financial market development, firm boundaries, and investors' attitudes toward tolerance on firm innovation (e.g., Kortum and Lerner, 2000; Aghion et al., 2005; Acharya and Subramanian, 2009; Nanda and Rhodes-Kropf, 2012, 2013; Hsu, Tian, and Xu, 2013; Seru, 2013; Tian and Wang, 2013). However, existing studies have largely ignored the role played by certain investment mechanisms that allow investors to keep a tight leash on entrepreneurs in motivating innovation activities. We contribute to this line of research by filling in this gap.

Our paper also builds on the empirical literature studying managers' short-termism. This literature shows evidence consistent with managerial myopia in publicly traded firms.[5] For example, Asker, Farre-Mensa, and Ljungqvist (2012) find that publicly listed firms exhibit substantial myopia behavior: compared with private firms, they invest less and their investment levels are less sensitive to changes in investment opportunities. Bushee (1998) shows that managers are more likely to cut R&D expenses in response to an earnings decline when a very large proportion of institutional ownership comes from short-term investors. Our paper instead focuses on the effect of VC staging on entrepreneurs' short-termism.

Finally, our paper adds to the large literature on the role of VC investors for value creation in entrepreneurial firms. This literature has shown that VC firms' experience, intensive monitoring, reputation, syndication, network positions, and industry expertise all enhance the value of VC-backed entrepreneurial firms. Recent studies in this line of research include Hochberg, Ljungqvist, and Lu (2007), Sorensen (2007), Nahata (2008), Gompers, Kovner, and Lerner (2009), Chemmanur, Krishnan, and Nandy (2011), Tian (2011), and Puri and Zarutskie (2012). For a survey of the literature, see Da Rin, Hellmann, and Puri (2013). Our paper adds to

[5] Stein (1989)'s model shows that managerial myopia is present even in a rational capital market, and the degree of myopic behavior will be influenced by capital market incentives that determine the extent to which managers care about short-term stock prices relative to long-term firm values.

this line of research by exploring a unique VC investment structure, staged capital infusions, on technological innovation of their portfolio firms.

3. RESEARCH DESIGN

3.1 Identification Strategy

Identifying the casual effect of VC staging on an entrepreneurial firm's innovations is challenging, because VCs optimally stage finance their portfolio firms based on entrepreneurial firms' characteristics (including their innovation potentials) that may not be observable to econometricians. To establish causality, we construct an instrumental variable for VC staging by exploring plausibly exogenous variations in the frequency of direct flights between VC domiciles and IPO firm headquarters.

The rationale follows Tian (2011), who highlights potential costs associated with VC stage financing, including negotiation and contracting costs associated with each round of financing, forgone economies of scale due to divided capital infusions, underinvestment in early-stage viable ventures, and induced short-termist behavior on the part of entrepreneurs. Tian (2011) demonstrates that the extent of VC staging and VC intensive monitoring are substitutes: an easier access to entrepreneurial firms leads to a lower VC monitoring cost and thus a higher opportunity cost of stage financing. Intuitively, with more frequent direct flights, VCs rely less on staged capital infusions for their entrepreneurial firms, saving on the costs associated with staging.

Specifically, our instrument variable, *Direct Flight*, is calculated as the total number of direct flights (inbound and outbound) in the United States between the airports closest to the cities in which the VC and entrepreneurial firm are located during the firms' incubation period (from the first VC investment year to the firm's IPO year), scaled by the length of the incubation period. In case multiple VCs invest in one entrepreneurial firm, we weigh the frequency of each VC-entrepreneurial firm pair by the investment amount of each VC investor. If the locations of the VC and the entrepreneurial firm are within driving distance (i.e., shorter than 250 miles), we

assign to this pair the sample maximum of the frequency of direct flights.[6] Alternative cutoff points for this distance do not alter our results.

More frequent domestic direct flights allow for an easier access by a VC to the entrepreneurial firms that it funds. This easy access helps reduce its monitoring cost and consequently, reduces their stage financing incentives. Therefore, the proposed instrument satisfies the relevance condition.

Existing literature has established that an airline company's decision to schedule and/or maintain direct flight routes between any city pair is primarily driven by airline companies' own strategic considerations, such as industry peer competition and dominance (Borenstein and Netz, 1999), choice between "point-to-point" network and "hub-and-spoke" network (Brueckner, 2004), and alliances with other airlines (Bamberger, Carlton, and Neumann, 2004). Pricing, a key determinant for flight scheduling, is affected by physical distance, operation costs (Reiss and Spiller 1989), route concentration and competition (e.g., Borenstein, 1989; Gerardi and Shapiro, 2009), and passenger composition and market segmentation (Borenstein and Rose, 1994). City-pair direct service market structure is also restricted by government regulation, airport and aircraft fleet characteristics (Evens and Kessides, 1993; Pai, 2010), local population and labor force composition (Pai, 2010), and even the features of airlines' frequent flyer programs (Lederman, 2007).

Since city-pair direct flight service market structure is not directed at the locations of small start-up firms that may or may not go public in the unforeseen future, the availability and frequency of direct flights should affect an IPO firm's subsequent innovation only through its effect on a VC investor's monitoring cost and therefore staging decisions. This rationale ensures that our instrument reasonably satisfies the exclusion restriction.[7]

One reasonable concern of the proposed instrument is that the frequency of direct flights may be related to the local economic conditions of the cities in which the entrepreneurial firms are located, where the local economic conditions happen to be spurred by the innovation of these entrepreneurial firms. Another reasonable concern is that when founding their firms,

[6] Specifically, our sample maximum is 128 daily (inbound and outbound) flights. This is the route between Los Angeles (LAX) and San Francisco (SFO) during a period when carriers including Delta Airlines, United Airlines, US Airways, Alaska Airlines, and TWA compete against each other.
[7] See also Giroud (2013), who use the introduction of new airline routes as an exogenous variation in affecting the ease of monitoring and information acquisition about subsidiary plants by headquarters.

entrepreneurs with innovative projects endogenously choose to locate in cities that have more frequent direct flights to their investing VCs.

To address these concerns, we proceed as follows. First and most important, to account for (omitted) local shocks that may drive variation in the frequency of direct flights and local IPO firms' innovation productivity, we focus on the variation in direct flights that are unlikely to be driven by such shocks. Specially, we refine our instrument, restricting it to VC-entrepreneurial firm pairs in which the frequency of direct flights during the firm's incubation period is affected by airline restructuring events, such as bankruptcies, strategic alliances, and mergers and acquisitions. In these cases, the variation in the frequency of direct flights offered by an airline company arises from restructuring plans and strategic re-alignment, rather than local economic conditions (e.g., Kim and Singal, 1993; Park and Zhang, 1998; Borenstein and Rose, 2003; Cilibrto and Schenone, 2012).[8] More importantly, it is difficult to conceive of the scenario in which an entrepreneur with innovative projects is able to predict the occurrence of an airline restructuring event, let alone the final outcome of such an event.[9] Therefore, it is unlikely that an entrepreneur with innovative projects chooses venture location accordingly when he founds his entrepreneurial firm.

In the analyses with the refined instrument, we identify whether an airline operating direct flights between cities where VCs and their entrepreneurial firm reside experiences bankruptcy, strategic alliances, or mergers and acquisitions during the firm's incubation period. We then focus on VC-entrepreneurial firm pairs that are subject to this plausibly exogenous variation in the number of direct flights.[10]

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[8] For example, prior to the 2008 merger with Delta airlines, Northwest Airlines flew profitable and popular direct flights between its Minneapolis/St. Paul hub and Honolulu, Hawaii, using its then new and advanced Airbus 330. This route was subsequently cancelled after the merger as Delta, which previously had no such aircraft, moved the A330s for other longer-range flights, forcing passengers in this area to connect via west coast cities such as Los Angeles.

[9] Airline mergers and alliances are often subject to complex and lengthy regulatory approvals and antitrust investigations. Airlines' (successful and unsuccessful) merger activities can be related to bankruptcies (e.g., US Airways' $8 billion bid in 2006 for the bankrupted Delta that eventually failed). Airline mergers can also affect their strategic alliances: Delta's 2008 acquisition of Northwest Airlines resulted in Continental Airlines' departure from the SkyTeam Alliance, which later joined United Airlines for the Star Alliance. The proposed acquisition of American Airlines, a Oneworld Alliance member, by US Airways (a Star Alliance member) in February 2013, if eventually approved, can leave the members of Oneworld Alliance without (code-sharing) access to the US domestic air travel market.

[10] It is possible that a VC investor chooses to fly corporate jets to visit its entrepreneurial firms instead of taking commercial flights. However, the availability of corporate jets and the frequency of direct flights tend to be correlated. Most commercial airlines offer corporate jets services in addition to commercial flights. Econometrically, to identify causality by our IV and to ensure unbiased 2SLS estimates require not all, but only some, VC investors to

Second, as described also in Section 3.3 below, we include VC state fixed effects and IPO firm state fixed effects throughout our analyses. These location-based fixed effects control for time-invariant unobserved local factors that affect VC financing and an entrepreneurial firm's innovation potentials.

Lastly, it is possible that unobserved time-varying local factors also affect our results. For instance, more frequent direct flights could be related to a larger number of IPO firms that are innovative because of a local economic boom. Alternatively, more frequent direct flights could be related to more investments in innovative IPO firms because VCs are doing well. Our main approach—restricting our attention to VC-entrepreneurial firm pairs in which the frequency of direct flights during the firm's incubation period is affected by airline restructuring events—helps to address this potential concern. Nevertheless, to mitigate any lingering doubts, we control, additionally, local economic shocks that may affect IPO firms and VC investors. Since our focus is VC's stage financing during an IPO firm's incubation period, our data structure does not allow for inclusion of both year fixed effects and state fixed effects for VCs and IPO firms. Instead, we attempt to capture time-varying local shocks to VCs and IPO firms by constructing *Local IPO Market* and *Local VC market*. Following Benveniste et al. (2003), for each IPO firm i, we construct *Local IPO Market* by counting the number of firms located in the same state that went public during firm i's incubation period. For each VC j that invests in IPO firm i, we construct *Local VC Market* by counting the number of IPO firms that VC j has invested during firm i's incubation period. Using IPO proceeds instead of the numbers of IPOs generates similar results; these results are not reported but are available upon request.

3.2 Measuring Innovation and VC Staging

We use VC staging to capture the extent to which a VC investor keeps a tight leash on its IPO firm during the firm's incubation period. To measure the extent of VC staging, we use the number of financing rounds a VC invests in the IPO firm before it goes public.

The leashing hypothesis suggests that more interference from VCs when interacting with their entrepreneurial firms induces more short-termist behaviors, discouraging these firms from engaging in innovative projects, which otherwise tend to be risky and time-consuming. To

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take commercial flights. The extent of the exogenous variation generated by the IV affects only the power of the test, which we now provide several verifying statistics.

clearly identify the effect of VCs' tight leash on entrepreneurial firms' innovation, we look for a firm's innovation output *after* it goes public. Specifically, innovation output for an IPO firm is measured for the period from year t to year $t + 5$, where t is the year when a VC-backed firm goes public. We design the test this way because before a firm goes public, VC staging and firm's innovation are mingled together; thus it is difficult to establish a causal link between them. After a firm goes public, the number of rounds is a done deal and all new patent filings should be affected by the number of VC financing rounds (if there is a causal effect from VC staging to firm innovation).

To gauge an IPO firm's innovation output, we construct two measures based on the information retrieved from the National Bureau of Economic Research (NBER) patent database. Griliches, Pakes, and Hall (1988) argue that a patent's application year, instead of its grant year, better captures the actual time of innovation. Our first measure is thus an IPO firm's number of patent applications filed in a given year that are eventually granted. While patent counts are straightforward to compute, this measure cannot distinguish groundbreaking innovations from incremental technological discoveries. To further assess a patent's impact, we construct the second measure of innovation productivity by counting the number of citations that each granted patent receives in subsequent years. Controlling for firm size, the number of patents captures the quantity of a firm's innovation output while the number of citations per patent captures the quality of the firm's innovation output.

Following the existing innovation literature, we adjust the two innovation measures to address the truncation problems associated with the NBER patent database. The first truncation problem arises as the patents appear in the database only after they are granted. In fact, we observe a gradual decrease in the number of patent applications that are eventually granted as we approach the last few years in the sample period. This is because the lag between a patent's application year and grant year is significant (about two years on average) and many patent applications filed during these years were still under review and had not been granted by 2006. Following Hall, Jaffe, and Trajtenberg (2001, 2005), we correct for this truncation bias in patent counts using the "weight factors" computed from the application-grant empirical distribution using the patents filed and granted between 1995 and 2000.

The second type of truncation problem is regarding the citation counts, as a patent can keep receiving citations over a long period of time (e.g., 50 years), but we observe at best the

citations received up to 2006. Following Hall, Jaffe, and Trajtenberg (2001, 2005), we correct for this truncation bias by dividing the observed citation counts by the fraction of predicted lifetime citations that is actually observed during the lag interval. More specifically, we scale up the citation counts using the variable "hjtwt" provided by the NBER patent database that relies on the shape of the citation-lag distribution.

One advantage of the NBER patent database is that it is unlikely to be affected by the survivorship bias. As long as a patent application is eventually granted by the United States Patent and Trademark Office (USPTO), it is attributed to the applying firm at the time of application even if the firm later gets acquired or goes bankrupt. Moreover, because patent citations are attributed to a patent but not the applying firm, the patent that is granted to a firm that later gets acquired or goes bankrupt can still keep receiving citations long after the firm disappears.

Our main measures for innovation are thus $ln(Patents)$ and $ln(Citations)$, computed as the natural logarithm of patent counts, and the natural logarithm of the number of citations per patent, respectively. To avoid losing firm-year observations with zero patents or citations per patent, we add one to the actual values when calculating the natural logarithm.

It is important to note that using patenting activity to measure firm innovation is not without limitations. For example, patenting is only one of several ways in which firms use to protect returns from innovation, and different industries have various innovation duration and patenting propensity. However, we believe that an adequate control for heterogeneity in firm industries, firm development stages at the first round of VC financing, and VC investors should alleviate this concern and lead to reasonable inferences that can be applicable across industries and firms.

3.3 Control Variables

We construct a vector of VC firm and investment characteristics that could affect an IPO firm's innovation output documented by the existing literature. First, we control for VC characteristics such as the size of VC syndicates (the number of VC investors investing in a given IPO firm) and a measure for VC reputation, as developed by Nahata (2008). Second, we control for *ex ante* IPO firm characteristics that may affect their post-IPO innovation productivity. Specifically, we include a firm's *ex ante* innovation output, captured by the number

of patent counts and citations per patent at the time when it receives the first round of VC financing. We also include in the regressions a firm's age and its development stage when it receives the VCs' first round of investment, as well as the length of the firm's incubation period.

Following the innovation literature, we control for a vector of firm and industry characteristics that could affect a firm's innovation output post IPO. We compute each variable for IPO firm i over its fiscal year t after IPO. The controls include firm size (the natural logarithm of book value assets), investments in intangible assets (R&D expenditures over total assets), profitability (return on assets (ROA)), asset tangibility (net properties, plants, and equipment (PPE) scaled by total assets), leverage, product market competition (the Herfindahl index based on sales), and institutional ownership.

To minimize the impact of outliers on our results, we winsorize all the continuous variables at the 1^{st} and 99^{th} percentiles. The exceptions are the Herfindahl index and institutional ownership, whose value ranges between 0 and 1.

Lastly, we include various fixed effects to control for unobserved industry-specific, IPO year-specific, and VC and IPO firm location-specific variations that can affect VC staging and firm innovation. In particular, VC state fixed effects and IPO firm's state fixed effects take into account time-invariant local factors that affect their financing and innovation potentials. As described in Section 3.1, to capture time-varying local shocks to VCs and IPO firms, we also control *Local IPO Market* and *Local VC Market* in the regressions.

4. DATA AND SAMPLE CHARACTERISTICS

4.1 Data Sources and Sample Selection

We extract a sample of equity IPOs between 1980 and 2004 from the SDC Global New Issues database. To allow for the availability of the post-IPO innovation output information from the NBER patent database, we end the sample period of IPOs in 2004. Following the IPO literature, we exclude from the initial IPO sample spin-offs, closed-end funds, Real Estate Investment Trusts (REITs), unit offerings, reverse leveraged buyouts (LBOs), foreign issues, offerings in which the offer price is less than $5, finance (SIC codes between 6000 and 6999), and utilities (SIC codes between 4900-4999). We also exclude firms with missing identities of their VC investors and those with missing or inconsistent data.

We obtain VC investment data from the Thomson VentureXpert database for entrepreneurial firms that went public in the sample period and merge it with our sample of IPO firms. The sample examined thus includes VC-backed firms that went public during the period between 1980 and 2004. We update and cross-reference the information provided by the VentueXpert database with other sources. Specifically, we update and fill in the missing observations for the date on which the firm was founded using Jay Ritter's database (http://bear.cba.uf.edu/ritter/ipodata.htm). We also manually correct obviously inconsistent information obtained from VentureXpert by visiting the firms' websites and reading firms' registration statements with Securities and Exchange Commission (SEC).

Our measure for VC staging is the number of financing rounds a VC invests in the IPO firm during the firm's incubation period. Gompers and Lerner (2006) show that the VentureXpert database reports 28% more financing rounds than actually occurred because Thomson frequently splits financing rounds. This leads to a single financing round to be presented as several separate rounds by different VC firms on different (but proximate) dates. We correct VentureXpert's over-reporting problem following the procedures described in Tian (2011).

We collect innovation output data and construct our main innovation variables from the latest version of the NBER patent database that is constructed based on information provided by the USPTO.[11] This database contains patent and citation information from 1976 to 2006. It provides annual information on patent assignee names, the number of patents, the number of citations received by each patent, a patent's application year as well as its grant year, a patent's technology class, etc.

To construct instrument variables, we obtain the information on direct flights from the U.S. Department of Transportation's Bureau of Transportation Statistics.[12] Specifically, its "Airline On-Time Performance Data" contains on-time arrival information for non-stop domestic flights by major commercial air carriers. The dataset covers direct flight information since October, 1987. Information on airline restructuring—bankruptcies, strategic alliances, and mergers and acquisitions—is from Wikipedia and airlines' websites.[13]

[11] Available at http://www.uspto.gov/. See Hall, Jaffe, and Trajtenberg (2001) for details.
[12] Available at http://www.rita.dot.gov/bts/node/11792
[13] We also obtained airline merger and acquisition information from http://www.airlines.org/Pages/m_About.aspx.

We obtain from VentureXpert information on cities in which VC and entrepreneurial firms reside. We then manually identify the corresponding nearest commercial airports through internet searches, including using Google maps and MapQuest.

To construct the control variables, we collect financial statement information from Compustat and institutional holdings data from Thomson's CDA/Spectrum database (form 13F).

Our final sample contains 1,840 VC-backed entrepreneurial firms that went public during the 1980-2004 period (10,755 firm-year observations). There are 25 unique air carriers providing direct flight services between VC domiciles and IPO firm headquarters during our sample period. A total of 54 airline restructuring events occurred, 35 of which involve bankruptcies, 13 are mergers and acquisitions, and 6 are strategic alliances. Out of the 1,840 IPO firms, 1,115 firms experience airline restructuring events during their incubation periods, accounting for 60.6% of our sample.

4.2 Summary Statistics

Table 1 provides summary statistics of the variables, for the full sample, and for the subsample of firms whose incubation periods overlap with airline restructuring events, respectively. Panel A presents the IPO firm-level descriptive statistics of VC staging, investment characteristics, and entrepreneurial firm characteristics during the incubation period. For the full sample, an average IPO firm receives 4.8 rounds of financing from its VC investors, and receives investments from 7.9 VC investors across all financing rounds. When receiving its first round of VC financing, an average firm has 0.2 patents and is 3.2 years old. During a firm's incubation period, which averages around 4.25 years, its VCs invest into 19 other IPO firms. During the same period, there are 225 firms that went public from the same state. There are on average 76 daily flights (inbound plus outbound) between VC domiciles and IPO firm headquarters. Furthermore, the descriptive statistics of the variables in the subsample in which the variations in the frequency of direct flights during firms' incubation periods are due to airline restructuring activities are comparable to those in the full sample.

Panel B reports the IPO firm-year level descriptive statistics for innovation and control variables during the period after a firm goes public. For the full sample, an average firm has 1.9 granted patents per year during the five year period after the IPO, with each patent receiving 7.1 future citations. Regarding other variables, an average IPO firm has book value assets of $121

million, R&D-to-assets ratio of 16%, ROA of -11%, leverage ratio of 14%, and 19% of shares held by institutional investors.

Panel C reports the geographic distribution of IPO firms and VCs. Our sample firms are distributed among 42 states and VCs are distributed among 39 states.[14] We observe that 41% of our sample firms are headquartered in California, followed by Massachusetts (11.01%), Texas (5.62%), New York (4.31%) and New Jersey (3.49%). California is also the state where the most VCs reside (35.76% of our sample VCs), followed by New York (18.68%), Massachusetts (14.23%), Connecticut (5.3%), and Illinois (3.48%).

5. VC STAGING AND IPO FIRM INNOVATION

5.1 Baseline Regressions

We first explore the leashing hypothesis versus agency hypothesis in a naïve OLS panel regression framework. Specifically, we estimate the following model:

$$Innovation = \beta_0 + \beta_1(\#of\ Rounds) + \Omega' Z + \alpha_{IPO\ Year} + \alpha_{Industry} + \alpha_{VC\ State} + \alpha_{Firm\ State} + \varepsilon$$

The dependent variable is one of our two main innovation variables, patent outputs or citations per patent, measured during the post-IPO five year period. *# of Rounds* is the key variable of interest, measured by the number of VC financing rounds before the firm goes public. A higher number indicates greater intensity of VC stage financing. Z is a vector of control variables described in Section 3.3. $\alpha_{IPO\ Year}$ captures IPO year fixed effects (Lerner, 1994), $\alpha_{Industry}$ captures IPO firm's industry fixed effects, $\alpha_{VC\ State}$ captures VC firm's state fixed effects, and $\alpha_{Firm\ State}$ captures IPO firm's state fixed effects. We cluster standard errors at the IPO firm level.

Column 1 of Table 2 reports the results estimating the above equation, with $ln(Patents)$ as the dependent variable. The coefficient estimate of *# of Rounds* is insignificant. This finding suggests that the intensity of VC staging does not appear to be related to the innovation output of the entrepreneurial firms after they go public. In column 2, we control, additionally, the two measures capturing local shocks, *Local IPO Market* and *Local VC Market.* In columns 3 and 4, the dependent variable is $ln(Citations)$. In neither case, the coefficient for *# of Rounds* is statistically significant.

[14] We are unable to identify information on home state for 6 sample firms and 177 VCs.

The results in Table 2 are not surprising given that VC's staging decision is endogenous to entrepreneurial firms' characteristics, including their innovation potentials, which are unobservable to researchers. Therefore, the coefficient estimates of *# of Rounds* are likely biased.

To address the identification concern and to establish causality, we construct an instrumental variable for VC's financing rounds during IPO firms' incubation period using the daily number of inbound and outbound domestic direct flights between cities where VC and entrepreneurial firm are located. As explained in Section 3.1, we also use a refined instrument that is based on the number of direct flights being affected by airlines' restructuring events.

In Table 3, we present the regression estimates for our 2SLS analysis, where the instrumental variable, *Direct Flight*, is constructed for the full sample. Panel A reports the first-stage regression estimates with *# of Rounds* as the dependent variable. The main independent variable is the constructed instrument, *Direct Flight*. Control variables are the same as those in the OLS regressions reported in Table 2. Robust standard errors are clustered at the IPO firm level.

Consistent with the intuition for the instrument construction and in light of Tian (2011), column 1 of Panel A shows that the coefficient estimate of *Direct Flight* is negative, and is significant at the 1% level. More frequent direct flights allow for the ease of VC monitoring, substituting the need for splitting funding to more financing rounds to alleviate the hold-up problem, thus saving the costs associated with staging for VCs. The Stagier and Stock (1997) *F*-statistics of the first-stage in IV estimation is 17.63, suggesting that the instrument is highly correlated with the endogenous right-hand-side variable in the second stage, and that it does not appear to suffer from the weak instrument problem.

In column 2, we control, additionally, two measures for local shocks that affect IPO firms and investing VCs during firms' incubation period. We observe that *Direct Flight* continues to be negatively related to *# of Rounds*. The coefficient estimate on *Direct Flight* suggests that one standard deviation (50.38) increase in the number of daily direct flights is associated with a drop of 0.3 financing rounds (= -0.006×50.38), which is equivalent to 10.28% of the standard deviation of *# of Rounds*.

Panel B reports the second-stage regression estimates, with firm's post-IPO innovation output variables as the dependent variable and the predicted values of the number of financing rounds as the independent variable.

The coefficient estimates of instrumented *# of Rounds* are negative and significant in all four columns. The results suggest that VC staging is negatively related to IPO firm's innovation, in terms of both patent quantity and quality. This finding suggests that more frequent interference by VCs during an IPO firm's incubation, captured by a larger number of financing rounds, are detrimental to nurturing firm innovation. This finding is consistent with the leashing hypothesis, but is inconsistent with the agency hypothesis.

Importantly, the effects we document are not only statistically significant, but also economically large, when we exploit the exogenous variation in the extent of VC staging. When we consider only the variation in the number of VC financing rounds due to the frequency of direct flights between the cities where VCs and their entrepreneurial firms reside, one additional financing round—which brings the number of rounds from the sample mean (4.75 rounds) to the 66th percentile—leads to a 28.3% decrease in the number of patent applications that are eventually granted, a change which brings the patent counts from the sample mean (1.90 patents) to 1.36, or from the 82nd percentile to the 77th percentile.

5.2 Airline Direct Flights Subject to Restructuring

In Table 4, we undertake our 2SLS analysis using the refined IV based on the subsample of VC-IPO firm pairs in which the frequency of direct flights is affected by airline restructuring events, such as bankruptcies, mergers and acquisitions, and strategic alliances. As discussed before, the variation in the frequency of direct flights offered by an airline company due to its restructuring events is plausibly exogenous, as it is driven by airlines' own restructuring plans and strategic re-alignments rather than by local economic conditions or the market size of the business and leisure travels that may be related with innovation.

Panel A of Table 4 repeat the same set of first-stage regressions as in Panel A of Table 3, but restrict to the subsample of VC-IPO firm pairs in which the IPO firm's incubation period overlaps with airline restructuring events. We observe from columns 1 and 2 of Panel A that the coefficient estimates of the instrument, *Direct Flight*, are negative and significant at the 1% level, regardless of whether or not we include additional controls for local shocks to firms and VCs. The Stagier and Stock (1997) *F*-statistics suggest that we can reject the null hypothesis that the instrument is weak.

In Panel B of Table 4, we report the second-stage regression results in the refined IV

setting. We observe similar findings: the coefficient estimates of instrumented *# of Rounds* are negative and significant at the 5% level in all columns. The estimates are still strongly supportive of a negative effect of VC staging on IPO firms' subsequent innovation output. For instance, one additional financing round—which brings the number of rounds from the subsample mean (5.3 rounds) to the 76th percentile—leads to a 27.2% decrease in the number of patent filings that are eventually granted, a change which brings the patent counts from the subsample mean of 2.25 to 1.64, effectively reducing innovation output from the 79th percentile to the 74th percentile level.

Comparing the results obtained from the OLS analysis in Table 2 and the 2SLS analysis in Tables 3 and 4, it is evident that the OLS biases the coefficient estimate of *# of Round* upward, which suggests that some omitted variables simultaneously make a firm more innovative and more likely to receive a larger number of VC financing rounds. An example of such an omitted variable could be the entrepreneurial firm's technology complexity. For instance, a new venture in the early stage of developing a new and complex technology is, by nature, very difficult for the VC investor to evaluate. Therefore, the venture is likely to receive multiple financing rounds from the VC (Gompers, 1995). Meanwhile, the development of this technology, once successful, is likely to result in many innovative products and patents. This positive correlation between staging and firm innovativeness caused by omitted variables is the main driving force that biases the coefficient estimate upward. Once we use the IV to clean up the correlation between VC staging and the omitted variable left in the residual term, the endogeneity of VC staging is removed and the coefficient estimate decreases, i.e., becomes negative.

6. CROSS-SECTIONAL ANALYSES

In this section, we examine how VC staging affects IPO firm innovation output differently in the cross section in the 2SLS framework. We use the cross-section variation in IPO firm's innovation difficulty, product market competition, and VC's industry experience to further identify the possible causal effect of VC staging on IPO firm innovation output.

In all three sets of the 2SLS analyses, we use the refined IV and focus on the subsample of VC-IPO firm pairs in which the frequency of direct flights is affected exogenously by airline restructuring events, such as bankruptcies, mergers and acquisitions, and strategic alliances. To save space, we only tabulate the second-stage results.

6.1 Innovation Difficulties

Our analysis so far demonstrates that a tighter leash, or more interference, by VC investors during IPO firms' incubation period, degrades the quantity and quality of their innovation. If VC staging indeed induces short-termist behaviors of entrepreneurs and impedes innovation, then a natural cross-sectional implication is that VC staging should be particularly detrimental in industries in which innovation is difficult to achieve. The intuition is that a tight leash hampers innovation incentives especially when the process to innovate is long and the resources demanded are large so that early failures are more likely to be observed. This is because it forces entrepreneurs to focus more on short-term performance targets, instead of leaving enough room to allow them to engage in long-term innovative projects.

We split our sample of IPO firms based on whether or not innovations are more difficult to achieve in the industry to which they belong. Following the work of Hall, Jaffe, and Trajtenberg (2005), we classify our sample into two categories based on patent technology class: more demanding industries that include pharmaceutical, medical instrumentation, chemicals, computers, communications, and electrical industries, and less demanding industries that include software programming, internet applications, and other low-tech industries. In drug and electronics industries, the innovation process is typically long, failure risk is high, and resources demanded are larger. On the other hand, fostering innovations is less difficult and resource demanding in software and low-tech industries.

Table 5 reports the 2nd-stage of the 2SLS estimates for the two subsamples. For brevity, control variables and various fixed effects are included in the regressions but are not tabulated. We observe that the coefficient estimates of *# of Rounds*—instrumented by *Direct Flight* that varies due to airline restructuring—are negative and significant in more demanding industries. By contrast, VC staging does not seem to significantly affect innovation in industries where innovation is less difficult to achieve. The evidence suggests that the effect of VC staging on firm innovation is more detrimental in industries in which innovation is more difficult to achieve, which is consistent with our conjecture.

6.2 Product Market Competition

Short-term pressure imposed upon firms can be exacerbated by product market competition (Aghion, Van Reenen, and Zingales, 2013). To keep competitive advantage over its

rivals to survive, a firm more likely engages in short-term actions when the competition pressure from peer firms is higher (i.e., when the product market competition is fiercer). To the extent that product market competition is an alternative mechanism that keeps entrepreneurs on a tight leash, we expect VC staging financing to particularly adversely affect firm innovation if the entrepreneurial firm is operating in a more competitive product market.

To test this conjecture, we split our sample of IPO firms based on whether or not a firm operates in a more competitive product market. The extent of product market competition is measured by the Herfindahl index computed based on the three-digit SIC code during the year when the IPO firm receives its first round VC financing. Industries with more competitive product markets are those whose Herfindahl indices fall below the sample median.

Table 6 reports the 2nd-stage estimates of the 2SLS regressions for the "more competitive industry" subsample (columns 1 through 4) and for the "less competitive industry" subsample (columns 5 through 8), respectively. Consistent with our conjecture, the coefficient estimates of instrumented *# of Rounds* are negative and significant in columns 1 through 4 while those are not statistically significant in columns 5 through 8. The evidence suggests that VC staging negatively affects IPO firm's innovation output only if the IPO firm operates in more competitive product markets. Its effect is absent in firms operating in less competitive product markets.

6.3 Industry Expertise

Lastly, we examine how the effect of VC staging on entrepreneurial firms' post-IPO innovation output varies with the extent of industry expertise of VC firms. The intuition is as follows: if VCs are more experienced with the industry to which their portfolio firms belong, they would have a better understanding about the business and innovative nature of the entrepreneurial firm. Consequently, their staged capital infusions should be less detrimental to these firms' innovation output. On the other hand, if a VC is less experienced with the industry in which the entrepreneurial firms operate, the downsides of keeping a tight leash dominate. Therefore, its frequent interferences should have a more negative effect on their innovation output.

We measure a VC's industry expertise on a rolling 10-year window basis. Industry classification is based on the "major" industry classifications defined in the VentureXpert

database.[15] For each entrepreneurial firm in our sample, we identify its lead VC's industry experience at the time when the firm receives its first VC investment. The industry experience is computed by dividing the total number of entrepreneurial firms that a VC has invested in an industry in the previous 10 years by the total number of entrepreneurial firms that the VC has invested in all the industries during the same period. This measure thus captures a lead VC's experience in a specific industry at the time when it makes the initial investment into the entrepreneurial firm. A higher value of this measure suggests that a VC has more experience and exposure in the industry to which the entrepreneurial firm belongs.

We use the median value of a lead VC's industry experience to define VC industry expertise. The "more experienced" subsample contains IPO firms that involve VCs with above-sample median industry experience, whereas the "less experienced" subsample contains IPO firms that involve VCs with below-median industry experience. We expect that stage financing is mostly detrimental among these firms in which the VCs are less experienced with the industry to which the entrepreneurial firms belong, and should not prevail among firms whose lead VCs are more experienced about the nature and challenge of the industry where they operate.

Table 7 reports the 2[nd]-stage estimates of the 2SLS regressions for the subsamples where VCs are less experienced in the industry to which the firm belongs (columns 1 through 4) and where VCs are more experienced in the industry in which a firm operates (columns 5 through 8), respectively. The coefficient estimates of instrumented *# of Rounds* are negative and significant at the 5% level for the "less experienced VCs" subsample, but are insignificant for the "more experienced VCs" subsample. The evidence suggests that VC staging negatively affects innovation output in IPO firms when VCs are less experienced in the industries in which their portfolio firms operate, but this effect is not observed if the VC investors have expertise in the IPO firm's industry. The evidence is consistent with our conjecture.

Overall, the cross-sectional tests further lend credence to our causal inferences of the negative effect of VC staged capital infusions on firm innovation. While the documented results could be driven by VCs endogenously choosing to stage less in more innovative firms, our tests suggest that the negative relation is unlikely to be entirely driven by this alternative selection

[15] Specifically, the industries include: Biotechnology, Communications and Media, Computer Related, Medical/Health/Life Science, Non-High-Technology and Semiconductors/Other Elect.

story. Instead, coupled with our results from identification tests reported in Section 5, there appears a treatment effect at least partially in play.

7. EXTENSIONS AND ROBUSTNESS

7.1 Ease of Monitoring or Interference

We instrument VC stage financing using the frequency of direct flights during an entrepreneurial firm's incubation period. We argue that more frequent direct flights allow for ease of access by VCs to the entrepreneurial firm they fund, which reduces the need for stage financing to mitigate the hold-up problem, leading to a reduced intensity of VC's leashing on the firm, which, in turn, spurs firm innovation.

However, one possible alternative argument is that the frequency of direct flights may affect a firm's innovation output via ease of monitoring instead of through a lower level of VC interference. To test the validity of this argument, one may be tempted to run a reduced form regression in which the innovation outcome variable is regressed on the number of direct flights and check whether the coefficient estimate of the direct flight variable is statistically significant. However, this empirical design cannot address the concern. This is because the coefficient estimate of the direct flight variable in the reduced form regression is by definition positive and significant, given the negative coefficient estimate of the direct flight variable in the 1st-stage and the negative coefficient estimate of the instrumented VC staging variable in the 2nd-stage. Therefore, to address this concern, we have to rely on an alternative empirical design.

VC monitoring can affect not only a firm's innovation but also its routine operations. Therefore, if the frequency of direct flights merely portrays the ease of VC monitoring, then we should expect to observe that the IPO firm's routine operations, such as ROA and asset turnover, be improved if VCs can monitor the entrepreneurial firms with less cost in the presence of more daily direct flights. We thus estimate a reduced form OLS regression below:

$$Operation = \beta_0 + \beta_1(Direct\ Flight) + \Omega' Z + \alpha_{IPO\ Year} + \alpha_{Industry} + \alpha_{VC\ State} + \alpha_{Firm\ State} + \varepsilon$$

where the dependent variable is either *ROA* or *Asset Turnover* and *Direct Flight* is the key variable of interest. If *Direct Flight* merely captures the ease of VC monitoring, its coefficient estimate should to be both positive and significant.

Panel A of Table 8 reports the coefficient estimates of the OLS panel regression examining the effect of *Direct Flight* on firm's operating performance, measured from year t to year $t+5$ after the firm goes public. We observe that *Direct Flight* is insignificantly related to either ROA or Asset Turnover, regardless whether it is based on the entire sample of direct flights, or a subsample of direct flights that are affected by airline restructuring. In most cases, the coefficient estimates are negative.

In Panel B of Table 8, we focus on an alternative measure for performance: post-IPO survival rate. Bhattacharya, Borisov, and Yu (2013) find that the first three years after IPO are crucial to a firm's long-term survival. The mortality rates of U.S. public firms initially increase, peaking at three years after a firm goes public, and then decrease with age. If the variation in the frequency of direct flights captures the ease of VC monitoring, then we expect that VC stage financing positively and significantly affects an IPO firm's survival rate.

Following Bhattacharya, Borisov, and Yu (2013), we construct a dummy for involuntary delisting that equals one if an IPO firm is delisted due to liquidation, delisting, and/or permanent trading halts (CRSP delisting codes 400-490 or 500-591) in a year after IPO, and zero otherwise. Panel B reports the marginal effects of the coefficient estimates from the probit regression, with the involuntary delisting dummy as the dependent variable. Again the main independent variable, *Direct Flight*, is insignificantly related to post-IPO survival.

The results in Table 8 suggest that the frequency of direct flights is not merely a proxy for monitoring easiness. Instead, it appears that it affects innovation output through its effect on a VC's staging incentives.

7.2 Alternative Sample Structure and Restrictions

Since the number of financing rounds an IPO firm receives before it goes public is time-invariant for each IPO firm in our baseline panel regressions, an alternative way of analyzing the data is to run cross-sectional regressions. We then estimate the effect of VC staging on innovation in a cross-sectional data framework and report the 2SLS results in Table 9. The dependent variables are the total number of granted patents that are filed by each IPO firm within the first three years after IPO and the average number of citations each of these patents receives.

We impose the arbitrary three-year threshold to facilitate comparisons of innovation-output across IPO firms because some IPO firms get acquired or delisted a few years after IPO.

The independent variable is the total number of financing rounds an IPO firm receives during its incubation period. The values of all control variables are measured either as of the venture's first VC financing round year or the venture's IPO year. Unlike previous tables where the observation unit is IPO firm-year, the observation unit in Table 9 is IPO firm.

Table 9 reports the 2^{nd}-stage estimates of the 2SLS regression results in the full sample (columns 1 through 4) and in the subsample based on the refined IV from airline restructuring (columns 5 through 8), respectively. The coefficient estimates of instrumented *# of Rounds* are negative and significant in all columns, consistent with the implications of the leashing hypothesis.

A second concern is that our main sample includes firms located in areas without direct flight services. In an alternative specification, we exclude firms that never had direct flight services to where their VCs are located during the incubation period. This restricted sample thus compares firms that have direct flight services available, but with varying degree of frequency of daily direct flights. This restricted sample also allows us to address the concern that VC investors may choose to fly corporate jets to visit the entrepreneurial firms instead of taking commercial flights. This is because, in our setting, as long as not all VCs and entrepreneurial firms use corporate jets to visit each other, the variation in direct flight frequency allows us to distinguish between those that are affected by the availability and frequency of direct flights and those that are not. By restricting to the subsample where direct flights are available to all the VC-entrepreneurial firm pairs, we focus our attention to the group of VC-entrepreneurial firm pairs that are least affected by the availability of corporate jets and explore the within-group variation. We find similar results (not tabulated): more frequent direct flight is associated with smaller number of financing rounds, which subsequently, leads to more innovation output.

7.3 Alternative Measures of Innovation Quality

In another robustness check, we explore the VC's "leashing" effect on the fundamental nature of an IPO firm's innovation along the dimensions of patent generality and originality. Patents that are being cited by a wider array of technology classes of patents are viewed as having greater generality. Specifically, we define *Generality* as one minus the Herfindahl index of the three-digit technology class distribution of all the patents that cite the current patent. A greater value of the variable indicates that the current patent affects the subsequent innovations

in a broader range of industries. In a similar spirit, patents that cite a wider array of technology classes of patents are viewed as having greater originality. We thus define *Originality* as one minus the Herfindahl index of the three-digit technology class distribution of all the patents that the current patent cites. A higher patent originality score means that the patent is drawing on a more diverse array of existing knowledge.

Table 10 reports the 2^{nd}-stage estimates from the 2SLS regressions for patent generality and originality, in full sample (columns 1 through 4) and in the subsample based on the refined IV from airline restructuring (columns 5 through 8), respectively. The coefficient estimates of *# of Rounds* are negative in all columns and are mostly significant, suggesting that a VC's tight leash, proxied by a larger number of financing rounds, leads IPO firms to generate patents with lower level of generality and originality. The evidence is consistent with the leashing hypothesis.

8. CONCLUSIONS

In this paper, we aim to tackle the question that whether investors' tight leashes on entrepreneurs promote or impede technological innovation by examining the effects of VC stage financing on IPO firms' innovation output. We find IPO firms financed by a larger number of VC financing rounds are significantly less innovative: these firms generate fewer patents and their patents receive fewer future citations. Using plausibly exogenous variation in the frequency of direct flights between VCs and entrepreneurs that is caused by airline restructuring, we show that the negative effect of VC stage financing on IPO firm innovation appears causal. We further explore the effect of VC staging on firm innovation in the cross section. We find that VC staging is more detrimental to firm innovation when innovation is more difficult to achieve, when the IPO firm is in more competitive product markets, and when VCs are less experienced in the industry in which entrepreneurs operate. Our paper uncovers a previously under-recognized adverse consequence of keeping entrepreneurs on a tight leash—its hindrance to technological innovation. Compared to other costs associated with VC staging as identified in the literature, the costs of stifled innovation can be much more substantial.

We acknowledge that two important caveats need to be borne in mind when interpreting or generalizing our results. First, while we show a negative effect of VC staging on firm innovation, consistent with the leashing hypothesis, we cannot rule out the possible positive role played by VC staging in promoting firm innovation, as suggested by the agency hypothesis. This

is because our evidence reflects only the net effect of VC staging on firm innovation. A tight leash kept by VCs could play both a positive role (by mitigating agency and hold-up problems) and a negative role (by imposing pressure on entrepreneurs to meet short-term stage targets) in motivating firm innovation. However, in practice, the former is dominated by the latter so that we observe a net negative effect of VC staging on firm innovation. Second, although we demonstrate one particular adverse effect of VC staging, we are agnostic about how VC stage financing, a unique feature of VC investment, affects entrepreneurial firm performance in many other ways (many of which could be positive). Hence, it is in appropriate to conclude, if based solely upon our evidence, that VC staging are detrimental to firm performance or social welfare. Further, while venture capital is a key ingredient of the capital market and our paper examines its influence on newly public firms' incentives to innovate, a proper evaluation of the overall effect of the financial and capital investment system on a nation's innovation productivity and competitive advantage is beyond the scope of this paper.

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Appendix
Variable Definitions and Data Sources

Innovation Measures (Data Source: NBER Patent Data)	
$ln(Patents)$	Natural logarithm of one plus the total number of patents a firm filed (and eventually granted) in a given year. The total number of patents is winsorized at the 1st and 99th percentiles.
$ln(Citations)$	Natural logarithm of one plus the total number of citations received on the patents that a firm filed (and eventually granted), scaled by the number of the patents filed (and eventually granted) by the firm. The total number of citation counts per firm is winsorized at the 1st and 99th percentiles.
$ln(Patents\ at\ 1st\ Round)$	Natural logarithm of one plus the total number of patents a firm filed (and eventually granted) before or at the time when it receives the first round of VC financing. The total number of patents is winsorized at the 1st and 99th percentiles.
$ln(Citations\ at\ 1st\ Round)$	Natural logarithm of one plus the total number of citations received on the patents a firm filed (and eventually granted) before or at the time when it receives the first round of VC financing. The total number of citation counts per firm is winsorized at the 1st and 99th percentiles.
Generality	One minus the Herfindahl index of the three-digit technology class distribution of all the patents that cite a firm's given patent. We then take the average for all patents generated by the firm.
Originality	One minus the Herfindahl index of the three-digit technology class distribution of all the patens that a firm's current patent cites. We then take the average for all patents generated by the firm.
VC and Project Characteristics (Data Source: VentureXpert)	
# of Rounds	The total number of financing rounds an entrepreneurial firm receives from investing VCs prior to its IPO. Winsorized at the 1st and 99th percentiles.
Firm Stage	A dummy variable that equals one if an entrepreneurial firm is in its seed/startup or early stage, and zero if is in its expansion, late, or buyout/acquisition stage, when it receives the first round of VC financing
Incubation Period	The length of time between the date when an entrepreneurial firm receives its first VC financing and the date of its IPO. Winsorized at the 1st and 99th percentiles.
Local VC Market	Total number of IPO firms that VCs invest during an IPO firm i's incubation period, excluding firm i itself. Winsorized at the 1st and 99th percentiles.
VC Syndication Size	The number of VCs that invested in the entrepreneurial firms. Winsorized at the 1st and 99th percentiles.
VC Reputation	The weighted average of reputation of firm i's lead VC firms. A VC firm's reputation is measured by the dollar market value of

	all companies taken public by the VC firm from the beginning of calendar year 1980 until a given calendar year then normalized by the aggregate market value of all VC-backed companies that went public from the beginning (Nahata, 2008).
IPO Firm Characteristics (Data Sources: COMPUSTAT and SDC)	
Size	Natural logarithm of book value of total assets (COMPUSTAT data item #6), which is measured at the end of the fiscal year. Total assets are winsorized at the 1^{st} and 99^{th} percentiles.
Firm Age	The difference between current year and the firm's founding year. Winsorized at the 1^{st} and 99^{th} percentiles.
R&D	Research and development (R&D) expenditure (data item #46), scaled by book value of total assets (#6) measured at the end of fiscal year. This variable is set to 0 if missing. Winsorized at the 1^{st} and 99^{th} percentiles.
ROA	Return on assets ratio defined as operating income before depreciation (#13), scaled by book value of total assets (#6), measured at the end of the fiscal year. Winsorized at the 1^{st} and 99^{th} percentiles.
PPE	Property, plant & equipment (#8), scaled by book value of total assets (#6) measured at the end of the fiscal year.
Leverage	Book value of debt (#9 + #34) divided by book value of total assets (#6), measured at the end of the fiscal year. Winsorized at the 1^{st} and 99^{th} percentiles.
Local IPO Market	Total number of firms that are headquartered in the same state as IPO firm i and went public during firm i's incubation period, excluding firm i itself. Winsorized at the 1^{st} and 99^{th} percentiles.
Institutional Ownership	Institutional holdings of shares of a firm during the year, calculated as the arithmetic mean of the four quarterly institutional holdings reported through form 13F.
Industry Concentration	The Herfindahl index of the industry where a firm operates, measured at the end of the fiscal year. Industry classification is based on the two-digit SIC code.
Instrumental Variable (Data Sources: Bureau of Transportation Statistics and Wikipedia)	
Direct Flight	The number of direct flights (inbound and outbound) between the airports where VC and the entrepreneurial firm are located. Computed as the sum of direct flights during the incubation period scaled by the length of incubation period, weighted by investment amounts of VCs.

Table 1
Descriptive Statistics

This table reports the summary statistics for variables constructed based on the sample of U.S. firms which went public from 1980 to 2004. The unit of analysis is IPO firm in Panel A, and is IPO firm-year in Panel B. "# of Patents at 1st Round" is the total number of patents a firm filed (and eventually granted) before or at the time when it receives the first round of VC financing. "# of Citations at 1st Round" is the total number of citations received on the patents a firm filed (and eventually granted) before or at the time when it receives the first round of VC financing. "# of Patents" is the total number of patents a firm filed (and eventually granted) in a given year after IPO; "# of Citations" is the total number of citations received on the patents that a firm filed (and eventually granted), scaled by the number of the patents filed (and eventually granted) by the firm; "Assets" is the book value of total assets (COMPUSTAT data item #6). These variables are winsorized at the 1st and 99th percentiles to mitigate the influence of outliers on the results. The rest of the variables are defined in Appendix. Panel C reports the geographic distribution of sample IPO firms and VCs.

Panel A: IPO Firm-level Variables

	25th	Mean	Median	75th	Standard Deviation	# of obs.
Full Sample						
# of Rounds	2	4.75	4	6	2.94	1,840
Firm Stage	0	0.70	1	1	0.46	1,816
# of Patents at 1st Round	0	0.21	0	0	1.05	1,840
# of Citations at 1st Round	0	2.48	0	0	12.62	1,840
VC Reputation	0	0.02	0.00	0.02	0.03	1,840
VC Syndication Size	3	7.88	7	11	5.59	1,840
Incubation Period	2.05	4.25	3.55	5.58	3.08	1,840
Firm Age	0.33	3.18	1.37	4.00	4.55	1,837
Local IPO Market	45	225.05	135	358	226.51	1,834
Local VC Market	2.67	19.41	13.2	26.33	23.91	1,835
Direct Flights	23.27	76.24	85.67	128	50.38	1,668
Subsample for Airline Restructuring						
# of Rounds	3	5.34	5	7	2.94	1,115
Firm Stage	1	0.75	1	1	0.43	1,094
# of Patents at 1st Round	0	0.19	0	0	1.00	1,115
# of Citations at 1st Round	0	2.36	0	0	12.47	1,115
VC Reputation	0	0.02	0.00	0.02	0.03	1,115
VC Syndication Size	5	8.87	8	12	5.35	1,115
Incubation Period	2.44	4.59	3.97	6.07	3.04	1,115
Firm Age	0.27	2.70	1.07	3.16	4.13	1,113
Local IPO Market	62	276.29	196	460	246.19	1,115
Local VC Market	4.21	18.73	13.62	25.62	21.48	1,115
Direct Flights	21.41	68.23	66.99	127.68	46.81	1,078

Table 1 continued.

Panel B: IPO Firm-year Level Variables

	25th	Mean	Median	75th	Standard Deviation	# of obs.
Full Sample						
# of Patents	0	1.89	0	1	5.15	10,755
# of Citations	0	7.12	0	3.75	16.89	10,755
Generality	0	0.09	0	0	0.19	10,755
Originality	0	0.11	0	0	0.21	10,755
Assets (Millions)	20.66	121.01	50.14	113.45	230.97	9,131
R&D	0	0.16	0.10	0.21	0.20	9,916
ROA	-0.26	-0.11	0.01	0.14	0.39	9,055
PPE	0.06	0.18	0.12	0.22	0.17	9,128
Leverage	0.00	0.14	0.04	0.19	0.22	9,106
Industry Concentration	0.03	0.05	0.04	0.05	0.06	9,940
Institutional Ownership	0	0.19	0.07	0.33	0.25	10,755
Asset Turnover	0.31	0.83	0.72	1.12	0.80	8,540
Involuntary Delisting	0	0.05	0	0	0.22	10,755
Subsample for Airline Restructuring						
# of Patents	0	2.25	0	2	5.70	6,451
# of Citations	0	7.42	0	4.95	17.31	6,451
Generality	0	0.09	0	0	0.19	6,451
Originality	0	0.13	0	0.22	0.23	6,451
Assets (Millions)	23.99	130.17	56.05	124.95	233.54	5,492
R&D	0	0.18	0.12	0.25	0.22	5,924
ROA	-0.33	-0.16	-0.05	0.12	0.41	5,438
PPE	0.05	0.16	0.10	0.19	0.16	5,491
Leverage	0.00	0.13	0.03	0.16	0.21	5,475
Industry Concentration	0.02	0.04	0.04	0.05	0.03	5,934
Institutional Ownership	0	0.21	0.08	0.36	0.26	6,451
Asset Turnover	0.24	0.76	0.63	1.04	0.82	5,062
Involuntary Delisting	0	0.05	0	0	0.22	6,451

Table 1 continued.

Panel C: Geographic Distribution of IPO Firms and VCs

State	# of IPO Firms	% of IPO Firms	# of VC	% of VCs
AL	9	0.49%	6	0.06%
AZ	17	0.93%	22	0.20%
CA	752	41.00%	3,859	35.76%
CO	52	2.84%	160	1.48%
CT	28	1.53%	572	5.30%
DC	4	0.22%	44	0.41%
DE	4	0.22%	21	0.19%
FL	39	2.13%	45	0.42%
GA	54	2.94%	102	0.95%
IA	2	0.11%	24	0.22%
ID	3	0.16%	0	0.00%
IL	38	2.07%	376	3.48%
IN	7	0.38%	34	0.32%
KS	5	0.27%	4	0.04%
LA	2	0.11%	12	0.11%
MA	202	11.01%	1,535	14.23%
MD	35	1.91%	169	1.57%
ME	2	0.11%	10	0.09%
MI	8	0.44%	39	0.36%
MN	47	2.56%	183	1.70%
MO	11	0.60%	43	0.40%
MS	3	0.16%	1	0.01%
MT	2	0.11%	0	0.00%
NC	21	1.15%	57	0.53%
ND	1	0.05%	0	0.00%
NE	2	0.11%	3	0.03%
NH	9	0.49%	27	0.25%
NJ	64	3.49%	349	3.23%
NV	2	0.11%	4	0.04%
NY	79	4.31%	2,016	18.68%
OH	15	0.82%	84	0.78%
OK	7	0.38%	11	0.10%
OR	20	1.09%	22	0.20%
PA	56	3.05%	217	2.01%
RI	2	0.11%	56	0.52%
SC	3	0.16%	0	0.00%
TN	15	0.82%	53	0.49%

TX	103	5.62%	341	3.16%
UT	6	0.33%	15	0.14%
VA	31	1.69%	39	0.36%
WA	62	3.38%	224	2.08%
WI	10	0.55%	11	0.10%
Total	1,834	100%	10,790	100%

Table 2
The Effect of VC Staging on Innovation: OLS Regressions

This table reports the OLS panel regression analyses examining the effect of "# of Rounds" on IPO firms' innovation outcomes. The dependent variables are "$ln(Patents)$" and "$ln(Citations)$" for each entrepreneurial firm from year t to year $t+5$ after IPO, respectively. Definitions of variables are in Appendix. Industry classification is based on 2 digit SIC codes. Robust standard errors clustered at IPO firm level are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

Dependent variable	$ln(Patents)$		$ln(Citations)$	
	(1)	(2)	(3)	(4)
# of Rounds	0.006	0.005	0.003	0.002
	(0.008)	(0.008)	(0.012)	(0.012)
VC Reputation	0.143	-0.009	0.267	0.124
	(0.495)	(0.499)	(0.773)	(0.790)
VC Syndication Size	0.006	0.005	0.019***	0.019***
	(0.004)	(0.004)	(0.006)	(0.006)
Incubation Period	-0.007	-0.011	-0.018**	-0.012
	(0.006)	(0.008)	(0.008)	(0.012)
Stage	0.144***	0.145***	0.275***	0.282***
	(0.033)	(0.034)	(0.052)	(0.052)
$ln(Patents\ at\ 1st\ Round)$	0.190*	0.191*	-0.077	-0.089
	(0.109)	(0.108)	(0.125)	(0.126)
$ln(Citations\ at\ 1st\ Round)$	0.047	0.048	0.212***	0.214***
	(0.041)	(0.040)	(0.057)	(0.057)
Firm Age	-0.010***	-0.010***	-0.012**	-0.012**
	(0.003)	(0.003)	(0.005)	(0.005)
Size	0.157***	0.155***	0.099***	0.097***
	(0.015)	(0.015)	(0.021)	(0.021)
R&D	0.600***	0.588***	0.641***	0.635***
	(0.089)	(0.089)	(0.133)	(0.132)
ROA	0.162***	0.156***	0.115	0.111
	(0.044)	(0.044)	(0.071)	(0.071)
PPE	0.065	0.075	0.074	0.070
	(0.090)	(0.090)	(0.146)	(0.145)
Leverage	-0.113**	-0.110*	-0.251***	-0.246***
	(0.057)	(0.058)	(0.095)	(0.095)
Industry Concentration	0.882***	0.932***	0.339	0.354
	(0.253)	(0.255)	(0.508)	(0.509)
Institutional Ownership	0.052	0.048	0.164*	0.161*
	(0.063)	(0.063)	(0.085)	(0.085)
Local IPO Market		0.040		-0.042

		(0.042)		(0.059)
Local VC Market		0.022*		0.022
		(0.012)		(0.018)
Industry Fixed Effects	Yes	Yes	Yes	Yes
IPO Year Fixed Effects	Yes	Yes	Yes	Yes
Firm State Fixed Effects	Yes	Yes	Yes	Yes
VC State Fixed Effects	Yes	Yes	Yes	Yes
# of obs.	8,294	8,294	8,294	8,294
R Squared	0.281	0.282	0.239	0.240

Table 3
The Effect of VC Staging on Innovation: Instrumental Variable (IV) Analysis

This table reports the 2SLS panel regression analyses examining the effect of VC's staged financing on IPO firms' innovation outcomes. We instrument "# of Rounds" with the frequency of direct flights between VC domiciles and IPO firm headquarters, "Direct Flight". Panel A reports the first-stage results, which generate the fitted (instrumented) value of "# of Rounds" for use in the second-stage regressions. Panel B reports the results from the second-stage regressions. The dependent variables are "$ln(Patents)$" and "$ln(Citations)$" for each entrepreneurial firm from year t to year $t + 5$ after its IPO, respectively. Adjusted R squared is reported for the first-stage regressions. Since it is not meaningful in the second stage of 2SLS, we report root MSE instead. Definitions of variables are in Appendix. Industry classification is based on 2 digit SIC codes. First-stage F-test refers to the Stagier and Stock (1997) F-test of the first-stage in IV estimation. Robust standard errors clustered at IPO firm level are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

Panel A: First-stage Regression of Direct Flight on Number of Financing Rounds

Dependent variable	# of Rounds	
	(1)	(2)
Direct Flight	-0.006***	-0.006***
	(0.001)	(0.001)
VC Reputation	1.115	0.139
	(1.729)	(1.721)
VC Syndication Size	0.306***	0.300***
	(0.013)	(0.013)
Incubation Period	0.243***	0.239***
	(0.026)	(0.037)
Firm Stage	0.266**	0.278**
	(0.127)	(0.126)
$ln(Patents\ at\ 1st\ Round)$	-0.118	-0.145
	(0.217)	(0.212)
$ln(Citations\ at\ 1st\ Round)$	-0.130	-0.119
	(0.101)	(0.096)
Firm Age	-0.002	-0.002
	(0.013)	(0.013)
Size	-0.037	-0.049
	(0.041)	(0.040)
R&D	0.275	0.210
	(0.268)	(0.268)
ROA	-0.351**	-0.388***
	(0.145)	(0.145)
PPE	-0.958***	-0.901***
	(0.338)	(0.334)
Leverage	0.191	0.207
	(0.198)	(0.194)

Industry Concentration	-1.405	-1.165
	(1.362)	(1.376)
Institutional Ownership	-0.093	-0.133
	(0.176)	(0.177)
Local IPO Market		0.051
		(0.149)
Local VC Market		0.162***
		(0.040)
Industry Fixed Effects	Yes	Yes
IPO Year Fixed Effects	Yes	Yes
Firm State Fixed Effects	Yes	Yes
VC State Fixed Effects	Yes	Yes
First-stage F-test	17.63	15.95
# of obs.	7,577	7,577
R Squared	0.574	0.578

Panel B: The Effect of VC Staging on IPO Firm's Innovation

Dependent variable	$ln(Patents)$		$ln(Citations)$	
	(1)	(2)	(3)	(4)
# of Rounds (Instrumented)	-0.283***	-0.310***	-0.308**	-0.339**
	(0.104)	(0.114)	(0.126)	(0.138)
VC Reputation	0.663	0.190	1.023	0.499
	(0.797)	(0.823)	(1.049)	(1.076)
VC Syndication Size	0.092***	0.096***	0.111***	0.117***
	(0.032)	(0.035)	(0.039)	(0.042)
Incubation Period	0.058**	0.060**	0.050*	0.066*
	(0.025)	(0.029)	(0.030)	(0.035)
Firm Stage	0.225***	0.236***	0.365***	0.386***
	(0.057)	(0.061)	(0.072)	(0.077)
$ln(Patents\ at\ 1st\ Round)$	0.168	0.153	-0.099	-0.129
	(0.133)	(0.132)	(0.146)	(0.149)
$ln(Citations\ at\ 1st\ Round)$	0.005	0.007	0.169***	0.172***
	(0.050)	(0.050)	(0.065)	(0.066)
Firm Age	-0.011**	-0.011**	-0.015**	-0.015**
	(0.005)	(0.005)	(0.007)	(0.007)
Size	0.150***	0.143***	0.068***	0.060**
	(0.020)	(0.021)	(0.024)	(0.025)
R&D	0.617***	0.589***	0.586***	0.565***
	(0.126)	(0.127)	(0.164)	(0.165)
ROA	0.043	0.015	0.001	-0.029
	(0.069)	(0.075)	(0.095)	(0.100)
PPE	-0.103	-0.096	-0.090	-0.099
	(0.169)	(0.174)	(0.230)	(0.233)
Leverage	-0.033	-0.020	-0.118	-0.101
	(0.088)	(0.091)	(0.124)	(0.127)
Industry Concentration	0.618	0.711	-0.061	-0.001
	(0.487)	(0.521)	(0.728)	(0.759)
Institutional Ownership	0.000	-0.023	0.108	0.082
	(0.085)	(0.089)	(0.103)	(0.106)
Local IPO Market		0.040		-0.047
		(0.068)		(0.083)
Local VC Market		0.083***		0.094***
		(0.027)		(0.035)
Industry Fixed Effects	Yes	Yes	Yes	Yes
IPO Year Fixed Effects	Yes	Yes	Yes	Yes
Firm State Fixed Effects	Yes	Yes	Yes	Yes
VC State Fixed Effects	Yes	Yes	Yes	Yes
# of obs.	7,577	7,577	7,577	7,577
Root MSE	0.934	0.960	1.374	1.397

Table 4
The Effect of VC Staging on Innovation: Airline Restructuring Related

This table reports the 2SLS panel regression analyses examining the effect of VC's staged financing on IPO firms' innovation outcomes. The IV analyses are conducted based on the subsample where variations in frequencies of direct flights between VC domiciles and IPO firm headquarters are due to airline restructuring activities such as bankruptcies, mergers and acquisitions, and/or strategic alliances. We instrument "# of Rounds" with the frequency of direct flights between VC domiciles and IPO firm headquarters, "Direct Flight". Panel A reports the first-stage results, which generate the fitted (instrumented) value of "# of Rounds" for use in the second-stage regressions. Panel B reports the results from the second-stage regressions. The dependent variables are "$ln(Patents)$" and "$ln(Citations)$" for each entrepreneurial firm from year t to year $t+5$ after its IPO, respectively. Adjusted R squared is reported for the first-stage regressions. Since it is not meaningful in the second stage of 2SLS, we report root MSE instead. Definitions of variables are in Appendix. Industry classification is based on 2 digit SIC codes. First-stage F-test refers to the Stagier and Stock (1997) F-test of the first-stage in IV estimation. Robust standard errors clustered at IPO firm level are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

Panel A: First-stage Regression of Direct Flight on Number of Financing Rounds

Dependent variable	# of Rounds	
	(1)	(2)
Direct Flight	-0.008***	-0.008***
	(0.002)	(0.002)
VC Reputation	3.900	2.821
	(3.380)	(3.401)
VC Syndication Size	0.265***	0.261***
	(0.017)	(0.017)
Incubation Period	0.330***	0.326***
	(0.036)	(0.054)
Firm Stage	0.353**	0.372**
	(0.166)	(0.167)
$ln(Patents\ at\ 1st\ Round)$	0.311	0.260
	(0.319)	(0.307)
$ln(Citations\ at\ 1st\ Round)$	-0.228	-0.208
	(0.152)	(0.148)
Firm Age	-0.004	-0.005
	(0.018)	(0.018)
Size	0.004	-0.003
	(0.052)	(0.051)
R&D	0.388	0.351
	(0.329)	(0.331)
ROA	-0.435**	-0.461**
	(0.194)	(0.194)
PPE	-0.710	-0.642

	(0.464)	(0.459)
Leverage	0.039	0.073
	(0.231)	(0.229)
Industry Concentration	-0.861	-0.782
	(2.110)	(2.161)
Institutional Ownership	-0.070	-0.091
	(0.215)	(0.214)
Local IPO Market		0.019
		(0.221)
Local VC Market		0.142**
		(0.057)
Industry Fixed Effects	Yes	Yes
IPO Year Fixed Effects	Yes	Yes
Firm State Fixed Effects	Yes	Yes
VC State Fixed Effects	Yes	Yes
First-stage F-test	15.34	14.05
# of obs.	4,798	4,798
R Squared	0.560	0.562

Panel B: Second-stage Regression of the Effect of VC Staging on IPO Firm's Innovation

Dependent variable	$ln(Patents)$		$ln(Citations)$	
	(1)	(2)	(3)	(4)
# of Rounds (Instrumented)	-0.272**	-0.294**	-0.296**	-0.311**
	(0.110)	(0.120)	(0.131)	(0.140)
VC Reputation	2.323	1.808	4.078**	3.726*
	(1.496)	(1.542)	(1.888)	(1.921)
VC Syndication Size	0.076**	0.080**	0.088**	0.090**
	(0.030)	(0.032)	(0.036)	(0.037)
Incubation Period	0.078**	0.085**	0.071*	0.099**
	(0.034)	(0.040)	(0.041)	(0.047)
Firm Stage	0.258***	0.278***	0.383***	0.411***
	(0.075)	(0.081)	(0.093)	(0.098)
$ln(Patents\ at\ 1st\ Round)$	0.399**	0.375**	0.054	0.002
	(0.195)	(0.189)	(0.209)	(0.203)
$ln(Citations\ at\ 1st\ Round)$	-0.047	-0.040	0.140	0.152*
	(0.071)	(0.069)	(0.095)	(0.092)
Firm Age	-0.012*	-0.013*	-0.015	-0.016
	(0.007)	(0.007)	(0.010)	(0.010)
Size	0.158***	0.154***	0.031	0.029
	(0.025)	(0.026)	(0.031)	(0.032)
R&D	0.637***	0.625***	0.378*	0.377*
	(0.153)	(0.156)	(0.193)	(0.194)
ROA	0.052	0.027	-0.022	-0.041
	(0.089)	(0.096)	(0.122)	(0.127)
PPE	-0.067	-0.047	-0.067	-0.069
	(0.192)	(0.196)	(0.260)	(0.260)
Leverage	-0.040	-0.020	-0.180	-0.157
	(0.110)	(0.112)	(0.148)	(0.149)
Industry Concentration	-0.303	-0.275	-0.373	-0.329
	(0.781)	(0.824)	(1.274)	(1.303)
Institutional Ownership	0.011	-0.003	0.039	0.030
	(0.100)	(0.102)	(0.118)	(0.119)
Local IPO Market		-0.005		-0.157
		(0.097)		(0.108)
Local VC Market		0.081**		0.072*
		(0.033)		(0.041)
Industry Fixed Effects	Yes	Yes	Yes	Yes
IPO Year Fixed Effects	Yes	Yes	Yes	Yes
Firm State Fixed Effects	Yes	Yes	Yes	Yes
VC State Fixed Effects	Yes	Yes	Yes	Yes
# of obs.	4,798	4,798	4,798	4,798
Root MSE	0.950	0.971	1.369	1.378

Table 5
Industry-level Innovation Diffculties

This table reports the 2SLS panel regression analyses examining how the effect of "# of Rounds" on innovation outcomes varies with the degree of difficulty to innovate. The IV analyses are conducted based on the subsample where variations in frequencies of direct flights between VC domiciles and IPO firm headquarters are due to airline restructuring activities such as bankruptcies, mergers and acquisitions, and/or strategic alliances. As in Hall, Jaffe, and Trajtenberg (2005), more demanding industries include pharmaceutical, medical instrumentation, chemicals, computers, communications, and electrical industries, and the rest are classified as less demanding industries, which include software programming, internet applications, and other low-tech industries. The dependent variables are "$ln(Patents)$" and "$ln(Citations)$" for each entrepreneurial firm from year t to year $t+5$ after its IPO, respectively. We instrument "# of Rounds" with "Direct Flight", the frequency of direct flights between VC domiciles and IPO firm headquarters. For brevity, the first-stage regression in which the fitted (instrumented) value of "# of Rounds" is generated for use in the second-stage regressions is not tabulated. Control variables are included in the regressions but not reported. Definitions of variables are in Appendix. Industry classification is based on 2 digit SIC codes. Robust standard errors clustered at IPO firm level are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

	More Demanding Industries				Less Demanding Industries			
Dependent variable	$ln(Patents)$		$ln(Citations)$		$ln(Patents)$		$ln(Citations)$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
# of Rounds (Instrumented)	-0.327**	-0.347**	-0.354**	-0.371**	-0.110	-0.126	-0.167	-0.189
	(0.136)	(0.143)	(0.154)	(0.161)	(0.142)	(0.169)	(0.234)	(0.271)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local IPO Market	No	Yes	No	Yes	No	Yes	No	Yes
Local VC Market	No	Yes	No	Yes	No	Yes	No	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IPO Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VC State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# of obs.	2,742	2,742	2,742	2,742	2,056	2,056	2,056	2,056
Root MSE	1.103	1.123	1.459	1.471	0.580	0.589	1.136	1.143

Table 6
Product Market Competition

This table reports the 2SLS panel regression analyses examining how the effect of "# of Rounds" on innovation outcomes varies with the competitiveness of industries. The IV analyses are conducted based on the subsample where variations in frequencies of direct flights between VC domiciles and IPO firm headquarters are due to airline restructuring activities such as bankruptcies, mergers and acquisitions, and/or strategic alliances. Industry competitiveness is measured by the Herfindahl index computed for three-digit historical SIC code during the year when an entrepreneurial firm receives the first-round financing. Entrepreneurial firms in industries where the Herfindahl indices are above the sample median are considered as operating in less competitive industries and vice versa. The dependent variables are "$ln(Patents)$" and "$ln(Citations)$" for each entrepreneurial firm from year t to year $t+5$ after its IPO, respectively. We instrument "# of Rounds" with "Direct Flight", the frequency of direct flights between VC domiciles and IPO firm headquarters. For brevity, the first-stage regression in which the fitted (instrumented) value of "# of Rounds" is generated for use in the second-stage regressions is not tabulated. Control variables are included in the regressions but not reported. Definitions of variables are in Appendix. Industry classification is based on 4 digit SIC codes. Robust standard errors clustered at IPO firm level are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

	More Competitive Industries				Less Competitive Industries			
Dependent variable	$ln(Patents)$		$ln(Citations)$		$ln(Patents)$		$ln(Citations)$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
# Rounds (Instrumented)	-0.164*	-0.172*	-0.248**	-0.252**	-0.642	-0.691	-0.720	-0.779
	(0.092)	(0.097)	(0.118)	(0.122)	(0.607)	(0.670)	(0.700)	(0.776)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local IPO Market	No	Yes	No	Yes	No	Yes	No	Yes
Local VC Market	No	Yes	No	Yes	No	Yes	No	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IPO Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VC State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# of obs.	2,388	2,388	2,388	2,388	2,388	2,388	2,388	2,388
Root MSE	0.761	0.766	1.213	1.212	1.271	1.327	1.657	1.716

Table 7
VCs' Industry Experience

This table reports the 2SLS panel regression analyses examining how the effect of "# of Rounds" on innovation outcomes varies with VCs' industry experience. The IV analyses are conducted based on the subsample where variations in frequencies of direct flights between VC domiciles and IPO firm headquarters are due to airline restructuring activities such as bankruptcies, mergers and acquisitions, and/or strategic alliances. A VC's industry experience is computed by dividing the total number of entrepreneurial firms it has invested in an industry in the previous 10 years, by the total number of entrepreneurial firms that the VC has invested in all the industries during the same period. A VC is "more experienced" ("less experienced") if its experience in the industry where the entrepreneurial firm belongs to is above (below) the sample median, where industry classification is based on "major" industries defined in the VentureXpert database. The dependent variables are "$ln(Patents)$" and "$ln(Citations)$" for each entrepreneurial firm from year t to year $t+5$ after its IPO, respectively. We instrument "# of Rounds" with "Direct Flight", the frequency of direct flights between VC domiciles and IPO firm headquarters. For brevity, the first-stage regression in which the fitted (instrumented) value of "# of Rounds" is generated for use in the second-stage regressions is not tabulated. Control variables are included in the regressions but not reported. Definitions of variables are in Appendix. Industry classification is based on 2 digit SIC code. Robust standard errors clustered at IPO firm level are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

	Less Experienced VCs				More Experienced VCs			
Dependent variable	$ln(Patents)$		$ln(Citations)$		$ln(Patents)$		$ln(Citations)$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
# of Rounds (Instrumented)	-0.282**	-0.328**	-0.371**	-0.415**	-0.530	-0.568	-0.409	-0.409
	(0.130)	(0.155)	(0.160)	(0.187)	(0.508)	(0.562)	(0.468)	(0.494)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local IPO Market	No	Yes	No	Yes	No	Yes	No	Yes
Local VC Market	No	Yes	No	Yes	No	Yes	No	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IPO Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VC State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# of obs.	2,162	2,162	2,162	2,162	2,316	2,316	2,316	2,316
Root MSE	0.967	1.012	1.365	1.401	1.198	1.248	1.430	1.428

Table 8
Post-IPO Operating Performance

This table reports the panel regression analyses examining the effect of the frequency of direct flights during IPO firms' incubation periods on their operating performance from year t to year $t+5$ after its IPO. The independent variable of interest is "Direct Flight", which is the number of total daily direct flights between VC domicile and IPO firm headquarter during the firm's incubation period. We multiple this number by 100. In Panel A, we estimate an OLS regression. The dependent variable is "ROA" in columns 1 through 4, "Asset Turnover" in columns 5 through 8. In Panel B, we estimate a probit regression, and report the marginal effects of the coefficient estimates. The dependent variable is "Involuntary Delisting", a dummy variable equal to one if an IPO firm is delisted due to liquidation, delisting, and/or permanent trading halts (CRSP delisting codes 400-490 or 500-591) in a year after IPO, and zero otherwise. In columns 1, 2, 5 and 6 in Panel A and columns 1 and 2 in Panel B, the analyses are based on the full sample. For the rest, the analyses are based on the subsample where variations in frequencies of direct flights between VC domiciles and IPO firm headquarters are due to airline restructuring activities such as bankruptcies, mergers and acquisitions, and/or strategic alliances. Control variables are included in the regressions but not reported. Definitions of variables are in Appendix. Industry classification is based on 2 digit SIC code. Robust standard errors clustered at IPO firm level are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

Panel A: ROA and Asset Turnover

	ROA				Asset Turnover			
	All Direct Flights		Airline Restructuring		All Direct Flights		Airline Restructuring	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Direct Flight (× 100)	-0.011	-0.008	0.002	0.006	-0.033	-0.038	-0.006	-0.012
	(0.013)	(0.012)	(0.019)	(0.018)	(0.035)	(0.034)	(0.044)	(0.043)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local IPO Market	No	Yes	No	Yes	No	Yes	No	Yes
Local VC Market	No	Yes	No	Yes	No	Yes	No	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IPO Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VC State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# of obs.	6,932	6,932	4,367	4,367	6,963	6,963	4,387	4,387
R Squared	0.425	0.427	0.436	0.440	0.308	0.309	0.308	0.311

Table 8 continued.

Panel B: Involuntary Delisting

	All Direct Flights		Airline Restructuring	
	(1)	(2)	(3)	(4)
Direct Flight (× 100)	0.003	0.003	0.006	0.004
	(0.007)	(0.007)	(0.009)	(0.009)
Control Variables	Yes	Yes	Yes	Yes
Local IPO Market	No	No	Yes	Yes
Local VC Market	No	No	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes
IPO Year Fixed Effects	Yes	Yes	Yes	Yes
Firm State Fixed Effects	Yes	Yes	Yes	Yes
VC State Fixed Effects	Yes	Yes	Yes	Yes
# of obs.	8,013	8,013	5,125	5,125
Pseudo R Squared	0.045	0.047	0.041	0.046

Table 9
Cross-Sectional Regression

This table reports the 2SLS cross-sectional regression analyses examining the effect of "# of Rounds" on innovation outcomes. The dependent variables are "$ln(Patents)$" and "$ln(Citations)$", respectively, each summed over year t to year $t+3$ after its IPO. We instrument "# of Rounds" with "Direct Flight", the frequency of direct flights between VC domiciles and IPO firm headquarters. Columns 1 through 4 present the results based on the full sample. Columns 5 through 8 present the results based on the subsample where variations in frequencies of direct flights between VC domiciles and IPO firm headquarters are due to airline restructuring activities such as bankruptcies, mergers and acquisitions, and/or strategic alliances. For brevity, the first-stage regression in which the fitted (instrumented) value of "# of Rounds" is generated for use in the second-stage regressions is not tabulated. Robust standard errors are in parentheses. Definitions of variables are in Appendix. Industry classification is based on 2 digit SIC code. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

	All Direct Flights				Airline Restructuring Related			
Dependent variable	$ln(Patents)$		$ln(Citations)$		$ln(Patents)$		$ln(Citations)$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
# of Rounds (Instrumented)	-0.402**	-0.452**	-0.386**	-0.439**	-0.401**	-0.442**	-0.366*	-0.380*
	(0.160)	(0.180)	(0.195)	(0.218)	(0.172)	(0.192)	(0.190)	(0.206)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local IPO Market	No	Yes	No	Yes	No	Yes	No	Yes
Local VC Market	No	Yes	No	Yes	No	Yes	No	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IPO Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VC State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# of obs.	1,526	1,526	1,526	1,526	978	978	978	978
Root MSE	1.219	1.276	1.491	1.540	1.226	1.274	1.426	1.435

Table 10
Alternative Measures for Innovation Outcome: Generality and Originality

This table reports the 2SLS panel regression analyses examining the effect of "# of Rounds" on alternative measures for innovation outcomes. The dependent variables are "Generality" and "Originality" for each entrepreneurial firm from year t to year $t + 5$ after its IPO, respectively. We instrument "# of Rounds" with "Direct Flight", the frequency of direct flights between VC domiciles and IPO firm headquarters. The fitted (instrumented) value of "# of Rounds" generated from the first stage, which is identical to those in Table 3, is used in the second-stage regressions. For brevity, only the results from the second stage are tabulated. Columns 1 through 4 present the results based on the full sample. Columns 5 through 8 present the results based on the subsample where variations in frequencies of direct flights between VC domiciles and IPO firm headquarters are due to airline restructuring activities such as bankruptcies, mergers and acquisitions, and/or strategic alliances. Definitions of variables are in Appendix. Industry classification is based on 2 digit SIC code. Robust standard errors clustered at IPO firm level are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

	All Direct Flights				Airline Restructuring Related			
Dependent variable	Generality		Originality		Generality		Originality	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
# of Rounds (Instrumented)	-0.040**	-0.044**	-0.033*	-0.037*	-0.031**	-0.033**	-0.034	-0.036
	(0.016)	(0.018)	(0.020)	(0.022)	(0.016)	(0.017)	(0.021)	(0.023)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local IPO Market	No	Yes	No	Yes	No	Yes	No	Yes
Local VC Market	No	Yes	No	Yes	No	Yes	No	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IPO Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VC State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# of obs.	7,577	7,577	7,577	7,577	4,798	4,798	4,798	4,798
Root MSE	0.194	0.197	0.216	0.218	0.185	0.186	0.226	0.227