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Asymmetric Information, Capital Supply, and the Venture Capital Market

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Asymmetric Information, Capital Supply, and the Venture Capital Market

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Dedicated to Claire for her love, support, and inspiration and in memory of Robert Brazenor for reminding me to keep my "nose in the books."

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Asymmetric Information, Capital Supply, and the Venture Capital Market

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This dissertation provides an overview of venture capital and the effects that asymmetric information and limited and varying capital supply have on the allocation of venture capital to new projects.

I develop and solve a competitive search model where entrepreneurs have projects with different levels of risk and have private information about their projects' quality. The combination of low capital supply and asymmetric information can cause entrepreneurs with high-quality risky projects, which are most affected by asymmetric information, to avoid the venture capital market. Increases in capital supply reduce the cost to entrepreneurs of attracting venture capitalists and can cause increases in the proportion of funded risky projects. Moreover, the average output per dollar of venture capital investment can increase with venture capital supply. I extend the model to examine the effects of heterogeneity in the ability of venture capitalists to screen projects

and show that higher ability venture capitalists are more likely to fund risky projects that are subject to higher degrees of asymmetric information.

I develop a new source of exogenous variation for the local supply of venture capital by using variation in the returns of state-level pension funds. Using the excess returns of state-level pension funds as a source of exogenous variation, I find results consistent with the model's predictions. Specifically, I find that positive shocks to the local supply of venture capital cause venture capitalists to increase their likelihood of funding companies with higher ex ante and ex post measures of risk and asymmetric information.

Table of Contents

List of Tables

List of Figures

Chapter 1

Venture Capital: An Overview

Venture capital investment has grown rapidly over the last 30-years. In 2015, Preqin, a venture capital database provider, estimated that there were over 9,000 venture capital deals with over $136 billion dollars invested. Moreover, as I will discuss, venture capital firms (VC or VCs) are a leading provider of capital and support to young firms that go on to be drivers of innovation and economic growth. For instance, Puri and Zarutskie (2012) finds that although VC-backed firms represent only 0.11% of newly created companies, they accounted for 5.3-7.3% of overall employment.

In this chapter, I first describe what a venture capital firm is, what services they provide, and their importance to the economy. I then describe venture capital cycles and how they affect the venture capital market and VCs decisions. I also provide an overview of the current academic literature on how VCs select projects and an overview of search models and their use to characterize the market for venture capital investment.

1.1 What is Venture Capital?

Venture capital is a term frequently used both by academics and the popular media. However, the term is used loosely to refer to many different institutions. For the purposes of this dissertation, I will use the definition of a venture capital firm established by Metrick and Yasuda (2010), and consider the market for venture capital investment to consist of VCs and the entrepreneurs that seek their investment.[1] Metrick and Yasuda (2010) define a VC as having five main characteristics:

1. A VC is a financial intermediary, meaning that it takes the investors capital and invests it directly in portfolio companies.
2. A VC invests only in private companies. This means that once the investments are made, the companies cannot be immediately traded on a public exchange.
3. A VC takes an active role in monitoring and helping the companies in its portfolio.
4. A VCs primary goal is to maximize its financial return by exiting investments through a sale or an initial public offering (IPO).
5. A VC invests to fund the internal growth of companies.

The typical venture capital firm is structured as a limited partnership. The limited partners (LPs) provide the majority of the capital to be invested

[1]For a in-depth overview of academic research on venture capital, please see Rin, Hellmann, and Puri (2011).

by the general partners (GPs) of the VC (Sahlman, 1990). Limited partners frequently consists of pension funds, university endowments, and wealthy individuals. GPs typically earn compensation based on a percentage of the total assets under management as well as a percentage of the returns of the fund. GPs are generally given control over the fund's investments but are required to provide frequent and detailed updates to the LPs regarding fund performance. For a thorough description of the types of contracts and compensation structures used by venture capital funds, see Gompers and Lerner (1996) and Lerner and Schoar (2004).

Venture capital funds generally last approximately 10 years. During the first 5 years, the general partners of the firm invest the raised capital into portfolio companies. The remaining 5 years of the fund's life is then spent monitoring and developing the portfolio companies. Many times the venture capital fund might provide additional or follow-on financing as the successful portfolio company grows. Eventually once the successful companies are sufficiently mature, the venture capital firm will work with the management and prepare the portfolio company for an exit opportunity. Exits generally are via an initial public offering (IPO) or an acquisition. The exit opportunity allows the venture capital firm to earn a return on their investment(s) in the portfolio company and provide a return to their limited partners.

Typically after years 5-7 of the fund's life, the venture capital firm will begin to raise another fund. The goal of raising a follow-on fund is important to GPs, as the resulting management fees represent a significant proportion of their compensation. Kaplan and Schoar (2005b) and Crain (2014) show that the relationship between past fund performance and future fund size is increasing but concave. This is primarily due to venture capital firms with poor performance failing to raise a follow-on fund but the limited size of funds on the high-end. Fulghieri and Sevilir (2009) explore why venture capital funds choose to optimally limit their size. The VC trades off having a larger portfolio that is associated with higher revenue against the reduced entrepreneurial incentives for the entrepreneur due to the spreading of the VC's human capital. A small portfolio also limits the VCs ability to extract rents from the entrepreneur because there is less competition among portfolio companies for the VCs limited supply of human capital. This can improve the entrepreneur's incentives to exert effort ex ante and improve the expected value of projects.

Other types of venture capital firms that do not follow the traditional LP-GP structure exist as well. The two most notable examples are corporate venture capital firms (CVCs) and bank sponsored venture capital firms (BVCs). Hellmann (2002) provides a useful overview of CVCs, which are venture capital firms run by corporations rather than independent entities organized solely for investment purposes. Many times CVCs have a strategic interest in their portfolio company's products that arise from synergies with the corporation's core business. Therefore, these firms have motivations that are beyond the financial gain that a portfolio company provides. For a more detailed discussion of CVCs, please see Gbadji, Gailly, and Schwienbacher (2015). BVCs are rarer than CVCs and generally focus on later-stage companies. One primary explanation for BVCs is that they give the bank an advantage in garnering profitable debt and IPO underwriting business from the portfolio companies (Hellmann, Lindsey, and Puri, 2008). Although interesting, these alternative forms of VCs are not the primary focus of this dissertation.

VCs perform a variety of activities that make them different from other financial intermediaries. The first relates to the nature of the companies in which they invest. Amit, Brander, and Zott (1998) shows that VCs primarily select industries characterized by high information frictions and specialized knowledge. They argue that this is a result of the ability of VCs to gain a comparative advantage relative to traditional sources of financial capital. Ueda (2004) provides a theoretical rationale for an entrepreneur to seek venture capital financing. VCs have greater ability to screen projects but also can steal the project.[2] Entrepreneurs understand this trade-off and find venture capital financing to be more attractive when they have little collateral and have projects with high risk and high profitability.

Another distinction of venture capital investments are the types of contracts that VCs use. Kaplan and Stromberg (2003) and Kaplan and Stromberg (2004) provides an in-depth study of VCs' contracts with their portfolio companies. These contracts typically separate control rights from cash flows rights.

[2]This could be interpreted as the VC generating a new company based on the original company's technology, or more realistically passing the new technology or idea to one of the VC's existing portfolio companies.

Control rights give VCs the ability to replace management and change the direction of the company, especially when the company is doing poorly. In addition, the contracts often take the form of convertible preferred shares that are converted into common shares during a liquidity or exit event. Convertible shares often contain additional provisions that assign different conversion rates based on the valuation of the company during future investment rounds and liquidity events.

In addition to having unique contracting features, VCs frequently stage their investments in a company. Gompers (1995) is the first paper to empirically examine the staging of VC investments. He finds that the use of staging increased with proxies of asymmetric information and that VCs use staging to help with monitoring their investments. This is because the threat of cutting-off funding serves as an incentive for the entrepreneur. Tian (2011) shows that staging can be used as a substitute for monitoring. They find that as the distance between the VC and the portfolio company increases, a proxy for monitoring costs, the more likely the VC utilizes staging. Bergemann and Hege (1998) and Bergemann and Hege (2005) introducing a learning component into the motivation for staging. Increased investment allows the VC to learn about the project faster, but provides an incentive for the entrepreneur to divert the funds for their private benefit. They show that the optimal contract is time-varying and the threat of replacing the manager improves efficiency.

A further distinction of VCs from other financial intermediaries is that they provide more than just capital to their portfolio companies. Sahlman

(1990) finds that VCs spend a significant amount of time with their portfolio companies visiting them on average 19 times a year and spending over 100 hours in direct contact. Reported activities include mentoring, sitting on boards, and providing strategic advice. Lerner (1995) shows that VCs take an active role on portfolio company boards, especially following the departure of the CEO. Hellmann and Puri (2002) argues that VCs help to professionalize the portfolio company by introducing HR practices, stock options, and hiring marketing practices. VCs also provide their portfolio companies access to networks. Lindsey (2008) shows that VCs help to facilitate networks among their portfolio companies. These alliances provide the portfolio companies valuable alliances and are associated with increased valuations at exits.

By providing capital and other value-adding activities to young companies VCs play an important role in the economy. Using census establishment level data Puri and Zarutskie (2012) find that only 0.11% of newly formed companies receive venture capital investment. However, these companies went on to account for 5-7% of employment. Moreover, VC-backed firms were less likely to fail, and more likely to be acquired or have an IPO. Ritter (2017) finds supporting evidence in that approximately 35% of companies that undergo and IPO had some form of VC-backing. Chemmanur, Krishnan, and Nandy (2011) also use establishment level census data and find that relative to their peers VC-backed firms have higher total factor productivity (TFP) before receiving venture capital funding. Moreover, they have continued TFP growth after receiving funding. Thus, the driver of the success of VC-backed companies is due to both ex ante reasons (e.g., initial selection) and ex post reasons (e.g., monitoring and other value adding services). Empirically separating these two effects is difficult. Sorensen (2007) attempts to do so by building a structural model of the VC and entrepreneur matching process. He assumes that there is assortative matching between entrepreneurs and VCs, and then uses this to identify the effect of VCs on exit probabilities. He shows that there is evidence of both selection and value-adding effects of experienced VCs.

Venture capital investment also has effects beyond its effect on individual firms. These effects mostly consist of spillover effects from VC-backed portfolio companies into the economy. Kortum and Lerner (2000) use the introduction of the "prudent man rule" in 1979, which allowed pension funds to invest in VCs, as an exogenous shock to venture capital financing. They show that industries with higher pre-1979 levels of venture capital investment had accelerated levels of patenting and growth following the shock. They argue that this is evidence of the positive effect that venture capital investment can have on industry level innovation. Samila and Sorenson (2011) examine the effect that venture capital investment can have on the local economy. Using the average return of all college endowments interacted with past investment by local endowments as an exogenous shock to venture capital supply, they show that increased local venture capital supply leads to increased employment, income, and firm starts. They argue that this is evidence of VC investment causing the creation of more companies than they fund. Overall, there is strong evidence that VC investment has positive effects on both the companies they fund as well as the overall economy.

1.2 Venture Capitalists' Project Selection

A key function of VCs in the economy is allocating capital to new companies. However, the process through which VCs select their portfolio companies has received relatively little study. A primary contribution of this dissertation is to add to the literature on venture capital allocation by exploring how the limited and varying supply of venture capital and the existence of asymmetric information affects this allocation process. Thus, it is useful to first understand what factors are involved in a VC's decision making process.

A useful starting point is the recent survey by Gompers, Gornall, Kaplan, and Strebulaev (2016). The authors of this paper survey 885 VCs at 681 venture capital firms. They ask questions along 8 areas of interest: deal sourcing; investment selection; valuation; deal structure; post-investment value-added; exits; internal firm organization; and relationships with limited partners. They find that VCs generate deal flow primarily through their networks with other VCs and entrepreneurs. This typically results in approximately 200 potential deals per year. For early stage companies deals are generally sourced from other portfolio companies or company management. Whereas for later stage companies, deals are more likely to be either self-generated or come from other investors. From the subset of potential deals, the median VCs then select approximately 4 projects per year. The authors found that on average portfolio companies received 1.7 offers from VCs per round. The authors argue that multiple offers indicate that VCs are frequently competing with each other for deals.

Gompers, Gornall, Kaplan, and Strebulaev (2016) finds that VCs report that the most important characteristic when selecting among potential projects is the management team. This is followed by the business model, product, market, and industry. This finding supports the results of Kaplan, Sensoy, and Stromberg (2009), that VCs generally select the "jockey" over the "horse," but that both are important to the final decision. Among management team attributes, Gompers, Gornall, Kaplan, and Strebulaev (2016) find that the perception of the management team's ability is the most important part for selecting the portfolio company followed by the team's industry experience, entrepreneurial experience, and teamwork. They also find that the average deal takes approximately 83 days to close and the VC spends over 110 hours on due diligence. Importantly, VCs generally use valuation metrics that do not take into account the systematic risk of their investments, supporting the view that VCs generally view their investments as primarily consisting of idiosyncratic risk. VCs generally view deal selection as the activity through which they add the most value to the fund, followed by deal flow and post-investment value-add.

The results of the survey are consistent with prior evidence regarding VC project selection. Sorensen (2007) uses a structural model of matching between VCs and entrepreneurs and shows that deal flow and deal selection are more important than value-adding activity. The survey is also consistent with the model of Brander and Bettignies (2009), which utilizes a predator-prey framework. In their model, VCs favor industries where they have experience and a large pool of targets. However, as time goes on, the available opportunities are "used up" giving rise to investment cycles.

The survey evidence is also consistent with prior work on the role of syndication and competition between VCs. Lerner (1994) established that VCs frequently syndicate their investments, meaning a group of VCs will invest together in a deal as a joint entity. He argues that this is done to help VCs complement one another in the ability to select, monitor, and maintain future investments in portfolio companies. Despite the prevalence of syndication, there is still competition among VCs for deals. Hochberg, Ljungqvist, and Lu (2010) find that VCs use deal flow in networks to prevent entry of new VCs and reduce competition. They show that VCs punish other VCs that allow new entrants into syndicates and that valuations are significantly lower in areas with increased networking. Hochberg, Mazzeo, and McDevitt (2015) show that VCs compete with one another, but often choose to specialize to potentially avoid competition. Importantly, they show that VC network effects soften competition, but the market still becomes more competitive with increased entry.

Casamatta and Haritchabalet (2014) provide a theoretical model of whether entrepreneurs should shop their project to multiple VCs or agree to negotiate exclusively with a single VC. Shopping to multiple VCs ensures a higher payoff, but reduces the likelihood of receiving funding from any one VC. The optimal strategy then depends on the type of project and the private benefits the entrepreneur enjoys from receiving funding. The results of their model are also consistent with Hsu (2004). He finds finds that entrepreneurs shop their deals to VCs but often choose a higher reputation VC at a reduced valuation because of the more experienced VC's ability to add value. In addition, an experienced VC can increase the likelihood of the entrepreneur receiving future funding through a certification effect.

Beyond competition, another important characteristic that affects a VC's project selection is asymmetric information. As previously noted, VCs use a variety of techniques to overcome these issues including screening, syndication, and contracting. Amit, Brander, and Zott (1998) argue that a primary function of VCs is to act as an intermediary to overcome the adverse selection that financial intermediaries face when funding new companies. Koskinen, Rebello, and Wang (2014) develop a model where the adverse selection problem interacts with the bargaining power of VCs versus entrepreneurs in negotiations. Additionally, their model allows for the information asymmetry to change as the project matures. Initially the entrepreneur is the informed agent but in later negotiations the VC is the informed agent. They show that increased VC bargaining power leads to reduced over-investment and increased project screening as the cost of screening endogenously falls. Moreover, the number and size of rounds will increase with the bargaining power of entrepreneurs as will the number of late round liquidations. Despite these papers, it is still unclear how changing market conditions and asymmetric information affect the types of projects that VCs select both in terms of quality and other attributes.

1.3 Venture Capital Cycles

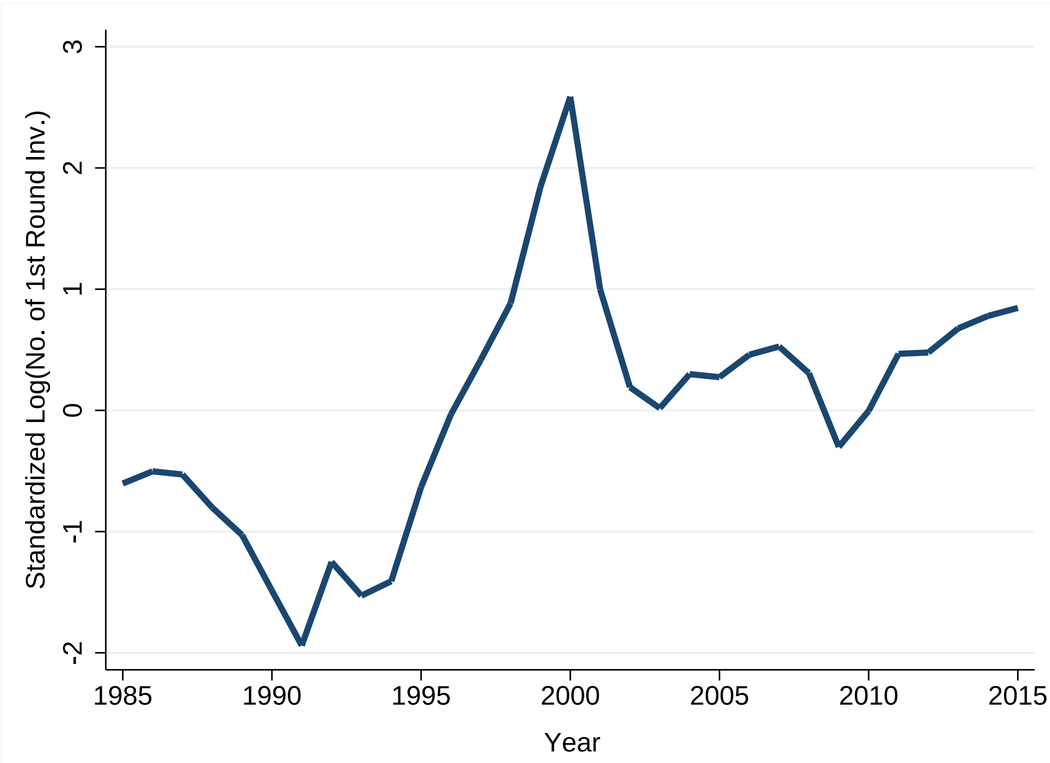
An important characteristic of the venture capital market, and a primary focus of this dissertation, is that there are wide fluctuations in venture capital activity over time. Figure 1.1, plots the standardized number of first rounds financed by VC firms from 1985-2010 using data from Thomson VentureXpert.[3] As can be seen from the figure, venture capital activity reached a peak during the late 1990's and early 2000's. However, it has fluctuated in other periods as well. Before exploring the effects of fluctuation in venture capital activity on the market, it is important to understand the sources of these fluctuations.

An early paper that explored fluctuations in venture capital activity was Gompers and Lerner (1999). They explore both demand side drivers and supply side drivers in activity. Demand side drivers include increased investment opportunities due to increased entrepreneurial entry, newly available technologies and markets, as well as changes to tax incentives. In addition, changes in macroeconomic conditions can have effects on the decision to enter entrepreneurship and therefore the demand for venture capital. Gompers

[3]For a full description of this data see Chapter 3.

Figure 1.1: Venture Capital Activity over Time.

This figure plots the number of first round investment by VCs in the United States from 1985 to 2010. All data is from Thomson VentureXpert. Only first round venture capital investments, as defined by Thomson VentureXpert, are included.



and Lerner (1999) show that demand side channels have important effects on overall venture capital firm fundraising. For instance, an increase in research and development (R&D) spending by industrial companies located in a a given state leads to increase in the flows of venture capital firms in that state.

The authors, however, argue that demand side factors are not the sole drivers of fluctuations in venture capital activity. Instead, supply side factors matter as well. For instance, the relaxation of the "prudent man" rule in

1979 allowed pension funds to invest in private equity. This in turn led to an increase in venture capital firm fundraising activities. Moreover, Samila and Sorenson (2011) show that positive shocks to the returns of the average college endowment are also related to increased venture capital investment. Thus, both demand side and supply side factors contribute to venture capital activity fluctuations.

The focus of this dissertation is primarily exploring how fluctuations in venture capital supply affects the market for venture capital investment. Kaplan and Schoar (2005a) shows that performance of VCs are pro-cyclical, but that it is the top performing VCs that drive this effect. However, Harris, Jenkinson, and Kaplan (2014) show that funds raised during "hot times" perform poorly relative to funds raised during "cold times." Robinson and Sensoy (2016) show that this is partly due to the liquidity premium, where funds raised in bad times must provide a premium to investors because they make capital calls when liquidity in the market is low and investors value their cash more.

Beyond performance, venture capital activity also affects the number and types of projects VCs choose to fund. Gompers and Lerner (2000) show that a shock to the supply of venture capital causes both an increase in the number of projects funded and an increase in the valuations of projects. Gompers, Kovner, Lerner, and Scharfstein (2008) show that VCs respond to public market signals, and raise more funds and invest more capital when investment opportunities are higher as indicated by public market proxies for an industry.

Thus, they argue that venture capital fundraising is not due to an overreaction but due to changes in underlying portfolio company fundamentals.

Nanda and Rhodes-Kropf (2013) show that changes in the supply of venture capital also affects the types of projects that receive funding. Specifically, they show that following a shock to the supply of venture capital, VCs fund companies with higher failure rates but also bigger payoffs when the companies succeed. This indicates that companies funded during "hot times" are not of lower quality, but instead have increased risk. Therefore, they argue that positive shocks to the supply of venture capital cause VCs to fund riskier and more innovative projects.

Understanding why venture capital is allocated to riskier companies during "hot times" is the central focus of this dissertation. The distinction between risk and quality is important. If the effect was that there was an increase in lower quality companies funded during "hot times," then this could be explained by competition driving VCs to fund lower value projects. However, if quality (expected NPV) is held constant, then risk alone would not affect the decision of a risk neutral or fully-diversified investor.[4] Therefore, explanations for why VCs fund riskier projects during hot times must be due to other market frictions.

Nanda and Rhodes-Kropf (Forthcoming) argue that this effect is potentially driven by "financing risk", which is the risk that a company may not

[4]Given that most VC investments are highly idiosyncratic in nature, a well-diversified VC firm can evaluate projects using a simple NPV rule (i.e., act as if they were risk-neutral).

be able to receive the next round of financing. In their model, VCs preserve a valuable real option by financing the company in stages. Financing risk can arise if frictions exist that prevent positive NPV projects from receiving VC investment. Nanda and Rhodes-Kropf (Forthcoming) do not model these frictions directly, but instead allow for some exogenous probability of receiving financing that fluctuates. When the probability of future financing is low, this reduces the likelihood of being able to exercise the option and thus the VC may fund the project upfront. If the option to wait is necessary for riskier companies to be a positive NPV investment, then these investments will not be made when funding probability is low. However, one issue with this model is that VCs cannot directly affect the likelihood of future funding. If a riskier project is successful after the first stage, then it is the most valuable project and thus should be able to have the highest likelihood of attracting capital in a competitive environment. Therefore, it is unclear if their prediction will continue to hold if the ability of entrepreneurs and inside VCs to attract future capital can depend on the market's updated expectation of a project's value (i.e., if the source of the variation in the probability of funding is modeled explicitly).

1.4 Venture Capital Market and Search

In order to take into account the competition for projects on the part of VCs and the competition for capital from VCs on the part of entrepreneurs, one needs a framework that allows for dual sided competition. A popular set of models that incorporate these effects are search models.[5]

The earliest form of search models come from the labor economics literature. In the earliest form of these models, workers sequentially sample offers from an exogenous distribution and stop searching when the offered expected lifetime wage is higher than their value from continually sampling. This is sometimes referred to as the island model, dating to Lucas and Prescott (1974). Other models have attempted to address the exogeneity of offer distributions by making it endogenous in the model. Diamond (1971) provides a key result that if firms are allowed to make offers and workers randomly match to positions, then all firms will offer the same equilibrium wage equal to the worker's reservation wage. This is known as the "Diamond Paradox."

Another line of models were introduced that allowed for endogenous wages and that could avoid the "Diamond Paradox." These are known as random matching and bargaining models and were first introduced by **?**, **?**, and **?**, and thus are frequently referred to as "DMP" models. In these models, firm post vacancies, workers apply, and then firms and workers randomly match. The key difference is that the firm and the worker bargain over the surplus created by their match after the match is formed. It is common in these models to assume that the bargaining process is via Nash Bargaining. The resulting wage depends on the worker's outside option, the productivity of the match, the tightness of the labor market, and the bargaining power of

[5]For a general overview of search models in various forms, see Rogerson, Shimer, and Wright (2005).

the worker and the firm. As the ratio of workers to vacancies increases, the likelihood of a worker matching with a firm decreases. This endogenously lowers the value of their outside option (returning to the labor market), and thus wages endogenously fall. This class of models have spawned numerous extensions and applications that researchers have used to examine unemployment, heterogeneous workers and firms, job flows across countries, and trade.[6]

Despite the prevalence of DMP type models, there were several difficulties with their use and application. Most notably, it is conceptually difficult to micro-found the matching function, which are often exogenously specified. Moreover, it is hard to motivate agents randomly searching in many contexts where one might expect them to direct their search activities (e.g., labor vacancies, purchasing goods, investing, etc.). In addition, economists generally believe that agents know the price range of the goods when they are shopping and can direct their search accordingly.

In order to accommodate these concerns, researchers developed an additional class of search models known as "directed" or "competitive" search models. An early version of these models appears in Montgomery (1991). In this model, all information is known and agents are homogeneous. Firms post vacancies associated with a specific wage, and workers probabilistically apply to vacancies. Both workers and firms optimize based on the beliefs of other agents behaviors. The matching function is shown to converge to an urn-ball

[6]For a detailed discussion of these models and extensions, please see Pissarides (2000).

function when the labor market is large and thus satisfies the first critique of DMP style models. In addition, workers choose which firms to apply to and wages (prices) help direct search activities. Montgomery (1991) shows that the symmetric equilibrium of this model has all firms playing a pure strategy and posting the same wage. The equilibrium wage depends on the level of market tightness, and wages increase as the ratio of vacancies to workers increases. Moreover, the author shows that the search market can be constrained efficient as wages correctly coordinate workers' applications.

Moen (1997) formalizes the competitive search framework and shows that it can produce efficient outcomes under a range of conditions. He then shows that this framework can be implemented in a setting similar to Montgomery (1991). Burdett, Shi, and Wright (2001) solves a more general form of the model that allows for strategic interaction among agents. However, they show that as the market grows, the equilibrium converges to that of Montgomery (1991) and Moen (1997).

In Montgomery (1991), Moen (1997), and the baseline model of Burdett, Shi, and Wright (2001), agents are homogeneous. In addition, in each of the papers all information is public. Guerrieri, Shimer, and Wright (2010) make an important contribution by utilizing a competitive search framework and allowing for heterogeneous agents and private information. Specifically, in their model the selling agent has private information about the quality of the good and the buying agent posts a contract. In equilibrium, buying agents post contracts that screen selling agents such that there is perfect separation.

This paper sparked numerous follow-on papers that have allowed for different settings and derived additional results as they relate to efficiency, different equilibria, and comparative statics.[7] Delacroix and Shi (2013) propose a different version of a competitive search setting where posting agents have private information and therefore prices act as a signaling as opposed to a screening device. In their model, sellers can choose their quality and in equilibrium only one quality of good is produced (either high or low). When the quality differential is large only high quality goods are produced and the equilibrium is efficient. However, when the differential is small only low quality goods are produced and there is insufficient entry.

Using a search framework, both DMP and competitive versions, is appealing to those interested in modeling the market for venture capital investment. The use of search is intuitive for these markets because they involve bilateral trading with little coordination and both sides of the market are in limited supply. Therefore, entrepreneurs should not be given full bargaining power and there is not a perfectly competitive supply of capital. Michelacci and Suarez (2004) and Inderst and Mueller (2004) are two earlier papers that utilized DMP style models to characterize the VC market. Michelacci and Suarez (2004) model a framework where capital is recycled back into the venture capital market following portfolio company exits. VCs provide important

[7]For example, Chang (2012), Lauermann and Wolinsky (2016) Eeckhout and Kircher (2010), Moen and Rosen (2011), Chiu and Koeppl (2016), Lester, Shourideh, Venkateswaran, and Zetlin-Jones (2017) all use versions and concepts similar to Guerrieri, Shimer, and Wright (2010).

monitoring for young startups and thus the ability to recycle informed capital through IPOs allows for greater firm creation and innovation. Inderst and Mueller (2004) focus on a different problem and examine a double-sided moral hazard problem where projects depend on unobservable effort of both the entrepreneur and the VC. Changes in capital market conditions affect the Nash bargaining outcome. Increased venture capital supply causes increased valuations, more projects to be funded, alters contract terms, and changes the incentives to screen projects. Hellmann and Thiele (2015) also utilizes a DMP style model but allows for two different types of financial intermediaries, "angels" and VCs. Angels fund the first round of projects and VCs fund the second round of projects. The authors rely on a Shapley bargaining framework in the second round negotiation between the angel, VC, and entrepreneur. Using this framework, they explore the tension between angels and VCs and how their relative competition changes with market conditions.

Jovanovic and Szentes (2013) utilize a competitive search model to characterize the venture capital market. In their model, entrepreneurs have homogeneous projects but differ in their initial wealth. Projects require continual investment and entrepreneurs can either self-fund or seek funding from VCs. Projects also require non-contractible effort from entrepreneur, creating a moral hazard problem. Entrepreneurs trade off solo financing their project, which may cause early termination if they run out of wealth, versus giving up part of their project to the VC. The contract between the VC and entrepreneur must also specify a termination time if the project remains unsuccessful. The

VCs trades keeping with the project versus the opportunity cost of not funding another project. Thus in equilibrium, VCs only continue funding projects with a higher quality than that of the self-financed entrepreneurs. Using this framework, the authors calibrate their model and estimate returns to VCs and solo entrepreneurs, which are difficult to identify in the data using reduced form techniques. Importantly, in Jovanovic and Szentes (2013) projects are homogeneous and all information is public.

In Chapter 2, I develop and solve a model that takes into account the competition between VCs for a limited number of projects and the competition between entrepreneurs for a limited supply of VCs. I model this dual sided competition problem using a competitive search framework similar in setup to that of Burdett, Shi, and Wright (2001) and Delacroix and Shi (2013). Modeling the market in this way, matches the arguments in Gompers and Lerner (2000) and Hochberg, Ljungqvist, and Lu (2010), that changes in competition resulting from changes in the supply of venture capital have important effects on the venture capital market. Moreover, I add an additional friction by allowing for asymmetric information between the entrepreneur and the VC regarding the quality of the project. I also allow for projects to be ex ante heterogeneous. In an extension to the model, I also allow for VCs to be heterogeneous with respect to their ability to screen projects. As far as I know, this is the first model of competitive search that allows for private information of project quality and ex ante heterogeneous agents on both sides of the market.

Importantly in the model, the degree of asymmetric information is tied to the degree of risk in the projects meaning riskier projects (higher payoff variance) have more asymmetric information. In the model, I show that the combination of search frictions and asymmetric frictions causes an increase in the supply of venture capital to lead to an increase in the ratio of risky to safe VC-backed projects in the economy. Therefore, I provide an alternative explanation for the results of Nanda and Rhodes-Kropf (2013) and provide a framework to better understand how capital is allocated by VCs to projects.

I then test the predictions of my model in Chapter 3. I introduce a new instrument for the local supply of venture capital, by using variation in the returns of state level pension funds. Using this as an exogenous shock to the local supply of venture capital, I show that increases in the supply of venture capital causes VCs to fund riskier projects, proxied by both ex post and ex ante measures. I also show that increases in the local supply of venture capital cause an increase in the likelihood that VCs invest in companies with higher levels of asymmetric information. Thus, my empirical results are consistent with my model's predictions.

Chapter 2

A Competitive Search Model of the Venture Capital Market

2.1 Introduction

In the model, some entrepreneurs are endowed with risky projects while others have relatively safe projects. Risky projects have a higher ex ante probability of failure but a higher payoff if successful. Projects can generate cash flows even without VC funding, representing an entrepreneur's outside option, but a fixed investment from a VC improves a project's expected payoff. Project risk is publicly observable, but entrepreneurs have private information about their projects' quality (high or low), which represents their type. The entrepreneur's type affects the expected value of risky projects more than safe projects. Thus, risky high-types have both the most valuable projects and the greatest degree of asymmetric information between the entrepreneurs and VCs.

Entrepreneurs attract VCs by offering to sell a share of their project in return for a VC's investment. VCs observe all posted offers and independently select a single entrepreneur to pursue. Given their inability to coordinate, some VCs pursue the same entrepreneur. In this situation, the entrepreneur selects a single VC and they trade at the posted terms. In contrast, entrepreneurs not pursued by any VCs receive their outside option.[1] Entrepreneurs maximize their expected payoff by choosing the return offered to VCs, and VCs choose projects to maximize their expected return taking into account the potential competition with other VCs. Entrepreneurs trade off the benefit from posting terms that have higher probabilities of attracting a VC against the cost of further diluting their equity stake.

As a benchmark, I first solve the model in a simplified case with *symmetric information* about project quality. In this benchmark case, VCs avoid low-type entrepreneurs and are more likely to fund high-type entrepreneurs with risky projects, whose projects have the most value. Increases in capital supply cause VCs to increasingly fund entrepreneurs with the lower-value but still high-quality safe projects. Thus, increases in the supply of venture capital cause the proportion of funded risky projects to fall. The benchmark case illustrates the importance of asymmetric information in driving the model's main predictions.

With private information, the model potentially produces multiple equilibria, but there is a unique equilibrium supported by plausible off-equilibrium

[1] This is known as directed or competitive search. Montgomery (1991), Moen (1997), and Burdett, Shi, and Wright (2001) give formal descriptions. For a general survey, see Rogerson, Shimer, and Wright (2005). Guerrieri, Shimer, and Wright (2010) examine competitive search in a screening-type game, while Delacroix and Shi (2013) examine it in signaling-type game. I provide a detailed discussion of the differences between these papers and mine in section 2.3. To my knowledge, my paper is the first to use competitive search in a signaling-type game where posting agents vary over two dimensions (i.e., risk and quality).

beliefs. In this unique equilibrium, high- and low-type entrepreneurs pool at the price that is best for high-type entrepreneurs, and VCs undervalue high-type entrepreneurs' shares. Further, the magnitude of the undervaluation increases with the degree of asymmetric information (i.e., is greater for risky projects). Moreover, because competition among VCs is positively correlated with the supply of capital, it is costlier for any entrepreneur to attract a VC when capital supply is low relative to when it is high. Therefore, if relative gains from trade for high-type entrepreneurs with risky projects are not too large, then the high cost they face from low capital supply, combined with the costly information friction, causes all high-type entrepreneurs with risky projects to choose their outside option and not seek VC funding. This leads to a lemons problem in the spirit of Akerlof (1970), where projects subject to greater asymmetric information do not receive funding when the supply of venture capital is sufficiently low.

An increase in venture capital supply increases competition among VCs and reduces an entrepreneur's cost of attracting a VC. A sufficient increase in supply makes it profitable for high-type entrepreneurs with risky projects to enter the VC market. Their entry partially alleviates the lemons problem, and VCs fund some risky projects. A second effect arises as more capital enters the market. In equilibrium, as an entrepreneur's likelihood of funding increases, he/she must offer relatively larger share increases to have the same relative effect on his/her likelihood. Thus, a positive venture capital supply shock makes it less expensive for entrepreneurs with risky projects to have a larger increase in their likelihood of attracting a VC relative to entrepreneurs with safe projects. Therefore, a positive capital supply shock causes an increase in the proportion of funded projects that are risky. Further, if risky projects are ex ante more valuable than safe projects, then an increase in venture capital supply also increases the average output per unit of a VC's investment.

This model is not the first to examine how a VC's project selection changes with market conditions. Nanda and Rhodes-Kropf (Forthcoming) propose a complementary theory that can also explain how increases in the supply of venture capital can lead to riskier VC-backed projects. Their model relies on the notion of "financing risk," which arises if a project would not receive future financing if the market were to turn "cold." VCs can avoid financing risk by investing more up-front but up-front investment sacrifices a valuable real option. Without the real option, risky projects have negative NPV. Therefore, risky projects only receive financing when the exogenous probability of future financing is high. Ewens, Nanda, and Rhodes-Kropf (2015) examine how the cost of setting up a startup affects project choice. They find that VCs fund riskier projects when such costs are low. My model abstracts from both of these channels by focusing on a single period, thereby removing financing risk, and by holding the costs of setting up a startup constant. Abstracting from these alternative channels highlights the importance of asymmetric information and search frictions to the relationship between capital supply and the funding of riskier projects.

Other models explore how a VC's adverse selection problem varies with market conditions but do not allow for search frictions or projects with different levels of asymmetric information. Zryumov (2015) models a dynamic adverse selection problem that varies with discount rates. Importantly, his model focuses on when entrepreneurs of different quality, but not levels of asymmetric information, choose to enter the market.[2] Koskinen, Rebello, and Wang (2014) model a VC's adverse selection problem that changes with the entrepreneur's bargaining power, but projects are ex ante homogeneous and there are no search frictions. Opp (2014) builds and calibrates a general equilibrium model to examine the role of VCs in intermediating startup investment. His model links the venture capital market to macroeconomic conditions, cycles, and asset prices. However, he does not examine the effects of capital supply on a VC's choice among projects with different levels of asymmetric information.

My model is also not the first to use a search framework to model the venture capital market. It is the first, however, that models a VC's choice among entrepreneurs with ex ante heterogeneous projects and private information about their projects' quality. Jovanovic and Szentes (2013) use a contract posting model similar to this paper's and analyze the decisions of entrepreneurs, who have ex ante homogeneous projects but different levels of wealth, to seek VC financing and when to terminate a project. In contrast to posting models, Inderst and Mueller (2004), Michelacci and Suarez (2004),

[2]In his model, VCs make offers from a distribution of prices which entrepreneurs then choose whether to accept. This is similar in spirit to Guerrieri, Shimer, and Wright (2010), where prices serve a screening as opposed to a potentially signaling role. However, in his model entrepreneurs always match with a VC.

and Hellmann and Thiele (2015) use models with random search to examine how competition relates to VC-deal valuations, flows, and the IPO decision. These papers do not allow for heterogeneous projects or model the adverse selection problem VCs face. Donaldson, Piacentino, and Thakor (2016) examine the coexistence of banks and VCs. In their model, entrepreneurs choose whether to pursue traditional or innovative risky projects depending on their random match (bank or VC) and the level of credit market competition. In equilibrium, entrepreneurs always choose risky projects if VC funded, and VC project choice is not their focus.

2.2 Model

2.2.1 Setup

I consider an economy populated by two types of agents: entrepreneurs and venture capitalists (VCs). All agents are risk neutral and share a common discount rate that is normalized to 0. Entrepreneurs and VCs have linear utility functions that depend only on the agent's total net payoff (proceeds less any investment). I focus on the environment where there is a single period in which entrepreneurs and VCs can match bilaterally.

2.2.1.1 Entrepreneurs

Entrepreneurs exogenously have one of two varieties of *projects* $i \in \{r, s\}$ and the project variety is publicly observed. There is a unit mass of entrepreneurs with each project. I refer to r projects as *risky* projects and s

projects as *safe* projects.[3]

Among a given variety of project, projects are either *Good* G or *Bad* B. A project is Good with probability p_i, and $1 \geq p_s > p_r > 0$. I introduce information asymmetries by having entrepreneurs receive a private *signal* $Z \in \{H, L\}$ with *precision* λ such that $\Pr(Z = H|Good) = \Pr(Z = L|Bad) = \lambda$ and is sufficiently precise to be useful (i.e., $\lambda > 0.5$). The *conditional probability of success* given signal Z is $\psi_{i,Z}$.[4] I refer to the entrepreneur's signal as his *type* and refer to entrepreneurs by their project variety and type — a risky high-type is an entrepreneur that received a high signal and has a risky project.[5] To allow for an unconditional expectation, let $Z = \emptyset$ denote the entrepreneur having no information about his type. If $Z = \emptyset$, then $\psi_{i,\emptyset} = p_i$. The signal represents a combination of the entrepreneur experimenting with his idea as well as learning about his own ability as an entrepreneur. The project signal explicitly generates the relationship between the degree of variation (i.e., risk) and the degree of information asymmetry between entrepreneurs and VCs. Specifically, projects with a greater degree of variation in their conditional probabilities will also have a greater degree of asymmetric information.[6]

[3] The model is robust to allowing for more than two varieties of projects and to allowing for free-entry of entrepreneurs under some assumptions regarding the distribution of entry costs and some slight modifications. However, it greatly complicates the analysis and provides little additional intuition.

[4] For example, the conditional probability of success given a high signal is

$$\psi_{i,H} = \frac{\lambda p_i}{\lambda p_i + (1 - \lambda)(1 - p_i)}.$$

[5] I use male pronouns to represent entrepreneurs and female pronouns for VCs.

[6] To see this, compare the conditional probabilities relative to the unconditional proba-

Entrepreneurs are penniless (i.e., do not have any initial wealth to contribute) but can seek funding for an *investment* I from a VC that improves the project's payoff.[7] I assume all project varieties require the same fixed investment.[8] If financed by a VC, Good projects pay R_i and Bad projects pay 0. Without VC funding, entrepreneurs with Good projects have some *alternative payoff* $\Omega(i, Z)$ that depends on the project i and the entrepreneur's type Z. The alternative payoff represents the entrepreneur's outside option to not receiving VC funding.[9] I make the following restrictions on the entrepreneur's outside option to simplify the problem and normalize the parameter space:

Assumption 1 (Outside Options).

Outside options for low-types are 0 and for high-types are positive. That is for $i \in \{r, s\}$*:*

$$\begin{aligned} \Omega(s, L) = \Omega(r, L) &= 0 \\ \Omega(i, H) &> 0 \end{aligned}$$

bilities for high-types with risky versus safe projects, so $\psi_{r,H}/p_r > \psi_{s,H}/p_s$.

[7]Although, VC investments are typically made over multiple rounds, for simplicity I focus on only one round of investment. This can be thought of as the first round (e.g., Seed or Series A) investment. For a more detailed discussion of theories and evidence related to multiple funding rounds see Gompers (1995) and Bergemann and Hege (2005), among others.

[8]An interesting extension would be to allow for projects to receive different levels of investment and have payoffs be a function of variety and investment. However, I expect the main predictions of the model to continue to hold.

[9]Realistically, the alternative payoff can be thought of as the entrepreneur's expected payoff from self-funding, bootstrapping, or seeking alternative financing sources (friends and family) without any beneficial VC support. For the purposes of this paper, I do not explicitly model these options and use the reduced form representation $\Omega(i, Z)$. Examples of companies that initially bootstrapped and were later successful include GoPro, Patagonia, and Github.

Assumption 1 sets the expected value of the outside option for a low-type to 0 and for a high-type to be positive.

2.2.1.2 VCs

There is a continuum of homogeneous VCs with an exogenously specified mass V that can invest I and improve the expected payoff of the project.[10] In order to make the model more interesting and simplify the model, I make the following parameter restrictions:[11]

Assumption 2 (Positive Ex Ante NPV and Low-Types have Negative NPV).

If there is no information about entrepreneur types, then a VC's investment improves the net expected value of projects. With a VC's investment, risky projects have higher payoffs. The net expected value of a low-type's project is negative. That is, for $i \in \{r, s\}$

$$\begin{aligned} p_i R_i - I &> p_i \Omega(i, \emptyset) > 0 \\ R_r &> R_s \\ \psi_{i,L} R_i - I &< 0. \end{aligned}$$

Assumption 3 (Relative Gains from Trade for High-Types).

If information is symmetric, then high-types with risky projects have larger gains from trade than high-types with safe projects.

[10] Alternatively, I could exogenously specify some entry costs for VCs and allow for an endogenous supply of VCs through a free-entry condition. Given the competitive nature of the model, the two versions are isomorphic.

[11] In Appendix B, I discuss relaxing Assumption 2 and argue that this does not materially affect the results but adds significant complication and loss of tractability.

$$\psi_{r,H}[R_r - \Omega(r,H)] > \psi_{s,H}[R_s - \Omega(s,H)] > 0$$

Assumption 2 ensures that a VC's investment has positive NPV, successful risky projects have higher payoffs with VC funding, and that a VC would never knowingly fund a low-type entrepreneur. Assumption 3 ensures that with symmetric information about entrepreneur type, a risky high-type has greater relative gains from trade with VCs. Importantly, Assumptions 2 and 3 can ***include*** the case where projects have the ***same expected value*** with no information (i.e, $p_r R_r = p_s R_s$).[12]

2.2.2 Search

For an entrepreneur and a VC to transact, the two agents must match. I characterize the matching process using a competitive search framework. The search process takes part in three stages. First, entrepreneurs post and commit to a contract that pays a *share* $\alpha \in [0, 1]$ of the project's payout R_i.[13] Let $\alpha = 0$ represent an entrepreneur not entering the VC market. Denote E_α as the mass of entrepreneurs posting given share α.

In the second stage, VCs observe all posted shares and for each posted share α update their expectation of the associated project's likelihood of suc-

[12] Assumption 3 is not necessary for the central predictions of the model, but, as will be discussed in section 2.3.1.1, Assumption 3 ensures that if all information was public and symmetric, then risky projects would have a higher probability of funding.

[13] Kaplan and Stromberg (2003) find that the use of equity contracts is relatively standard in the venture capital industry. Furthermore, given the $\{0, R\}$ payoff structure of the projects in the model, debt contracts would have the same implications.

cess $\mu(\alpha, i)$.[14] VCs then choose a single entrepreneur to pursue. Restricting VCs to pursue only one entrepreneur represents a constraint on VCs and corresponds with Hochberg, Ljungqvist, and Lu (2010) who find that VCs have limited capacity to source deals. Given the large number of players and the difficulty in potential coordination, I focus exclusively on symmetric equilibrium and require identical agents to play the same strategies.

In the third stage, matches are realized. If multiple VCs pursue the same entrepreneur, then the entrepreneur randomly selects a single VC. The selected VC invests I in return for share α, and unselected VCs receive 0. Unmatched entrepreneurs get their outside option if the project is successful. For a VC, the search friction is due to congestion, selecting an entrepreneur but not being selected if there are competing VCs. For entrepreneurs, the search friction is due to lack of coordination, posting a share but not attracting a VC.[15]

It is useful to discuss this environment in terms of a potential continuum of sub-markets. Each sub-market is defined by the publicly observable *project variety* $i = \{r, s\}$ and *posted share* α. Within a sub-market, all projects have the same expected payoff to the VC because projects have the same payoff if successful R_i, the same probability of success $\mu(\alpha, i)$, and the VC receives the

[14]Note that the updated believes of VCs depend on both the posted share and the project variety because the project variety ($i \in \{r, s\}$) is publicly observable.

[15]This framework originated in the labor and macroeconomics literature. Traditionally, firms post wages for jobs to which workers then apply. For this context, it can be thought of as entrepreneurs sending term sheets to all VCs, and each VC choosing one entrepreneur to pursue.

same share α. I refer to a VC choosing an entrepreneur in a sub-market as "entering" a sub-market.

The number of matches in a sub-market depends on the matching technology and the sub-market's *tightness* $\theta_{\alpha,i}$, the ratio of VCs to entrepreneurs in the sub-market. I assume an exogenous urn-ball matching technology. This is a standard matching function and is concave in θ, continuously twice differentiable, and the probabilities of matching are bounded between 0 and 1 for all $\theta > 0$.[16] The probability of a match for an entrepreneur and a VC is

$$F(\theta_{\alpha,i}) = \Pr(Entrepreneur\ Match) = 1 - e^{-\theta_{\alpha,i}} \tag{2.1}$$

$$F(\theta_{\alpha,i})/\theta_{\alpha,i} = \Pr(VC\ Match) = \frac{1 - e^{-\theta_{\alpha,i}}}{\theta_{\alpha,i}}. \tag{2.2}$$

The probability of an entrepreneur matching increases with market tightness θ, and $\lim_{\theta \to \infty} F(\theta) = 1$, while the probability of a VC matching decreases with θ, and $\lim_{\theta \to 0} F(\theta)/\theta = 1$.

An *entrepreneur's expected value* from posting share α is $\pi_{E,i,Z}(\alpha)$

$$\pi_{E,i,Z}(\alpha) = F(\theta_{\alpha,i})\psi_{i,Z}(1-\alpha)R_i + (1 - F(\theta_{\alpha,i}))\psi_{i,Z}\Omega(i,Z). \tag{2.3}$$

[16] I provide microeconomic foundations for this matching function in Appendix B. The intuition for this matching function is that if there are E urns for which V balls are placed independently with equal probability in each urn, then for large E and V, the number of balls per urn is a Poisson random variable with mean $V/E = \theta$ and the probability an urn does not get any balls is $e^{-\theta}$. Note that this matching function depends on which agent is the poster and which agent is the seeker and it is not symmetric. See Rogerson, Shimer, and Wright (2005) for a general discussion and Burdett, Shi, and Wright (2001) for a more detailed discussion. The model is robust to using the telephone line matching function (Prob(Entr. Match) = $\frac{\rho\theta}{(1+\rho\theta)}$) and under a wide-range of tested parameters the more generalized telephone matching function (Prob(Entr. Match) = $(1+\theta^{-\rho})^{-1/\rho}$ with $\rho > 0$).

It is the probability of matching $F(\theta_{\alpha,i})$ times the expected payoff of the project — accounting for the share sold $\psi_{i,Z}(1-\alpha)R_i$ — plus the probability of not matching $(1 - F(\theta_{\alpha,i}))$ times the expected value of the outside option $\psi_{i,Z}\Omega(i, Z)$.

A *VC's expected value* from entering a sub-market with posting α and project variety i is $\pi_V(\alpha, i)$

$$\pi_V(\alpha, i) = \frac{F(\theta_{\alpha,i})}{\theta_{\alpha,i}}[\mu(\alpha, i)R_i\alpha - I]. \tag{2.4}$$

It is a VC's probability of matching $F(\theta_{\alpha,i})/\theta_{\alpha,i}$ times the VC's expected payoff from her share $\mu(\alpha, i)R_i\alpha$ less her investment I. Denote the maximum of a VC's expected value among all sub-markets as U, which I refer to as a VC's *expected market payoff.*

Table 2.1 provides variable names and definitions. Figure 2.1 is a diagram of the setup.

2.3 Equilibrium and Analysis

2.3.1 Equilibrium

I define an equilibrium by building on the definitions used in Guerrieri, Shimer, and Wright (2010) and Delacroix and Shi (2013). Guerrieri, Shimer, and Wright (2010) have uninformed agents post contracts to which informed agents apply, creating a screening-type game. In contrast, in my model informed agents post contracts to which uninformed agents apply, creating a signaling-type game. Delacroix and Shi (2013) have the informed agents post-

Table 2.1: Variable Definitions.

Variable Name	Symbol(s)
Project Type	$i \in \{r, s\}$
Prob(Project=Good)	p
Signal	$Z \in \{L, \emptyset, H\}$
Signal Precision	$\lambda \in (0.5, 1)$
Prob(Project=Good|Z=H)	ψ_i
VC Investment	I
Project Payoff with VC	R_i
Alternative Payoff	$\Omega(i, Z)$
VC Supply	V
Posted Share	α_i
VC Belief of Prob(Project = Good)	$\mu(\alpha, i)$
Mass of Entr. in sub-market	$E_{\alpha,i}$
Market Tightness	$\theta_{\alpha,i}$
Prob(Entr. Match)	$F(\theta_{\alpha,i}) = 1 - e^{-\theta_{\alpha,i}}$
Prob(VC Match)	$F(\theta_{\alpha,i})/\theta_{\alpha,i}$
Entr., VC Expected Values	$\pi_{E,i,Z}(\alpha, i), \pi_V(\alpha, i)$
VC Market Payoff	U

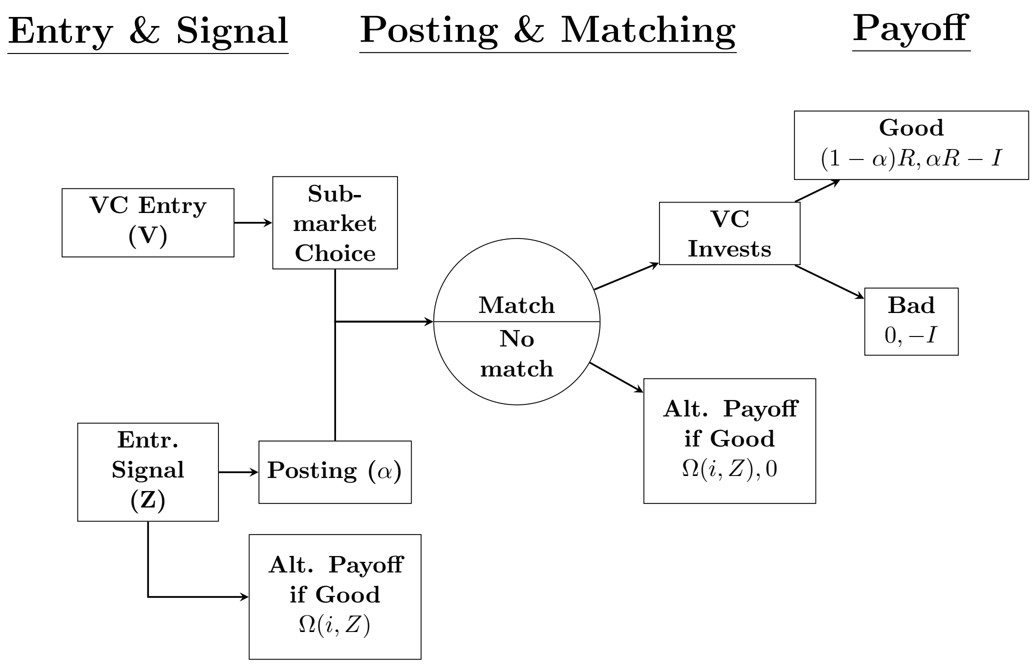
ing contracts. Unlike in my model, however, in their model the informed agents choose their quality before posting and quality is revealed probabilistically to the uninformed agent after matching but before trade occurs.[17] As will be discussed, these differences have important implications for the equilibrium outcomes.

For simplicity, I restrict entrepreneurs to playing symmetric pure strategies that consist of a posted share $\alpha^* \in [0, 1]$ for entrepreneurs with project

[17] In section 2.4, I allow some subset of seeking agents to observe the posting agent's type with some probability. However, I maintain the assumption that an entrepreneur is unable to choose his project's quality or his project's risk.

Figure 2.1: Diagram of Model.

This figure summarize the model for a given project i. The first term represents payoffs to entrepreneurs and the second to VCs.



i and type Z. I denote this strategy as $\alpha_{i,Z}$. I show in Appendix B, that with an additional mild condition on my equilibrium refinement, allowing entrepreneurs to play mixed strategies does not change the central predictions of the model. Denote $A = \bigcup_{i,Z} \alpha^*_{i,Z}$ as the set of all postings played in equilibrium. A VC's strategy consists of the probability $\sigma(\alpha, i) \in [0, 1]$ of entering each sub-market with a posting of $\alpha \in (0, 1]$ and a project variety i. VC responses depend on the posted share α, the project variety i, and their updated beliefs $\mu(\alpha, i)$. I define an equilibrium as follows:

Definition 1 (Symmetric Competitive Search Equilibrium). *A Symmetric Competitive Search Equilibrium (SCSE) consists of entrepreneur postings* $\alpha^*_{i,Z}$ *for all* $i \in \{r, s\}$ *and* $Z \in \{L, H\}$*, VC strategies* $\sigma(\alpha, i)$*, market tightness* $\theta_{\alpha,i}$*, VC beliefs* $\mu(\alpha, i)$*, and entrepreneur beliefs on* $\theta_{\alpha,i}$ *such that*

1. ***Entrepreneurs' optimal choices:*** *For a given* $i \in \{r, s\}$ *and* $Z \in \{L, H\}$*,* $\alpha_{i,Z}$ *is such that*

$$\max_{\alpha'_{i,Z} \in [0,1]} \pi_{E,i,Z}(\alpha'_{i,Z}) \leq \pi_{E,i,Z}(\alpha^*_{i,Z})$$

2. ***VCs' optimal choices:*** $U^* = \max\{0, \max_{\alpha \in A} \pi_V(\alpha, i)\}$*. VCs only enter a sub-market with posting* α *if the expected value from doing so is the market payoff* U^**. That is, for all* $\alpha \in (0, 1], i \in \{r, s\}$

$$\text{if } \sigma(\alpha, i) > 0 \text{ then } \pi_V(\alpha, i) = U^* \text{ and } \theta_{\alpha,i} > 0$$
$$\text{if } \sigma(\alpha, i) = 0 \text{ then } \pi_V(\alpha, i) < U^* \text{ and } \theta_{\alpha,i} = 0$$

3. ***Consistent VC beliefs:*** *For* $i \in \{r, s\}$

$$\alpha_{i,H} = \alpha_{i,L} = \alpha_i \implies \mu(\alpha_i) = p_i$$
$$\alpha_{i,H} \neq \alpha_{i,L} \implies \mu(\alpha_{i,H}) = \psi_{i,H},\ \mu(\alpha_{i,L}) = \psi_{i,L}$$

4. ***Probabilities sum to one:***

$$\sum_{\alpha_i \in A} \sigma(\alpha_i) = 1$$

5. ***Symmetry**: Entrepreneurs with a given project i and type Z have the same strategy $\alpha_{i,Z}$ for $i \in \{r, s\}$ and $Z \in \{L, H\}$. All VCs have the same strategy $\sigma(\alpha, i)$.*

Part (1) requires that entrepreneurs are maximizing their expected payoff. If an entrepreneur posts $\alpha_{i,Z}$ in equilibrium, then it must yield an expected payoff no less than any other potential posting α'. Part (2) requires that VCs optimally choose sub-markets in response to entrepreneur postings. If a VC visits a sub-market with positive probability ($\sigma(\alpha, i) > 0$, $\theta_{\alpha,i} > 0$), then a VC's expected payoff from entering must equal the equilibrium expected market payoff U^*. If they do not enter a sub-market ($\sigma(\alpha, i) = \theta_{\alpha,i} = 0$), then the expected payoff from entering must be strictly less than the expected market payoff. This is a requirement for all potential $\alpha \in (0, 1]$, so it is a refinement on entrepreneurs' beliefs of how market tightness $\theta_{\alpha,i}$ responds to α. Part (3) requires VC beliefs to be consistent with entrepreneurs strategies in equilibrium. Parts (4) and (5) requires probabilities to sum to 1 and strategies to be symmetric.

To solve for SCSE, I use methods similar to Montgomery (1991) and Burdett, Shi, and Wright (2001). I first solve for the relationship between the posting strategy of entrepreneurs and the expected market tightness given any VC's expected market payoff U'. Given this strategy, I solve for the equilibrium sub-market choice strategy of VCs and the equilibrium VC expected market payoff U^*. For exposition, I first solve the model under the simplified case where there is symmetric information about entrepreneur type (i.e.,

$\mu(\alpha_{i,Z}, i) = \psi_{i,Z})$.

2.3.1.1 Symmetric Information Benchmark

With symmetric information about entrepreneurs, Assumption 2 ensures VCs will never fund a low-type. Therefore, I only focus on the posting strategy of high-types because low-types will not affect the number of funded projects.

Given the competitive nature of the market, entrepreneurs take the VCs' expected market payoff U as given when choosing their posting.[18] High-type entrepreneurs choose the share posting $\alpha_{i,H}$, taking into the account the relationship between the posted share $\alpha_{i,H}$ and the market tightness $\theta_{\alpha_{i,H}}$, to maximize their expected value. An entrepreneur with a high-quality project problem is

$$\max_{\alpha \in [0,1]} \quad \pi_{E,i,H}(\alpha) = \psi_{i,H} \left[(1-\alpha) R_i (1 - e^{-\theta_{\alpha,i}}) + \Omega(i, H) e^{-\theta_{\alpha,i}} \right] \tag{2.5}$$

$$s.t. \quad (\psi_{i,H} \alpha R_i - I) \frac{1 - e^{-\theta_{\alpha,i}}}{\theta_{\alpha,i}} = U. \tag{2.6}$$

Intuitively, entrepreneurs trade off posting a higher share α that results in a higher probability of receiving funding against the cost of increased dilution if the project succeeds taking into account their outside if not funded. The constraint is due to VCs' optimal responses. As noted in part (2) of the definition of an SCSE, VCs only enter a sub-market if their expected payoff

[18] This is a common assumption in competitive search models and is known as the "market utility property."

from entering is equal to their expected market payoff U.

Solving for α and maximizing with respect to θ yields the following first-order condition (FOC)

$$U = e^{-\theta_{\alpha,i}}(\psi_{i,H}[R_i - \Omega(i,H)] - I). \tag{2.7}$$

This gives a mapping between an entrepreneur's optimal market tightness $\theta_{\alpha,i}$ and the VCs' expected market payoff U.

With symmetric pure strategies, there are only two potential sub-markets (risky or safe). Denote h_i for $i \in \{r,s\}$ as the mass of high-type entrepreneurs.[19] Let σ denote the probability of entering the risky sub-market, which implies $\theta_r = \sigma V/h_r$ and $\theta_s = (1-\sigma)V/h_s$. I can just focus on high-types because information is symmetric and only high-type entrepreneurs have positive NPV projects by Assumption 2. Part (2) of the definition of an SCSE requires that VCs only enter a sub-market if the expected value of entering equals the expected market payoff U^*, i.e., $\pi_V(\alpha,i) = U^*$. Using the FOC, requiring VCs to be indifferent between entering either sub-market, and solving

[19]Formally, $h_i = \lambda p_i + (1-\lambda)(1-p_i)$.

yields the following equilibrium

$$\alpha_i^* = \frac{U^*\theta_i^*}{(1-e^{-\theta_i^*})\psi_{i,H}R_i} + \frac{I}{\psi_{i,H}R_i} \tag{2.8}$$

$$\theta_r^*,\ \theta_s^* = \frac{V-h_s\Gamma}{h_s+h_r},\ \max\left\{\frac{V+h_r\Gamma}{h_s+h_r}, 0\right\} \tag{2.9}$$

$$\sigma^* = \min\left\{\frac{h_rV - h_rh_s\Gamma}{(h_s+h_r)V}, 1\right\} \tag{2.10}$$

$$U^* = \begin{cases} e^{-\frac{V-h_s\Gamma}{h_s+h_r}}(\psi_{r,H}[R_r - \Omega(r,H)] - I) & \text{if } \sigma \in (0,1) \\ e^{-V}(\psi_{r,H}[R_r - \Omega(r,H)] - I) & \text{if } \sigma = 1 \end{cases} \tag{2.11}$$

$$\text{where } \Gamma = \log\left(\frac{\psi_{s,H}[R_s - \Omega(s,H)] - I}{\psi_{r,H}[R_r - \Omega(r,H)] - I}\right). \tag{2.12}$$

Collectively, Eq. 2.8-2.12 define the equilibrium. Entrepreneurs and VCs are optimizing given their beliefs over equilibrium actions, beliefs are consistent with actions, all probabilities sum to one, and strategies are symmetric. Therefore, this equilibrium is an SCSE.

By Assumption 3, risky high-types have greater gains from trade, which implies Γ is negative. In return, the probability a VC enters the risky submarket σ is positive for all levels of venture capital supply V, and riskier projects will always have a higher market tightness and probability of funding. This is because risky high-types have greater gains from trade and face no information frictions when posting. Thus, they optimally post shares that have a higher likelihood of funding. Further, as I will discuss later, this also implies that if the supply of VCs V increases, there will be a decrease in the proportion of funded risky projects. This will be due to safe high-types responding to the supply shock by posting shares that have a larger relative increase in their likelihood of attracting a VC. This case highlights the role of asymmetric information in driving the model's main results.[20]

2.3.1.2 Asymmetric Information

Giving entrepreneurs a private signal regarding their quality generates the information friction in the model. The entrepreneur's problem is now

$$\max_{\alpha\in[0,1]} \quad \pi_{E,i,Z}(\alpha) = \psi_{i,Z}\left[(1-\alpha)R_i(1-e^{-\theta_{\alpha,i}}) + \Omega(i,Z)e^{-\theta_{\alpha,i}}\right] \tag{2.13}$$

$$s.t. \quad (\mu(\alpha,i)\alpha R_i - I)\frac{1-e^{-\theta_{\alpha,i}}}{\theta_{\alpha,i}} = U. \tag{2.14}$$

Substituting for α and maximizing with respect to θ yields the following FOC

$$U = e^{-\theta_{\alpha,i}}(\mu(\alpha,i)[R_i - \Omega(i,Z)] - I). \tag{2.15}$$

Eq. 2.15 gives a mapping between α and $\theta_{\alpha,i}$ based on VCs' beliefs $\mu(\alpha,i)$ and their expected market payoff U. Unlike the symmetric information benchmark, entrepreneurs' decisions now depend on how VCs update their beliefs after observing the posted share.

The definition of an SCSE only specifies beliefs over on-equilibrium actions. However, with private information there are numerous potential SCSE that can be supported by various beliefs over off-equilibrium actions, many of which might be considered "unreasonable". I refine beliefs over off-equilibrium

[20]If there was no information about type in the model and if projects had the same ex ante expected payoffs from VC funding (i.e., $p_r R_r = p_s R_s$) and the same expected outside option (i.e., $p_r\Omega(r,\emptyset) = p_s\Omega(s,\emptyset)$), then projects would have the same probability of funding and changes in supply would not affect the proportion of risky projects.

actions using the notion of the undefeated equilibrium in Mailath, Okuno-Fujiwara, and Postlewaite (1993).

I apply the refinement in the following way. Propose an equilibrium where $\hat{A}_i$ is the set of all equilibrium postings by entrepreneurs with project variety i, $\pi_{E,i,H}(\hat{\alpha})$ is a high-type entrepreneur's expected payoff, and a VC's market payoff is $\hat{U}$. Check whether there exists an alternative equilibrium with posting $\alpha' \notin \hat{A}_i$, and whether the payoff for a high-type entrepreneur deviating to α', given the beliefs and VC best responses in that alternative equilibrium, is greater than the proposed equilibrium — that is if $\pi_{E,i,H}(\alpha') > \pi_{E,i,H}(\hat{\alpha})$. If so, then beliefs for VCs in the proposed equilibrium after observing α' must be the same as those in the alternative equilibrium after observing α'. If the proposed equilibrium is not consistent with these updated beliefs, then the alternative equilibrium "defeats" the proposed one. If no alternative equilibrium defeats the proposed equilibrium, then I call it an "undefeated equilibrium."[21,22] The equilibrium refinement depends on the VC's expected market payoff U because U is fixed from an entrepreneur's perspective when forming beliefs about market tightness and the payoff from deviating.

[21]Spiegel and Spulber (1997), Taylor (1999), and Gomes (2000) use a similar form of this refinement to refine multiple potential equilibria in signaling settings.

[22]In Appendix B, I show that allowing for entrepreneurs to play mixed strategies does not change the results if I strengthen the refinement. Specifically, to deal with multiple undefeated equilibria I use the notion of the lexicographic maximal sequential equilibrium (lex-max) in Mailath, Okuno-Fujiwara, and Postlewaite (1993). If multiple undefeated equilibria exist, then I select the equilibrium that maximizes the payoff for the high-type entrepreneur, the lex-max equilibrium. The additional part of the refinement is only necessary to refine certain mixed-strategy equilibria that have a continuous support.

This is a logical method to refining off-equilibrium beliefs because low-types have the incentive to mimic high-types. Thus, a deviation that is an equilibrium action in alternative equilibria that yields a higher payoff for a high-type should be treated by VCs as a signal by high-types. An alternative refinement such as the Intuitive Criterion (Cho and Kreps, 1987) is not well defined in my setting. Further, using a refinement in the spirit of the Intuitive Criterion yields a single equilibrium in which neither type of entrepreneur enters the VC market.[23,24] Solving for the posting strategies of entrepreneurs that produce undefeated equilibria yields the following proposition.

Proposition 1 (Posting Strategy).

Taking U as given, when $p_i(R_i - \Omega(i,H)) - I \geq U$ then for $i \in \{r, s\}$: $\alpha^*_{i,L} = \alpha^*_{i,H} = \alpha^*_i$,

$$\alpha^*_i = \frac{U\theta_{\alpha^*_i,i}}{(1 - e^{-\theta_{\alpha^*_i,i}})p_i R_i} + \frac{I}{p_i R_i} \tag{2.16}$$

[23] This is formally argued in Appendix B. Because the Intuitive Criterion eliminates all but this equilibrium, more strict refinements in the spirit of D1 (Banks and Sobel, 1987) or the Perfect Sequential Equilibrium (Grossman and Perry, 1986) would also at least eliminate all but this equilibrium. For a further discussion of the comparison of refinements, please see Mailath, Okuno-Fujiwara, and Postlewaite (1993).

[24] My model provides a different result from the application of the Intuitive Criterion in Delacroix and Shi (2013). The results differ for two reasons. First, in their model the seeking agent would still trade with the low-type posting agent for some subset of prices. Second, the seeking agent can learn the posting agent's type with some sufficiently high probability. In return, high-types can set prices such that if the low-type is revealed, then the seeking agent will reject the contract. The combination of these two features of their model allows for separation to occur in equilibrium and using their application of the Intuitive Criterion yields the least-cost separating equilibrium.

and the resulting beliefs and market tightness from posting α_i^*

$$\mu(\alpha_i^*, i) = p_i \tag{2.17}$$

$$\mu(\alpha', i) = \psi_{i,L} \text{ for all } \alpha' \neq \alpha_i^* \tag{2.18}$$

$$\theta_i^* = \log\left(\frac{p_i[R_i - \Omega(i,H)] - I}{U}\right) \tag{2.19}$$

are part of an SCSE. The resulting equilibrium associated with this strategy is the unique undefeated pure-strategy equilibrium under Assumptions 1 to 3.

If $p_i(R_i - \Omega(i,H)) - I < U$*, then the only equilibrium strategy for high-types with project* i *is to not enter the VC market* ($\alpha_{i,H} = 0$)*. This is the only equilibrium strategy, so it must produce the unique undefeated equilibrium.*

Proofs of all propositions are in Appendix A.

The condition on U is necessary for there to be an incentive for high-type entrepreneurs to post. If the payoff necessary to attract a VC is too high, then all high-type entrepreneurs prefer their outside option and do not enter the VC market. This results in VCs not funding any projects of the given variety because only low-types have an incentive to post and VCs will not fund low-type entrepreneurs. For the remainder of the paper, I assume $p_i(R_i - \Omega(i,H)) > I$. This condition ensures that if there is an unlimited supply of VCs, then high-type entrepreneurs with either project will post in the VC market.

A fully separating SCSE with high-type entrepreneurs entering the VC market cannot exist. If a high-type posts a share $\alpha < 1$, then low-type entrepreneurs always have an incentive to mimic. Low-types always mimic because (a) they will never get funding from VCs if they separate because their projects have negative expected NPV by Assumption 2 (i.e., their projects are "lemons"); and, (b) the mimicking payoff is higher for a low-type entrepreneur than his outside option, which is zero under Assumption 1 (A). Selling the whole project ($\alpha = 1$) is not an equilibrium because a high-type would always prefer seeking his alternative option to selling the whole project. Therefore, a fully separating SCSE that has posting by high-types does not exist.

Among pooling equilibria, any other pooling equilibrium results in a lower expected payoff to the high-type entrepreneur than the proposed equilibrium. This is because the proposed equilibrium maximizes the expected payoff to the high-type given pooling. Using the refinement, if off-equilibrium beliefs are $\mu(\alpha_i^*) = p_i$, then high-types will deviate to α^* with probability 1. Therefore, the proposed pooling equilibrium defeats any alternative pooling equilibrium. However, the proposed pooling equilibrium is undefeated since no other equilibrium defeats it.

Given the strategy of entrepreneurs for any U, solving for the equilibrium involves solving for the strategy of VCs $\sigma(\alpha, i)$ and a VC's equilibrium expected market payoff U^*. Similar to the benchmark case, to solve for the equilibrium use Eq. 2.15 to solve for the strategy of VCs $\sigma^*(\alpha, i)$, and therefore θ_i^*, in terms of V. This yields the following equilibrium:

$$\theta_r^*,\ \theta_s^* = \max\left\{\frac{V-\gamma}{2}, 0\right\},\ \max\left\{\frac{V+\gamma}{2}, 0\right\} \tag{2.20}$$

$$\sigma^* = \min\left\{\max\left\{\frac{V-\gamma}{2V}, 0\right\}, 1\right\} \tag{2.21}$$

$$U^* = \begin{cases} e^{-(V)}(p_s[R_s - \Omega(s,H)] - I) & \text{if } \sigma = 0 \\ e^{-(V+\gamma)/2}(p_s[R_s - \Omega(s,H)] - I) & \text{if } \sigma \in (0,1) \\ e^{-(V)}(p_r[R_r - \Omega(r,H)] - I) & \text{if } \sigma = 1 \end{cases} \tag{2.22}$$

$$\text{where } \gamma = \log\left(\frac{p_s[R_s - \Omega(s,H)] - I}{p_r[R_r - \Omega(r,H)] - I}\right). \tag{2.23}$$

Collectively, Eq. 2.16-2.18 and Eq. 2.20-2.23 define the equilibrium. If $\sigma = 0$, then risky high-type entrepreneurs do not post and there is no "entry" by VCs into the safe sub-market. If $\sigma \in (0,1)$, then all entrepreneurs post and there is positive entry by VCs into both sub-markets. Finally, if $\sigma = 1$, then safe high-type entrepreneurs do not post and there is no "entry" by VCs into the risky sub-market.

The above is an SCSE if beliefs are defined such that for any deviation $\alpha' \neq \alpha_i^*$, $\mu(\alpha', i) = \psi_{i,L}$. High- and low-type entrepreneurs with either project have no incentive to deviate because VCs will never fund a deviating entrepreneur and if a high-type is not posting (i.e., $\alpha = 0$), then he is doing so because his outside option has a higher expected payoff than the payoff from posting a share that attracts a VC with positive probability. A VC has no incentive to deviate because she is getting her maximum expected payoff and takes market tightness as given. Finally, beliefs are consistent with equilibrium strategies, probabilities sum to 1, and strategies are symmetric. Thus, this is the unique undefeated equilibrium.[25]

Note that α_i^* is always greater than $I/(p_i R_i)$, the optimal share with perfect competition among VCs. Thus, VCs always earn positive rents from being in limited supply. I refer to Eq. 2.16-2.18 and Eq. 2.20-2.23 as the *undefeated SCSE*.

My equilibrium outcomes differ from those of Delacroix and Shi (2013). In the baseline version of their model, agents choose their product quality ex ante and in equilibrium products are either all high-quality or all low-quality. In contrast, in my model quality is assigned exogenously and in equilibrium agents of both qualities receive investment. Further, I allow entrepreneurs to differ in both quality and risk. Thus, in my model the equilibrium has both risky and safe projects of both qualities being funded when venture capital supply is sufficiently high. This additional feature allows me to explore how the number of funded risky and safe projects changes with the supply of venture capital.

2.3.2 Analysis

Focusing on the undefeated SCSE, I examine how venture capital supply shocks affect the described economy. I first examine the equilibrium level of market tightness θ^* and then how the *number of funded companies* of each

[25]Note uniqueness is in terms of equilibrium strategies and outcomes. Other equilibria can exist with slightly modified off-equilibrium beliefs but they will yield the same equilibrium strategies and outcomes.

project X_i responds to capital supply shocks. I also examine how venture capital supply affects the output per dollar of VC investment.

2.3.2.1 Project Choice

My framework provides a smooth relationship between the posted share and the likelihood of attracting VC funding. All else equal, selling a larger share of the project increases the likelihood of attracting a VC. The exact relationship, however, depends on VCs' beliefs of the project's probability of success and the degree of competition among VCs.

An entrepreneur chooses his optimal share taking into account the opportunity cost of his outside option, costs from dilution if matched, and the benefits from attracting VC funding. If the entrepreneur's type was public, then only high-types would get funding under Assumption 2 that low-types have projects with negative NPV. In this situation, risky high-types have a higher likelihood of receiving funding under Assumption 3 that risky high types have larger relative gains from trade — as shown in section 2.3.1.1. Risky high-types choose to post shares that have a higher likelihood of funding because their benefit from VC funding outweighs the opportunity cost from their outside option and their shares are fairly priced.[26]

[26] If projects have the same ex ante expected value and the same ex ante expected outside option, then without information about entrepreneur type, all entrepreneurs post shares that result in the same market tightness. This is because entrepreneurs face the same dilution costs, have the same outside options, and have the same benefits from funding. Thus, with no information both project varieties have the same probability of funding for any level of venture capital supply.

With private information about entrepreneur quality, there are multiple potential SCSE. However, there is a unique "undefeated" SCSE. In this equilibrium, the equilibrium share posting maximizes the payoff for high-types. Therefore, for the remaining analysis I refer to the equilibrium share posting as the high-type's optimal posting with the implicit assumption that low-types always mimic in equilibrium. The following is the relationship between the market tightness for risky and safe projects when there is private information:

Proposition 2 (Equilibrium Market Tightness).
For any supply of VCs $V > 0$, if relative gains from trade are not too large for risky projects $\frac{p_s}{p_r} > \frac{R_r - \Omega(r,H)}{R_s - \Omega(s,H)}$, then the market tightness θ is higher in the safe sub-market: $\theta_s^* > \theta_r^*$.

The intuition for this result is as follows. For simplicity, first fix payoffs such that projects have the same ex ante expected value with VC funding ($p_r R_r = p_s R_s$). A risky high-type's project has the highest expected value conditional on his signal. Thus, in a pooling equilibrium of high- and low-types, VCs undervalue a risky high-type's posted share by the greatest degree. Additionally, for the same share α, VCs earn the same expected value from entering either the risky or safe sub-market. In return, both risky and safe entrepreneurs would face the same likelihood of funding if they all posted the same share. However, risky high-types face a greater degree of undervaluation for the same likelihood of attracting a VC, meaning they find it relatively more expensive to attract VCs. Thus, the information friction and resulting undervaluation makes attracting VCs costlier for risky high-types.

With private information, high-type entrepreneurs choose their optimal shares by trading off the opportunity cost of their outside option and the dilution from matching, including the effect of the costly information friction, against the benefit from receiving VC funding. As long as the gains from trade are not too large for risky high-types, then the information friction and resulting undervaluation of shares is costly enough that risky high-types post shares with a lower likelihood of VC funding.[27]

The restriction on the relative gains from trade allows projects to have the same ex ante expected value ($p_r R_r = p_s R_s$) or risky projects to have higher ex ante expected value ($p_r R_r > p_s R_s$), and risky high-types to have relatively larger gains from trade (Assumption 3). If the gains from trade for risky projects were sufficiently larger than those for safe projects, then this would more than offset the costly information friction and the results would be similar to that in section 2.3.1.1. Therefore, as long as the gains from trade for risky projects are not too big, then entrepreneurs with risky projects have a lower market tightness θ in equilibrium.

I now turn to the main prediction of the model and examine how a shock to the supply of venture capital affects the aggregate risk of projects in

[27] The gains from trade assumption could be satisfied in many ways. For instance, assuming that projects have the same ex ante expected value with VC funding, that they have the same ex ante expected value of the outside options, and that the payoff of the outside option had increasing differences would satisfy this assumption. This could also be motivated by assuming that the outside option's payoff is a result of investment by "friends and family" in the project, which would not add the same value as a VC's investment but whom entrepreneurs are unwilling to potentially deceive.

the economy. Denote the ratio of funded risky projects X_r to safe projects X_s in the economy as

$$\kappa := \frac{X_r}{X_s}. \tag{2.24}$$

Proposition 3 (Ratio of Risky Projects — Venture Capital Supply).

If relative gains from trade are not too large for risky projects $\frac{p_s}{p_r} > \frac{R_r - \Omega(r,H)}{R_s - \Omega(s,H)}$*, then the ratio of risky projects in the economy* κ *is increasing in the supply of VCs* V *for all* $V > \gamma$ *and non-decreasing for all* V*.*

Because risky projects have a higher probability of failure ($p_s > p_r$) but larger payoffs if successful ($R_r > R_s$), an increase in the ratio of funded risky projects will cause an increase in the aggregate failure rate of funded projects and the average payoff of funded projects.

When the supply of venture capital increases, the increased competition among VCs reduces the cost to entrepreneurs of attracting VCs. In equilibrium, there are decreasing elasticities between the likelihood of matching with a VC and the expected return for the VC conditional on matching. This means that when the likelihood of matching is high, it takes a larger relative increase in the posted share to have the same relative effect on the likelihood compared to when the likelihood is low. In return, it becomes increasingly more expensive for entrepreneurs to attract VCs with higher likelihoods.[28] This makes it

[28] Decreasing elasticities are a standard feature of most of the matching functions used in the literature. As previously noted, this condition holds for the urn-ball function used in

less expensive for entrepreneurs with risky projects to increase their likelihood by the same amount relative to entrepreneurs with safe projects. Thus, following a positive supply shock, the change in risky high-types' optimal posted shares causes a greater increase in their likelihood of attracting VCs. In return, there is an increase in the proportion of funded projects that are risky.

The economic intuition is that an increase in competition among VCs improves an entrepreneur's trade-off between the posted share and the likelihood of attracting a VC. When competition among VCs is very low, risky high-types find their outside option relatively more attractive because of both the costly information friction and the low competition among VCs. Thus they stay out of the VC market completely. Given that VCs will never fund low-types, without high-type entry no risky projects receive funding. An increase in competition among VCs, due to a positive capital supply shock, makes the VC market more attractive relative to risky high-types' outside options. In return, they enter the VC market and post a share such that risky projects have some likelihood of attracting a VC. For additional increases in capital supply, risky high-types have a greater benefit from the increase in VC competition. Therefore, entrepreneurs with risky projects have a greater increase in their likelihood of attracting a VC.

this paper, as well as the telephone line matching function and the generalized telephone matching function. The basic intuition is that as the posted share increases, VCs will pursue a project with a higher likelihood. However, as the likelihood of VCs pursuing increases, the probability that any one given VC matches falls. Therefore, a VC requires increasingly larger shares to increase her likelihood of pursuing by the same relative amount, generating the decreasing elasticities of matching with respect to the VC's share.

Figure 2.2 provides a graphical representation of the intuition. When the supply of venture capital is low, the low competition among VCs requires entrepreneurs to post a high share to attract VCs. If capital supply is low enough, then risky high-type entrepreneurs find the VC market unattractive relative to their outside option and do not post (i.e., $\alpha_r^* = 0$). When capital supply is high, all entrepreneurs post a share that attracts some VCs, but entrepreneurs with safe projects always post a share with a higher probability of funding (higher θ). However, an increase in competition among VCs, due to a positive capital supply shock, has a greater effect on entrepreneurs with risky projects and they have a greater relative change in their probability of funding.

Figure 2.2: Optimal Posted Share and Equilibrium Probabilities of Funding.

This figure plots the optimal posted share α and the equilibrium probabilities of funding $F(\theta)$ for entrepreneurs with risky and safe projects for varying levels venture capital supply. The parameters assumptions are $I = 15$, $R_r = 500$, $R_s = 100$, $\Omega(r, H) = 180$, $\Omega(s, H) = 20$, $p_r = 0.1$, $p_s = 0.5$, and $\lambda = 0.9$. I allow V to vary between 0.01 and 1.75.

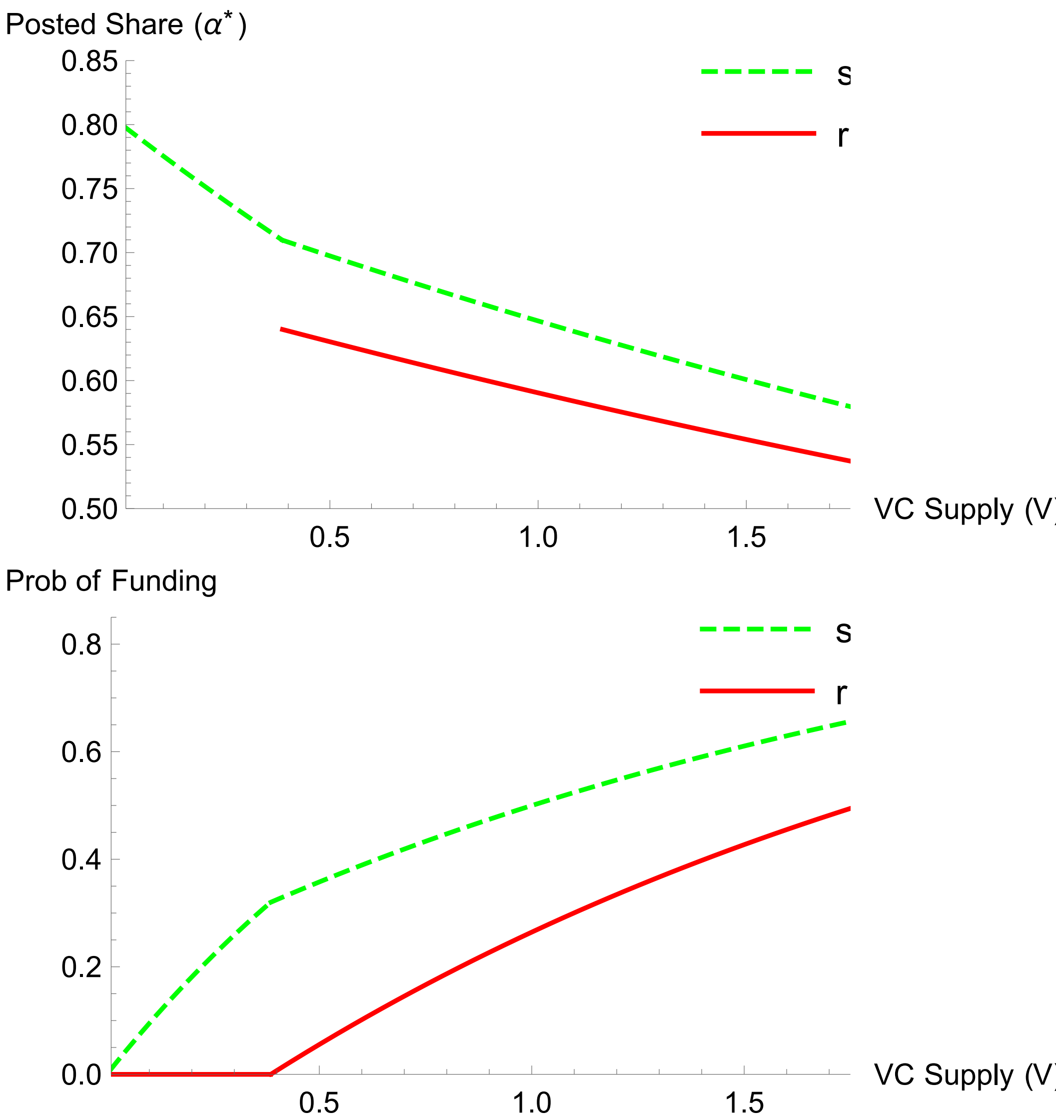
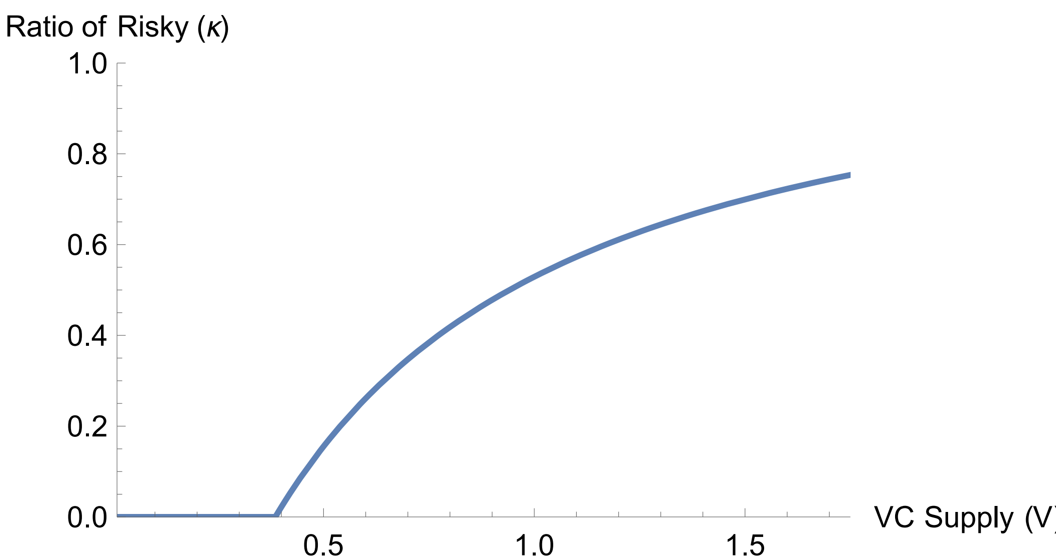


Figure 2.3 gives a graphical representation of Proposition 3, which results from the equilibrium outcomes presented in Figure 2.2.

Figure 2.3: Ratio of Risky Projects.

This figure plots the ratio of funded risky projects to safe projects in the economy (κ) for varying levels of venture capital supply. The parameters assumptions are: $I = 15$, $R_r = 500$, $R_s = 100$, $\Omega(r, H) = 180$, $\Omega(s, H) = 20$, $p_r = .1$, $p_s = .5$, and $\lambda = .9$. I allow V to vary between .01 and 1.75.



For completeness, I also examine how the ratio of funded risky projects to safe projects changes with the necessary VC investment I.

Proposition 4 (Ratio of Risky Projects — Investment).

If the supply of VCs is such that there is entry into both sub-markets and relative gains from trade are not too large for risky projects $\frac{p_s}{p_r} > \frac{R_r - \Omega(r,H)}{R_s - \Omega(s,H)}$*, then the ratio of risky projects to safe projects funded in the economy* κ *is decreasing in VCs' investment* I*.*

The intuition for this result is that a decrease in I reduces the effect of the information friction because the cost from investing in a Bad project is lower for the VC. The decrease in I provides a greater benefit to entrepreneurs with risky projects because they are more subject to the information friction. In return, there is less distortion and a relative increase in the funding of risky projects. This is consistent with the evidence of Ewens, Nanda, and Rhodes-Kropf (2015). They find that a reduction in the costs necessary to fund startups causes the funding of risky experimental firms to increase.

2.3.2.2 Output per Unit of VC Investment

The model has additional implications if projects do not have the same ex ante expected value conditional on VC funding. Specifically, if a risky projects has a higher ex ante expected value $p_r R_r = \chi + Y$ and $p_s R_s = Y$, where $\bar{\chi} > \chi > 0$, and $\bar{\chi} = p_r \Omega(r, H) - p_s \Omega(s, H)$, then the results from Proposition 3 continue to hold. Define the *Output per Unit of VC Investment* as the total payoff of funded projects over total investment and denote this as η, where with pooling

$$\eta := \frac{F(\theta_r)(Y + \chi) + F(\theta_s)(Y)}{[F(\theta_r) + F(\theta_s)]I}. \tag{2.25}$$

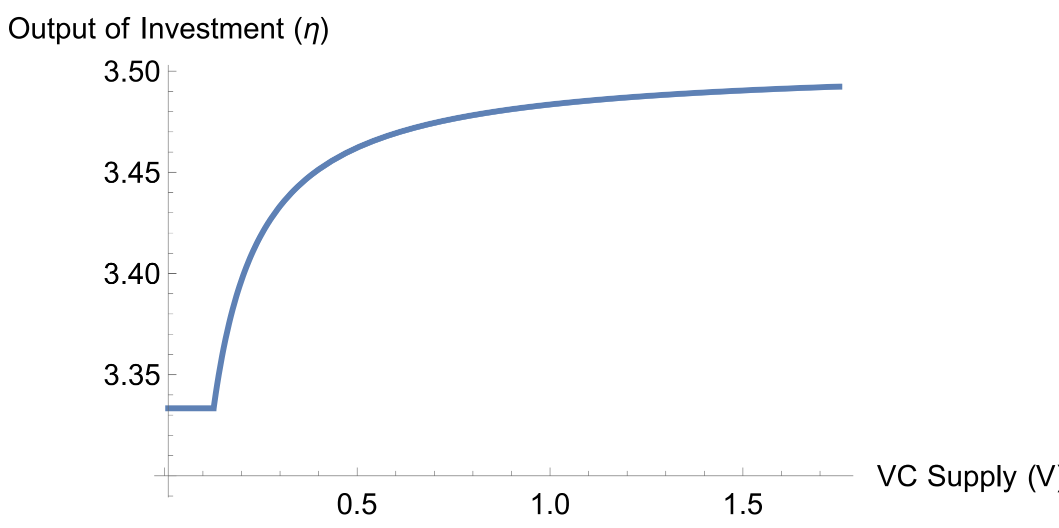
Proposition 5 (Output per Unit of VC Investment).

If the additional value of risky projects χ with VC funding is such that $\bar{\chi} > \chi > 0$, then the output per unit of VC investment η is increasing with the supply of VCs V for $V > \gamma$, and non-decreasing for $V \leq \gamma$.

Figure 2.4 gives a graphical representation of Proposition 5. The intuition is that information frictions can cause ex ante better projects to not receive funding when capital supply is low. However, increases in capital supply make the VC market relatively more attractive to risky high-types, who in this case have ex ante better projects. When supply increases, risky high-types optimally choose a share that has a greater increase in the probability of attracting a VC. In return, there is a proportional increase in the funding of the more valuable projects. This result stands in contrast to arguments that higher inflows of capital necessarily lead to only low-quality projects receiving funding.

Figure 2.4: Output per Unit of VC Investment.

This figure plots the output per unit of VC investment (η) in the economy for varying levels of venture capital supply. The parameter assumptions are: $I = 15$, $Y = 50$, $\Omega(r, H) = 180$, $\Omega(s, H) = 20$, $p_r = 0.1$, $p_s = 0.5$, $\lambda = 0.9$, and $\chi = 5$. I allow V to vary between 0.01 and 1.75.



Output per unit of VC investment increasing with capital supply has important implications for public policy. If projects that are ex ante more valuable are also riskier, then they may not receive funding due to low capital supply and costly information frictions. An increase in venture capital supply can help improve the local startup community by increasing the number of projects funded and encouraging entrepreneurs with more valuable projects to seek VC funding. This provides a potential explanation for why areas with high venture capital supply also have greater innovation (Kortum and Lerner,2000).

2.4 Heterogeneous VCs

In the baseline model VCs are homogeneous. Realistically, however, VCs differ in their ability to screen firms. The following analysis allows VCs to have different abilities to screen projects. I focus on screening to examine how this interacts with the information frictions present in the model. Screening by VCs would include things such as due diligence, identifying good management teams, and understanding future product market opportunities.[29]

The addition of heterogeneous VCs allows for additional empirical predictions regarding the types of investors that will tend to fund riskier projects. As I will show, higher ability VCs initially switch to funding riskier projects following an increase in the supply of lower ability VCs and higher ability VCs

[29] For a discussion of the ability of VCs to screen see Kaplan and Stromberg (2004) and Casamatta and Haritchabalet (2007), among others.

fund riskier projects on average.

2.4.1 VCs

The primary change to the model is to give some VCs the ability to screen entrepreneurs. For simplicity, I assume there is a unit mass of high-ability VCs that can observe the entrepreneur's signal with some probability $\delta > 0$. I refer to these VCs as "experienced". There is also a mass of VCs that cannot screen projects. I refer to these VCs as "tourists" and denote their mass V_T. A VC's ability and the mass of each class of VCs is public. Entrepreneurs can post contracts that specify different payoffs for selecting experienced or tourist VCs. I also assume that VCs can observe whether other VCs are attempting to fund the entrepreneur, which simplifies the analysis. All remaining aspects of the model with regard to search, signals, posting, and matching are the same as with homogeneous VCs.

2.4.2 Equilibrium

The definition of the equilibrium is similar to that in the baseline setting with homogeneous VCs but has one additional feature. Entrepreneurs now post contracts that specify the share of the project to be sold to either an experienced or a tourist VC and the probability that the experienced VC is chosen if both classes of VCs pursue a project. Sections of this analysis closely follow Shi (2002), which models workers with different abilities to add value applying to firms that post vacancies and wages.

Given the added complexity, I only focus on the pooling equilibrium that is best for the high-type entrepreneur and I assume that VCs assign the low-type to any off-equilibrium posting. I also assume the limiting condition on the relative gains from trade is satisfied. The entrepreneur chooses the share for experienced VCs α_E, the share for tourist VCs α_T, and the probability ξ they select an experienced VC if matched with at least one high-ability and one low-ability VC. Denote the probability of a VC matching with an entrepreneur for experienced and tourist VCs as

$$Q_E = \frac{\left[\xi + (1-\xi)(e^{-\theta_T})\right](1-e^{-\theta_E})}{\theta_E} \tag{2.26}$$

$$Q_T = \frac{\left[(1-\xi) + \xi(e^{-\theta_E})\right](1-e^{-\theta_T})}{\theta_T}. \tag{2.27}$$

The intuition for the above is as follows. An entrepreneur selects an experienced VC if no tourist VC pursues ($e^{-\theta_T}$) or if at least one tourist pursues ($1-e^{-\theta_T}$) but the entrepreneur selects the experienced VC with probability ξ. Therefore, an experienced VC is selected with probability $\xi+(1-\xi)e^{-\theta_T}$. Conditional on choosing an experienced VC, the probability that an entrepreneur selects the given experienced VC is $\frac{1-e^{-\theta_E}}{\theta_E}$. Therefore, the unconditional probability of a given experienced VC being chosen is Q_E. Q_T is derived similarly.

Given the assumptions behind selecting the best pooling equilibrium for high-type entrepreneurs with project i, the high-type entrepreneur's problem is

$$\max_{\alpha_E,\alpha_T,\xi} \quad \psi_H\left[(1-\alpha_E)R\theta_E Q_E + (1-\alpha_T)R\theta_T Q_T + \Omega(H)(1-\theta_E Q_E - \theta_T Q_T)\right] \tag{2.28}$$

$$s.t. \quad \left[g(\psi_H\alpha_E R - I) + (1-h)(1-\delta)(\psi_L\alpha_E R - I)\right]Q_E = U_E \tag{2.29}$$

$$(p\alpha_T R - I)Q_T = U_T. \tag{2.30}$$

Substituting for α_E and α_T and taking the FOC with respect to θ_E, θ_T, and ξ, a high-type entrepreneur's expected value is maximized when $\xi = 1$. In equilibrium, if at least one experienced VC applies, then only an experienced VC will be chosen. This matches the results of Hsu (2004). He finds that when entrepreneurs have multiple VC options they will give up potentially higher valuations to choose a more prestigious VC.

There will be two parameter regions depending on the mass of low-ability VCs. If V_T is low, then low-ability VCs only enter the safe sub-market and only fund safe projects. Using Eq. 2.28, taking FOC, denoting h_i as the probability of a high signal, and simplifying, the optimal θ are:

$$\theta_{E,i} = \log\left(\frac{\delta I(\lambda - h_i)}{U_E - U_T(1-\delta(1-\lambda))}\right) \tag{2.31}$$

$$\theta_{T,i} = \log\left[\frac{p_i[R_i\Omega(i,H)] - I}{U_T}\right] - \theta_{E,i}. \tag{2.32}$$

From Eq. 2.32, if $U_T > p_r(R_r - \Omega(r,H)) - I$, then low-ability VCs do not enter the risky sub-market. Denote this V_T as $\overline{V}_T$. Assuming $V_T < \overline{V}_T$, then the optimal θs are

$$\theta_{E,r} = \log\left[\frac{p_r[R_r - \Omega(r,H)][1-\delta(1-\lambda)] - I[1-\delta(1-h_r)]}{U_E}\right] \quad (2.33)$$

$$\theta_{E,s} = \log\left(\frac{\delta I(\lambda - h_s)}{U_E - UT[1-\delta(1-\lambda)]}\right) \quad (2.34)$$

$$\theta_{T,r} = 0 \quad (2.35)$$

$$\theta_{T,s} = \log\left[\frac{p_s[R_s - \Omega(s,H)] - I}{UT}\right] - \theta_{E,s}. \quad (2.36)$$

The above can be used to solve for the effect of V_T on σ_E by noting that $\sigma_E = \theta_{E,r}$.

If $V_T > \overline{V}_T$, then low-ability VCs enter both sub-markets. Using the fact that U_E must be the same for high-ability VCs if $\sigma_E \in (0,1)$, then solving for the equilibrium level of U_E and U_T and using θ, σ, and U to solve for α will complete the equilibrium. Collectively, Eq. 2.29-2.36, $\overline{V}_T$, and σ_E, $\sigma_T \in [0,1]$ define the equilibrium, which leads to the following proposition:

Proposition 6 (VC Project Choice — Heterogeneous VC).
The effect of tourist VC supply V_T on the probability of entering the risky sub-market for experienced VCs (σ_E) and tourist VCs (σ_T) is as follows:

$$\sigma_E \text{ is} \begin{cases} \text{Increasing in the supply of tourist VCs } V_T & \text{if } V_T \leq \overline{V}_T \\ \text{Constant in the supply of tourist VCs } V_T & \text{if } V_T \geq \overline{V}_T \\ > 1/2 & \text{as } V_T \to \infty \end{cases}$$

$$\sigma_T \text{ is} \begin{cases} 0 & \text{if } V_T \leq \overline{V}_T \\ \text{Increasing in the supply of tourist VCs } V_T & \text{if } V_T > \overline{V}_T \\ \to 1/2 & \text{as } V_T \to \infty \end{cases}$$

Plots of the equilibrium proportion of VC-backed risky projects and project choices for high-ability and low-ability VCs are shown in Figure 2.5.

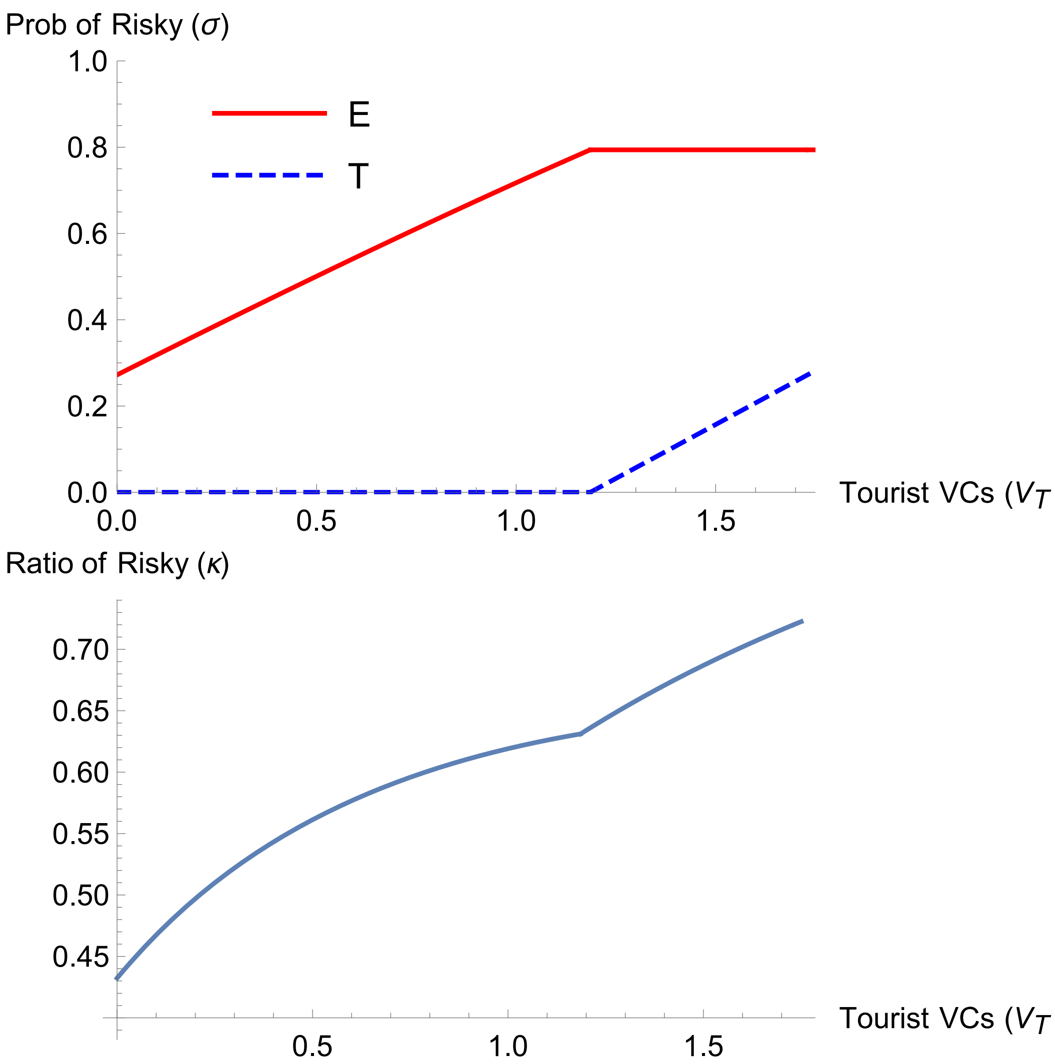
As the supply of low-ability VCs increases, high-ability VCs increase their probability of choosing to fund risky projects. Eventually the supply of low-ability VCs is high enough such that their increased entry does not affect the decision of high-ability VCs. The intuition for this result is as follows. When the supply of low-ability VCs is low, a shock to low-ability VC supply causes safe high-types to reduce the premium to high-ability VCs relatively more because they have an increased likelihood of matching with a VC and the screening ability of the VC is less important. The screening ability is less important because safe high-types gain less from screening out low-types relative to risky high-types. In response, high-ability VCs switch to funding riskier projects. This continues until either the supply of low-ability VCs is high enough ($V_T > \overline{V}_T$) or high-ability VCs only fund risky projects ($\sigma_E = 1$).

If $V_T > \overline{V}_T$, the comparative statics are similar to the baseline version. As the supply of low-ability VCs increases, the premium paid to VCs decreases, but this has a relatively larger effect on risky projects. In return, risky projects become relatively more attractive to low-ability VCs and they increasingly fund these projects. At the same time, once low-ability VC supply is high enough, $V_T > \overline{V}_T$, the increase in low-ability supply causes the premium offered to high-ability VCs to decrease. However, this decrease happens in both sub-markets and they perfectly offset such that it does not affect a high-ability VC's decision.

The empirical implications of Proposition 6 are that as the number of tourists enter the market high-ability VCs will increasingly fund riskier projects and high-ability VCs always fund riskier projects on average.

Figure 2.5: Probability of Choosing Risky Sub-Market and Proportion of Risky Projects.

The top figure plots the probability a VC searches for a risky project (σ). The solid red line is for experienced VCs and the dotted blue line is for tourist VCs. The bottom figure plots the change in the proportion of funded risky projects for the whole economy (κ) as the supply of tourist VCs changes. The parameters assumptions are $I = 20$, $R_r = 510$, $R_s = 100$, $\Omega(r, H) = 180$, $\Omega(s, H) = 20$, $p_r = 0.1$, $p_s = 0.5$, $\lambda = 0.9$, and $\delta = 0.2$. I allow V_T to vary between 0 and 1.75.



Chapter 3

Shocks to Capital Supply and VC-Backed Projects

3.1 Introduction

The main empirical prediction of the model is that positive shocks to the supply of venture capital cause an increase in the proportion of VC-backed projects that are risky. To test this prediction, one needs an exogenous source of variation in capital supply. To get this source of variation, I use lagged excess returns of state-level pension funds, which I find are related to the supply of venture capital. My key identifying assumptions are that the market for VC investments is locally segmented, that state-level pension funds are a significant source of venture capital, and that state-level pension fund excess returns are independent of the investment opportunities of local VCs and entrepreneurs.[1] The intuition for the instrument is that pension funds

[1]Sorenson and Stuart (2001) and Hochberg, Ljungqvist, and Lu (2010) find that the venture capital market is generally segmented into local markets, especially for early-stage companies. Hochberg and Rauh (2012) find that pension funds overweight their investment in local private equity funds, and provide a significant portion of the total investment in private equity funds. Furthermore, startups of the type that generally receive VC investment sell their products to markets driven by national as opposed to local conditions. Thus, investment opportunities of VCs and entrepreneurs are plausibly independent of pension fund returns. To further rule out this concern, I also control for proxies of local economic conditions in my analysis.

rebalancing their portfolios following a positive shock to returns provides a shock to the local supply of venture capital independent of local investment opportunities.

Using lagged state-level pension fund excess returns as the source of exogenous variation in local supply, I find results consistent with the predictions of my model. A positive shock to venture capital supply causes not only the failure rate of VC-backed companies to increase, but also, conditional on having an IPO, increased IPO valuations. This finding indicates VCs increase their investments in companies that are ex post riskier. Further, I find that increased venture capital supply increases a VC's likelihood of investing in startups with higher ex ante measures of risk and asymmetric information — startups in industries where public companies had above-median stock return volatilities or above-median R&D.

Empirically, this paper builds on the strategy of and finds similar results to Nanda and Rhodes-Kropf (2013) but with several important differences. I examine state-level venture capital supply as opposed to national supply and use excess returns to state-level pension funds rather than the total funds raised by leveraged buyout funds as my exogenous shock to supply. Additionally, I examine ex ante industry-based measures using public company proxies, which should be unrelated to VC-backed company quality. I also examine whether more experienced VCs, my proxy for screening ability, invest in riskier companies on average. The results with respect to VC experience are consistent with Crain (2014), who finds that experienced VCs tend to invest in riskier projects. His focus, however, is on the change in a VC's preference for risk over its life cycle and not the effects of capital supply.[2]

3.2 Hypotheses

My model makes several testable predictions. Proposition 3 predicts that following an increase in the supply of venture capital, there will be an increase in the proportion of VC-backed projects that are risky. In the model, riskier projects have both higher failure rates and conditional on success, higher payoffs. This leads to the following hypothesis:

Hypothesis 1 (Ex Post Risk).
An increase in venture capital supply causes an increase in the average failure rate of VC-backed companies and, conditional on success, higher payoffs of VC-backed companies.

This hypothesis examines ex post measures of risk — that is, after VC investment. However, Proposition 3 also implies an increase in the funding of ex ante riskier projects. This leads to the following hypothesis:

Hypothesis 2 (Ex Ante Risk).
An increase in venture capital supply causes an increase in the likelihood that

[2] Several other papers examine how changes in the supply of venture capital generally affect other VC decisions. Notably, Hochberg, Ljungqvist, and Lu (2010), Hochberg, Mazzeo, and McDevitt (2015), and Cabolis, Dai, and Serfes (2015) examine how competition relates to a VC's entry and networking decisions, or specialization within an industry or project stages.

VCs invest in projects with higher measures of ex ante risk and asymmetric information.

Proposition 6 predicts that higher ability VCs will fund riskier companies on average. It does not predict whether they have higher or lower failure rates or whether they are more or less responsive to changes in supply. The model does predict that projects backed by high-ability VCs will have higher payoffs. This leads to the following hypothesis:

Hypothesis 3 (VC Experience).
High-ability VCs will on average fund projects with higher measures of ex ante risk and asymmetric information. The payoffs of projects backed by high-ability VCs will be higher than those backed by low-ability VCs.

3.3 Data

The primary source of data is the Thomson SDC VentureXpert (VX) database. This is one of the two primary databases used in the literature and contains information on portfolio companies, VC funds, and VC firms. I collect all US based venture capital rounds between 1980 and 2015. I restrict the sample to companies that had their first round between 1985 and 2010. This is to ensure that I am capturing the company's first round and that I have ample time to track the company following its first round. I exclude all investments classified as buyouts or that are made by non-venture capital firms. Round information includes, when available, the date of the round, a listing of the investors, and the total amount invested. I also collect information on the company's location, founding date, and industry.

I match these data with the Thomson SDC New Issues database and the Field-Ritter IPO data, as used in Field and Karpoff (2002) and Loughran and Ritter (2004), from Jay Ritter's website. The Field-Ritter IPO data is for CUSIPS, and for IPO dates and company founding years when not available from the Thomson SDC New Issues database. The Thomson SDC New Issues database and the VX database do not yield perfect matches. Remaining unmatched firms were hand matched. Offer price and shares offered are from Thomson SDC and missing observations were hand filled when available. I calculate pre-IPO valuations using common shares outstanding from CRSP on the day of the IPO. I clean the matched IPOs using the filters of Ritter and Welch (2002).

I also utilize information on public pension funds. This information is from the U.S. Census Annual Survey of Public Pension Funds. This covers state and local pension funds and collects information on their total size, investment allocation, investment income, and expenditures. It includes all state-level pension funds and samples local pension funds. I also utilize additional information on local home prices from the Federal Housing Authority (FHA). I report in Table 3.1 summary statistics for the variables used in my analysis.

3.4 The Supply of Venture Capital

I primarily follow the methodology of Samila and Sorenson (2011) to measure local venture capital supply. Specifically, I proxy for the availability of VCs in the local market with the log of one plus the number of investments by VCs in a state and quarter, regardless of the location of the investment.[3]

I use the company's state as my definition of the local market as VCs tend to invest close to where they are located, especially in early rounds. Sorenson and Stuart (2001) find that VCs have a significantly higher likelihood of investing in companies that are geographically close and Lerner (1995) finds that VCs invest locally to improve the oversight of their portfolio companies. In my sample, companies receive their first round investment from VCs that are significantly closer relative to VCs that make later round investments. For instance, the median VC is 63% further away from the portfolio company in a later round relative to the median VC in the portfolio company's first round. I define the local market at the state level to maintain consistency with my instrument, which is defined at the state level.[4] My proxy from supply is

[3] I add one to account for states with no VCs investing in the given quarter. As a robustness check, I also used the supply measure of Nanda and Rhodes-Kropf (2013), the log of one plus the number of companies that receive their first round of financing in a given state and quarter, and the log of one plus the total amount invested by VC funds in the state. The results are of similar economic magnitudes and significance. However, since my instrument focuses on VCs in a state, I use the VC-state based measure. Further, since round size is not always reported in the database and when it is reported it is not clearly attributed to one firm, I use the total number of investments by VCs in a given state.

[4] Hochberg, Ljungqvist, and Lu (2010) examine networking between VCs and its relationship to competition and find similar results when they define the market at either the state or MSA level.

a departure from Nanda and Rhodes-Kropf (2013) who examine changes in venture capital supply at the national level and likewise instrument for supply with changes in the lagged total funds raised by U.S. leveraged buyout funds. This is an important difference because competition for first round financing is generally localized. Thus, local, as opposed to national, capital supply shocks are likely to have a greater effect on the decisions of VCs regarding first round investments. Nonetheless, my results are consistent with and support those in Nanda and Rhodes-Kropf (2013).

3.4.1 Exogenous Shocks to Supply

To establish that shocks to the supply of venture capital cause VCs to invest in different types of projects, changes in supply need to be exogenous. Endogeneity is a concern in this context because capital supply could increase when riskier investment opportunities are available. If investment conditions are not fully observable, then changing conditions and not capital supply would be potentially driving any observed effect. Therefore, to establish causality I need exogenous shocks to the local supply of venture capital.

My identification strategy is based on three key identifying assumptions. The first is that institutional investors will tend to overweight investments in local private equity funds. Hochberg and Rauh (2012) provide support for this assumption. They find that institutions, especially public pension funds, exhibit substantial home bias when allocating their investments to private equity.

The second identifying assumption is that state-level pension funds represent a significant portion of the total limited partner money invested in VC funds. Gompers and Lerner (1999) provide support for this assumption. They find that changes in ERISA rules, which only had an effect on pension funds, had a significant impact on VC fundraising and that pension funds are an important source of limited-partner money for VC funds. Because state pension funds are often orders of magnitude larger than the entire VC market in their states, they can still have an effect despite VC investment making up only a small portion of their overall asset allocations.[5] The first two assumptions establish the instrument's relevance.

The third identifying assumption establishes the necessary exclusion restriction of the instrument. Specifically, that the excess returns of a pension fund are unrelated to changes in the prospects of entrepreneurs in which VCs are likely to invest. VC fund returns are unlikely to drive pension fund returns because they only make up a small portion of pension fund investments. For instance, in my sample the median pension fund at the state level only allocated 6% to alternative assets, of which VC funds are only a small portion. Thus variation in pension fund returns is likely due to the fund's investment manager selection and general asset allocations and not its investment in local

[5]Using my data, I make the following back-of-the-envelope calculations to demonstrate that state pension fund reallocations can have a large effect on the local VC market. For instance, Texas has state-level pension investment holdings of $165 billion in 2013. A 1% excess return then implies that $1.65 billion needs to be reinvested. If 0.5% of this rebalancing is allocated to local VC funds, then this implies a $8.25 million increase in local VC funding. In 2013, this would represent a 5.5% increase in the local supply of venture capital relative to the total $150 million raised by Texas VC funds.

VC funds. Further, the products of startups in which VCs generally invest are sold to a national as opposed to a local market. Therefore, changes in local economic conditions that affect the pension fund's returns are likely to be independent of entrepreneurs' prospects. I also include controls for local economic factors to further address this concern.

I use the lagged 3-year excess compound returns for state-level pension funds as an exogenous source of variation in local venture capital supply. I use state-level pension funds as they have the necessary size and sophistication to make significant VC investments.[6] Formally, I calculate the annual aggregate return for state-level pension funds in a given state. I then calculate the rolling 3-year compound return. I use lagged three-year returns following Samila and Sorenson (2011) because VCs do not immediately invest all the funds they raise. To handle outliers, I winsorize returns at the 1% level. I also calculate the rolling 3-year aggregate return for all state-level pension funds in the country. The excess return is the state pension fund's 3-year return less the value-weighted national 3-year return.

Using excess returns accounts for any aggregate changes to the US economy. For instance, if all pension funds did well because of a national productivity shock, then this would not be reflected in a given state's excess return. Furthermore, calculating excess returns relative to the national average

[6]State-level pension funds would include such institutions as CALPERS and CALSTRS in California, whereas local pension funds would include county and city employee, police, and fire fighter pension funds.

return controls for changes in general pension fund investment strategies. For instance, if funds overweighted bonds on average, then this would be reflected in the national average return.

To further address concerns that state-level pension fund excess returns are not independent of a state's economic conditions, I control for the aggregate returns of local pension funds in the state. This is a good proxy for local conditions because local pension funds likely exhibit greater home bias and are more dependent on the state's economic conditions than their larger and more diversified state-level counterparts.[7] Further, local funds are unlikely to impact venture capital supply given their small size and allocations to VC funds.[8]

3.5 Ex Post Measures of Risk

Proposition 3 predicts that an increase in the supply of venture capital causes an increase in the proportion of funded projects that are risky. This prediction leads to Hypothesis 1 that: an increase in the supply of venture capital causes both an increase in failure rates and an increase in the payoffs

[7]In unreported regressions, I find that lagged local pension fund returns are a significant predictor of state-level GDP per capita, whereas lagged state-level pension fund returns are an insignificant predictor both before and after controlling for lagged local-pension fund returns.

[8]For instance, in my sample the median state over 90% of all funds invested in pensions were in state-level pension funds. The median size of local pension funds in my sample is only $776 million, of which only 2% is invested in alternative assets. This compares to a median size of almost $15 billion for state-level pension funds and almost 6% invested in alternative assets.

of successful projects.

3.5.1 Failure Rates

In order to test Hypothesis 1, I first need to establish what constitutes a failed company. Although VX sometimes reports when a company fails, many times companies are considered active despite having no current commercial activity (e.g., “zombie” firms). Therefore, I follow Hall and Woodward (2010) and consider a company failed if it is listed as “Bankrupt” or “Defunct”, or if it has no activity in the VX database anytime after 5-years from its last investment and it was not acquired or did not have an IPO. Using this measure, approximately 43% of the companies in my sample eventually fail.[9]

There are likely additional factors that affect whether a startup will fail beyond changes to the supply of venture capital. Therefore, I control for several additional company and round characteristics. These include the the total syndicate members in a round, the total dollar amount invested in the company during the quarter of its first round, and the age of the company at its first round. Kerr, Kerr, and Nanda (2015) show that local changes in home prices affect the demand for entrepreneurs and the decision to start a new company. Therefore, I also control for changes in local home prices using state-level seasonally adjusted quarterly housing price indices from the FHA.

[9]This estimate is in line with Hall and Woodward (2010) (49%). Using the VX failure definition, the failure rate is approximately 22%. The results are qualitatively similar using alternative failure definitions.

To control for non-time-varying difference in states, I include state-level fixed effects. I also control for changes in the venture capital market over time through the use of year fixed effects. Thus, the empirical analysis focuses on the effects of cross-sectional variation in state-level venture capital supply.[10] Finally, I also attempt to control for general industry effects. Although the model allows for VCs to change the industries in which they are investing, which is the focus of Hypothesis 2, I want to capture industry differences in failure rates and success. Therefore, I use industry-level fixed effects using the fifth industry subgroup provided by VX, which roughly maps to a two-digit SIC code.

I test whether increased venture capital supply causes increased company failure rates by running a linear probability model (LPM) using my proxies for local capital supply and company failure.[11] Formally, I run the following regression

$$Fail_i = \beta_1 VCSupply_{j,t} + \beta_2 X_i + \beta_3 X_j + \iota_k + \tau_t + \epsilon_i. \tag{3.1}$$

Each observation is the first quarter that company i receives its first investment. X_i are company-level controls, X_j are state-level controls, and ι_k and

[10] Although the variable of interest, venture capital supply, is in the time series within a state, year fixed effects allow me to isolate the cross-sectional variation in local venture capital supply. If instead I control only for long-term changes in the VC market using time fixed effects based on the business cycle, then my results are statistically stronger and have the same directional effects.

[11] The results are robust to using a logistic regression. However, my instrumental variable regressions are done using 2SLS and thus to ease comparison I use a LPM.

τ_t are the industry and year fixed effects. Table 3.2 reports the results of this regression.

From Table 3.2, there is a significant positive relationship between my proxy for venture capital supply in the quarter-state and the failure rate of companies that received their first round of funding in that quarter-state. I include additional controls for company, round, and local characteristics in column (2). Many of the controls have effects in the direction that one would expect. For instance, companies that raise a larger amount or have a larger syndicate in their first round are less likely to fail. In column (3), I control for time and industry fixed effects. The effect of my proxy for local supply is robust and of similar magnitude when I include these additional controls.

As previously noted, my proxy for venture capital supply is potentially endogenous. Therefore, I use trailing 3-year state-level pension fund excess returns as a source of exogenous variation in supply and use a 2SLS framework. Furthermore, I control for potential changes in the state economy using trailing 3-year local-level pension returns. I report the results from this regression in column (4) and the first-stage statistics in the bottom panel.

The results of the first-stage regression indicate that lagged excess state-level pension fund returns are a good predictor of my proxy for the local supply of venture capital. The coefficient is significant and in the direction one would expect. For the average state in my sample, a one standard deviation in excess returns results in about a 6% increase in my proxy for supply. Further, this is relatively strong instrument as indicated by the high F-stat and marginal R^2.

The coefficient on the instrumented proxy for local supply is economically and statistically significant. A 10% increase in local capital supply causes a 1.6% increase in failure rates. An increase in failure rates alone, however, would not indicate that VCs are investing in riskier startups because failure rates could reflect quality and not risk. Therefore, to demonstrate that the companies are riskier and not just of lower quality, I examine the payoffs of companies that are successful. If increases in supply cause increased failures but also increased payoffs conditional on success, then this would indicate riskier projects being funded.

3.5.2 IPO Payoffs

I now examine the second part of Hypothesis 1, that conditional on success companies funded during times of increased venture capital supply are more highly valued. I use whether a company went public in an IPO as my indicator of success, which is the traditional measure of success used in the venture capital industry. In my sample, roughly 10% of the companies had an IPO, which is in line with other industry estimates of VC-backed companies. Although this does not capture companies that were successful but had an exit via acquisition, capturing value associated with exits via acquisition is difficult given that valuations and contract terms in acquisitions are often not disclosed.

I use the pre-money valuation of the company at its IPO as the proxy for the company's degree of success. I calculate this as the product of the IPO offer price and the number of common-share equivalents outstanding on the day of the IPO less the proceeds from the IPO. The model predicts that companies first funded when venture capital supply is high have an increased degree of success. To test this, I regress the log of the pre-money IPO valuation on my proxy for local supply at the time of the company's first round of financing. Formally, I run the following regression

$$\log(IPO\,Val_i) = \beta_1 VCSupply_{j,t} + \beta_2 X_i + \beta_3 X_j + \iota_k + \tau_t + \epsilon_i. \tag{3.2}$$

Each observation is the first quarter that company i receives its first investment. X_i are company-level controls, X_j are state-level controls, and ι_k and τ_t are the industry and time fixed effects. Table 3.3 reports the results of this regression.

The level of venture capital supply at the time of the company's first investment has a positive effect on the pre-money valuation for companies that have an IPO. I include additional controls for the total number of unique investors, the total amount raised by the company, and the time between the first round and the IPO. The effects of many of these additional controls are as expected. For instance, companies that raised more money are associated with having more highly valued IPOs. The relationship between supply and degree of success is also robust to including time and industry fixed effects.

I use trailing 3-year excess state-level pension returns as an exogenous shock and instrument for local venture capital supply. Furthermore, I control for potential changes in the local economy using trailing 3-year local-level pension fund returns. I report the results from this regression in column (4). Similar, to Table 3.2, state-level pension fund excess returns are a strong predictor of the proxy for local supply with an F-stat greater than 20 and a relatively large marginal R^2. Importantly, the coefficient on the proxy for local supply in the second stage remains positive and significant.[12] Using the results from column (4), indicates that a 10% increase in my proxy for local capital supply at the company's first round causes a 7.5% increase in the valuation of the company if it has an IPO.

Taken together, the results from Tables 3.2 and 3.3 indicate that an increase in local venture capital supply causes an increase in the failure rate of companies as well as an increase in the valuations of those companies that have an IPO. This indicates an increase in the proportion of riskier companies being funded during periods of increased capital supply and provides support for the central prediction of my model.

[12]The IV coefficient is significantly larger in magnitude than the OLS coefficients. First, this large increase in magnitude could be potentially due to measurement error in my proxy for local supply, which would downwardly bias my OLS estimates. Second, if there are local unobservable factors that attract both lower quality entrepreneurs and more VCs, then this would also downwardly bias my OLS estimates since even if these entrepreneurs' projects undergo an IPO, they are likely to be at a lower valuation. However, it is unlikely that any unobservable factors would also be associated with state-level pension fund excess returns and thus my shock is plausibly exogenous. Furthermore, given the large standard errors around my IV estimates, the magnitudes of the coefficients should be taken with caution.

3.5.3 VC Fixed Effects

I further test Hypothesis 1 by examining the effects of increased venture capital supply on individual VCs. The analysis uses similar regressions to the previous tests, but now the unit of observation is the VC-company level for each VC that invested in the company's first round. For example, if a company had 3 VCs in its first round, then this would represent 3 observations in the sample. It does not include any later investments by the VC in the company. For VC firms with multiple funds, I aggregate each fund into a single VC firm. This expanded sample allows me to examine whether changes in local supply affect the decision of VCs holding constant any non-time-varying VC attributes.

One potential concern is that a VC's size could cause it to invest differently. Therefore, to capture a time-varying effect in the size of the VC firm, I used the total amount invested by a given VC in the prior two years.[13] Furthermore, to account for any potential correlation among the residuals within companies and among the residuals within a quarter, I double cluster on both the quarter and company.

I first examine the effect of venture capital supply on the likelihood of failure. To facilitate this test, I use a LPM with a specification similar to the one used in Table 3.2. Table 3.4 reports the results of this regression using the instrumented specifications.

[13] If multiple VCs invested in a given round, the amount invested was split evenly among the VCs.

The results from column (1) show a positive and significant effect of venture capital supply on the likelihood of a VC funding a company that eventually fails. This indicates that the prior results are robust to within-VC variation, meaning it is not just due to different VCs but also due to VCs changing their project-selection strategies.

I also test the extension of my model by examining whether a VC's greater experience, a proxy for its ability to screen projects, leads it to fund relatively riskier projects. I use a similar definition as Nanda and Rhodes-Kropf (2013) and classify VCs as experienced if they have more than 5 first-round investments in the prior 2 years. I focus on a VC's experience with first-round investments because these should be most indicative of the VC having project-screening ability. I report the results from including this indicator variable in column (2).[14] A VC's experience reduces the failure rate of its investments relative to inexperienced VCs, all else equal. Importantly, the model does not make a strong prediction regarding the likelihood of failure because the screening ability of an experienced VC may offset its higher likelihood of investing in riskier projects. However, this specification does reveal that experienced VCs generally have lower failure rates.

Using a similar specification to Table 3.3, I examine whether changes in venture capital supply cause VCs to invest in companies with greater potential

[14]Note I do not include VC fixed effects in this specification because there is little time variation in VC experience. Additionally, I do not include the total amount invested by the VC, as this is highly correlated with having more than 5 investments.

payoffs, controlling for non-time-varying VC attributes. I report the results from these regressions in columns (3) and (4). Firms that receive their first round of funding when venture capital supply is high have a higher valuation at their IPO. Using VC fixed effects ensure that the effect is not driven by new investors chasing riskier projects. Instead, changing capital supply causes VCs to change their project-selection strategies. The coefficient in column (4) on VC experience indicates that companies funded by experienced VCs have higher IPO valuations. This supports Hypothesis 3 that higher ability VCs will fund companies that have larger payoffs on average. However, one should view these results cautiously because this specification cannot rule out experienced VCs having better value-adding abilities.

The results in Table 3.4 provide further support for Proposition 3 of the model, which predicts increases in venture capital supply cause VCs to fund riskier projects on average. An exogenous positive shock to local venture capital supply causes VCs to fund projects that both are more likely to fail but, conditional on success, have bigger payoffs. However, this result only addresses ex post measures of risk, which are realized after the VC has made their initial investment. It is possible that changes in capital supply affects the behavior of VCs after they make their investment, which could also affect failure rates and IPO valuations. Therefore, I also examine whether increases in capital supply cause VCs to invest in companies with higher ex ante measures of risk and asymmetric information.

3.6 Ex Ante Measures

Hypothesis 2 predicts that an increase in venture capital supply causes an increase in the likelihood that VCs will invest in ex ante riskier companies that have a greater degree of asymmetric information. I test this prediction using two proxies of ex ante portfolio-company risk and asymmetric information and my instrumented proxy for local supply.

The first ex ante measure is whether VCs increase their likelihood of investing in portfolio companies that are in industries with high levels of research and development (R&D) spending. High R&D industries are generally considered to be riskier and to have greater information asymmetries. Since private company R&D spending is not available, I use public companies as proxies. Specifically, I map 3-digit SIC codes to VX industries using the method of Gompers and Lerner (2000).[15] Using these industry mappings, I then calculate equal weighted R&D-to-Asset ratios for each quarter using either 5-year rolling R&D to Asset ratios or historical R&D-to-Asset ratios starting at the beginning of my sample. I consider an industry to be high R&D in a quarter if it has an above-median R&D-to-Asset ratio, calculated across all industries, in the prior quarter.

My second ex ante measure is whether the portfolio company is in an

[15]Formally, I map VX industries to public company SIC codes at the 3-digit level using the SIC code of companies in the VX database that went public. If the plurality of firms that went public had a 3-digit SIC code in a VX industry (defined at the 5th level, so 72 industries), this VX industry was assigned the 3-digit SIC code. Additionally, if a VX industry had more than 20 companies with a given 3-digit SIC code, then that SIC code was assigned to that VX industry.

industry with high return volatility. I use the same industry mappings to generate an industry index and the aggregate returns for all public companies in that index. I then calculate CAPM betas using the method of Campbell, Lettau, Malkiel, and Xu (2001) and total return volatility. In both calculations, I use 5-year rolling calculations.[16] Because VCs often have limited ability to diversify, I also consider an alternative version of risk based on the idiosyncratic risk of each of the companies in the given industry index. Specifically, for each company I calculate the rolling 5-year monthly stock return volatility and then average across all companies in the index. For each of the measures, I consider an industry to be high risk if it has an above-median return volatility, calculated across all industries, in the prior quarter.

Using industry-based measures of public companies should reduce concerns that the proxies are capturing quality and not risk or asymmetric information. For quality to be driving the ex ante measures, it would need to be the case that portfolio companies in industries where the public companies have above-median levels of R&D or return volatility are also of lower quality. Given the established nature of public companies and the use of industry averages it is unlikely that quality is correlated with the industry measures.

I test whether an increase in local venture capital supply increases the likelihood that VCs invest in ex ante riskier companies using similar specifications to those of Table 3.4. I also test whether experienced VCs invest in

[16]The results are similar using varying time-period calculations.

riskier companies on average. I report the results in Table 3.5.

From Table 3.5 Panel A, an increase in venture capital supply causes VCs to be more likely to invest in companies that are in ex ante riskier industries as measured by industry R&D spending or return volatility. For instance, a 10% increase in local supply causes an almost 2% increase in the probability that a VC will invest in a portfolio company in a high-R&D industry. Similarly, a 10% increase in supply increases the likelihood of investing in a high-return-volatility industry by roughly 2% when volatility is measured across the industry or when looking at the average idiosyncratic volatility. The results in Table 3.5 support Hypothesis 2 and provide further support for the central predictions of the model.

In Table 3.5 Panel B, I also find that higher ability VCs invest in riskier companies and companies with greater asymmetric information. On average, VCs with more experience have a 2-3% higher likelihood of investing in a company in an industry where public companies have either high R&D or high return volatility. Note that the coefficient on the instrumented supply proxy is no longer significant in several specifications. This is because I am no longer controlling for the VC fixed effect. If low-ability VCs are more likely to invest in safer startups, then their entry brings down the average likelihood of a VC investing in riskier projects when capital supply increases. In return, the effect may no longer be statistically detectable in certain specifications. The coefficients, however, are of similar magnitude to those in Panel A, indicating that although the effect is weaker, it is likely still present.

3.7 Measures of Asymmetric Information

A primary assumption in the model is that risky projects have higher degrees of asymmetric information (i.e, risky projects) relative to safe projects. Thus, the model predicts that not only should the proportion of riskier projects increase with the level of venture capital supply, but also the proportion of projects with greater degrees of asymmetric information. In this final section, I will attempt to test if this additional prediction holds. Importantly, this is a key differentiation of the predictions and empirical tests of my model versus those of Nanda and Rhodes-Kropf (2013) and Nanda and Rhodes-Kropf (Forthcoming). Respectively, these papers do not test how projects with different degrees of asymmetric information are funded following venture capital supply shocks empirically or model information problems theoretically.

It is difficult to test the degree of information asymmetry directly. However, the finance literature has developed several proxies for asymmetric information. One proxy is the degree of IPO underpricing. Sherman and Titman (2002) provide intuition for this proxy. Specifically, when building a book for an IPO, underwriters must incentivize investors to produce information. One way to do this is to underprice the IPO, so that the IPO investors are rewarded. If this information is more costly to produce or more valuable, such as the case for firms with high degrees of asymmetric information, than the underwriters must provide greater incentives and the IPO has a greater degree of underpricing.

Building on this intuition, I use two proxies for asymmetric information using IPO underpricing. The first proxy is the first day returns of VC-backed companies on the date of their IPO. The first day return is calculated from CRSP, based on the first day the company is in the CRSP daily stock price data. It is the return calculated by the closing price over the IPO price. I then regress this first day return of VC-backed companies, conditional on having an IPO, on the instrumented level of local venture capital supply when the company received its first round of financing. A positive coefficient on supply would indicate that a positive shock to local venture capital supply causes VCs to fund companies that go on to have greater IPO underpricing. The second proxy is at the industry level, and is whether the average company in the industry that has an IPO has an above median first day IPO return. The intuition is that industries that have higher average first day IPO returns are industries with greater degrees of asymmetric information. I report the results of these two regressions in Table 3.6.[17]

From Table 3.6 it is clear that a shock to local supply has a significant positive effect both on individual company's IPO underpricing and the likelihood of VCs investing in companies in industries with higher degrees of IPO underpricing. This provides further evidence of the channel identified in my model for how changes in venture capital supply affect the allocation of venture capital between different types of projects.

Another proxy frequently used in the accounting and finance literature

[17] I have run similar tests using a continuous measure of average industry level overpricing as well as aggregating results to the state level and found similar qualitative results.

for the degree of asymmetric information is the dispersion of analyst forecast. Sell-side analysts are key drivers of information production for public companies. Thus one would expect their information environment to be reflective of the general information environment of a company or industry. As noted by Barron, Kim, Lim, and Stevens (1998), the dispersion and forecast error of analysts can be used as measures of their information environment. This is supported by Diether, Malloy, and Scherbina (2002) who use analyst forecast dispersion as a measure of disagreement. Importantly, they show that this is not necessarily related to risk. Thus using forecast dispersion provides an alternative test of my model in that this measure of asymmetric information may not be directly tied to the risk of a company.

Similar to my previous tests, I define my measures at the industry level and examine if a shock to the local supply of venture capital causes VCs to increase their likelihood of investing in companies in industries with above median levels of the measure. Specifically, I use I/B/E/S earnings forecast data to calculate the mean and standard deviation of the monthly forecasts of analysts for each company I can match to CRSP. Following Diether, Malloy, and Scherbina (2002), I then standardize the standard deviation by the absolute value of the mean forecast, dropping forecasts where the mean was 0 or that contained less than 2 analysts. I refer to this as the *dispersion* of forecasts. I also calculate a measure of forecast error for each company. I calculate this by taking the absolute value of the difference between the actual and the forecast earnings scaled by the forecast. I refer to this as the *error* of forecasts. I use the same method to map companies to VX industries as in Table 3.5. For each industry, I then take the average of the dispersion and error for each company in the industry over the previous 5-years. I then regress whether a company in an industry with an above median level of dispersion or error received an investment from a VC on the instrumented local supply of venture capital. I report these results in Table 3.6.[18]

From Table 3.6, we can see there is a significant positive effect of local venture capital supply shocks on the likelihood that a VC invests in a company in an industry with an above median level of forecast dispersion or error. This is strong evidence that increases in the supply of venture capital cause VCs to invest in not only riskier companies, as shown in Tables 3.4 and 3.5, but also companies with higher proxies of asymmetric information. Overall, these results provide further evidence that is consistent with the model presented in Chapter 2.

[18] I have run similar tests using a continuous measure of forecast dispersion and forecast error as well as aggregating results to the state level. The results are qualitatively similar.

Table 3.1: Summary Statistics.

This table reports summary statistics for all firms in the regression sample, all firms in the IPO sample, and pension data for 1987-2010. Firm data is from SDC VenturExpert (VX) for all US firms that had their first round of financing between 1985 and 2010 and had sufficient data to be included in the regression sample. All rounds that are buyout or acquisition related are excluded. A company is considered to be failed if it had not been acquired or had an IPO and had not received any form of investment after 5-years. The number of investors in the first round syndicate is from SDC VentureXpert. Amount raised in the first round is the total dollar amount raised in the first financing round as recorded by VentureXpert. Age is the company's age at its first financing round in years. IPO data is from the Thomson SDC New Issues database and is supplemented with the Field-Ritter IPO database as well as the CRSP/Compustat merged database. Pre-money IPO valuations are calculated as the IPO offer price multiplied by the common shares outstanding on the date of the IPO less the IPO proceeds. Total funds raised is the total dollar value of funds the company raised across all rounds prior to its IPO. First round to IPO is the number of years between the company's first funding round and its IPO. State and local pension data are from the US Annual Retirement Survey and includes all sampled state-level pension funds for 1987-2011 and sampled local-level pension funds. State and Local Pension returns are calculated annually as the total investment income over the prior years assets. The three-year return is the rolling compound return for three years. Excess returns are the individual state-level pension return less the value-weighted return for all state-level pensions in the United States. Total Alt. Assets is all invested assets listed under "Other" or "Alternative" for state-level funds. Data for returns and allocations are winsorized at the 1% level. All dollar values are inflated(deflated) to 2010 values using the CRSP inflation index.

	Mean	S.D	25th Pctile.	Median	75th Pctile.	Obs
First Round Data						
Failure	0.428	0.495	0	0	1	19,230
Had IPO	0.091	0.287	0	0	0	19,230
No. Investors in Syndicate First Round	2.305	1.594	1	2	3	19,230
Amount Raised in First Round	7.571	17.78	1.337	3.718	7.968	19,230
Age at First Round (Years)	4.149	8.819	0.583	1.667	4.250	19,230
IPO Data						
Valuation at IPO ($ Millions)	460.4	1,915	98.22	206.6	402.8	1,665
Total Funds Raised ($ Millions)	62.87	93.75	15.21	39.15	80.59	1,665
First Round to IPO (Years)	5.011	3.441	2.583	4.333	6.750	1,665
State Pension Data						
3-Year Compound Return (State-Level)	0.265	0.182	0.160	0.290	0.370	1,065
3-Year Compound Return (Local-Level)	0.259	0.166	0.180	0.278	0.359	914
3-Year Excess Return (State-Level)	0.003	0.101	-0.038	0.006	0.052	1,065
Total Alt. Assets ($ Millions) (State-Level)	2,876	6,303	119.8	658.0	2,674	1,088
Total Inv. Assets ($ Millions) (State-Level)	30,540	48,219	6,021	15,317	33,939	1,088
Allocation to Alternative Inv. (%) (State-Level)	0.082	0.090	0.013	0.061	0.114	1,069

Table 3.2: Failure Rates.

This table reports the results of a linear regression of whether a VC-backed company failed on the level of venture capital supply, the instrumented supply, and various round and company controls in the quarter the company received its first round of VC financing. All observations where the first round of investment is between 1985 and 2010 are included. The unit of observation is a single company based on its first quarter in the Thomson SDC VentureXpert (VX) database. The number of VC investment is the total number of investment rounds from VCs in the state of the given company and quarter. This variable is instrumented using variations in historical excess state-level pension fund returns as described in the text. Pension data are from the US Census Annual Retirement Survey. Returns are lagged 1-year to the start of the first quarter in that fiscal year. All remaining variables are as defined in Table 3.1. Industry Fixed Effects are for the 72 VentureXpert industries described in the text. Standard errors are clustered on the quarter the company received its first VC financing.

	OLS			IV
Dep. Var. =1 if Failure	(1)	(2)	(3)	(4)
Log (No. of VC Investment in Qtr. & State)	0.0847***	0.0849***	0.0690***	0.1552**
	(0.0089)	(0.0084)	(0.0067)	(0.0695)
Log (Amount Raised in First Round)		-0.0394***	-0.0472***	-0.0492***
		(0.0031)	(0.0030)	(0.0031)
Log (No. Investors in Syndicate)		-0.0503***	-0.0390***	-0.0402***
		(0.0091)	(0.0088)	(0.0090)
Log (Age at First Round)		0.0239***	0.0128	-0.0012
		(0.0058)	(0.0078)	(0.0145)
Home Price Index		-0.3068***	0.2150	0.2885*
		(0.0962)	(0.1326)	(0.1527)
Local-Pension Return (3-Years)		0.0017*	0.0007**	-0.0005
		(0.0005)	(0.0003)	(0.0010)
First Stage				
State-Pension Excess Returns (3-Years)				0.0066***
				(0.0012)
F-Stat				28.7763
Partial R2				0.0095
State FE	Yes	Yes	Yes	Yes
Industry FE	No	No	Yes	Yes
Year FE	No	No	Yes	Yes
Adj. R2	0.0194	0.0475	0.0793	0.0711
Obs.	16565	16565	16565	16550

Table 3.3: IPO Pre-Money Valuations.

This table reports the results of a regression of pre-money IPO valuations on the level of venture capital supply, the instrumented supply, and various round and company controls. All observations where the first round of investment is between 1985 and 2010 and the company had an IPO are included. The unit of observation is a single company based on its first quarter in the Thomson SDC VentureXpert (VX) database. Pre-money IPO valuations are calculated as the IPO offer price multiplied by the common shares outstanding on the date of the IPO less the IPO proceeds. All companies that had an IPO price of less than $5, were ADR's, or were not listed on the NYSE, NASDAQ, or AMEX are excluded. The number of VC investment is the total number of investment rounds from VCs in the state of the given company and quarter. Total Funds Raised, is the total dollar value of funds the company raised across all rounds prior to its IPO. All remaining variables are as defined in Table 3.1. Industry Fixed Effects are for the 72 VX industries described in the text. Standard errors are clustered on the quarter the company received its first VC financing.

	OLS			IV
Dep. Var = Log(Pre-Money Valuation at IPO)	(1)	(2)	(3)	(4)
Log (No. of VC Investment in Qtr. & State)	0.3708***	0.2015***	0.1210**	0.7492**
	(0.0590)	(0.0473)	(0.0484)	(0.3476)
Log (Total Unique Investors)		-0.1298***	-0.1423***	-0.0459
		(0.0454)	(0.0479)	(0.0685)
Log (First Round to IPO)		-0.0652	0.0085	-0.0079
		(0.0907)	(0.0788)	(0.0816)
Log (Total Funds Raised)		0.3837***	0.3877***	0.3256***
		(0.0362)	(0.0396)	(0.0453)
Home Price Index		0.2767	0.8046	-0.2530
		(0.6303)	(0.8456)	(1.1038)
Local-Pension Return (3-Years)		-0.0041*	-0.0026	-0.0122**
		(0.0024)	(0.0020)	(0.0060)
First Stage				
State-Pension Excess Returns (3-Years)				0.0164***
				(0.0029)
F-Stat				21.4075
Partial R2				0.0258
State FE	Yes	Yes	Yes	Yes
Industry FE	No	No	Yes	Yes
Year FE	No	No	Yes	Yes
Adj. R2	0.0979	0.2683	0.397	0.306
Obs.	1281	1281	1281	1279

Table 3.4: Investor Level.

This table reports the results of running the specifications from Tables 3.2-3.3 except the unit of observation is at the VC-company level. All observations where the first round of investment is between 1985 and 2010 and the VC could be identified are included. Investments made by the same VC firm but a different fund are aggregated to the VC. VCs are considered experienced if they have had at least 5 first-round investments over the prior 2-years. All remaining variables are as defined in Tables 3.1 - 3.3. Industry Fixed Effects are for the 72 VX industries described in the text. VC fixed effects are run at the VC-firm level. Standard errors are double clustered on the company and the quarter the company received its first VC financing.

	Dep. Var = Failure		Dep. Var = IPO Val	
	(1)	(2)	(3)	(4)
Log (No. of VC Investment in Qtr. & State) - Instr.	0.1826**	0.2044***	1.0448*	0.6615*
	(0.0829)	(0.0666)	(0.5925)	(0.3707)
Experienced VC		-0.0158**		0.1371***
		(0.0061)		(0.0464)
Log (Amount Raised in First Round)	-0.0411***	-0.0486***		
	(0.0058)	(0.0044)		
Log (No. Investors in Syndicate)	-0.0386***	-0.0431***		
	(0.0107)	(0.0106)		
Log (Age at First Round)	-0.0256*	-0.0236		
	(0.0131)	(0.0151)		
Log (Amount Invested by VC prior 2-Years)	-0.0034		-0.1972**	
	(0.0092)		(0.0990)	
Home Price Index	0.2306	0.2921*	-0.5263	-1.6089
	(0.1734)	(0.1667)	(1.1283)	(1.2569)
Local-Pension Return (3-Years)	-0.0014	-0.0016	-0.0164**	-0.0118*
	(0.0010)	(0.0010)	(0.0074)	(0.0070)
Log (Total Unique Investors)			-0.0887	-0.1405*
			(0.1083)	(0.0749)
Log (First Round to IPO - Months)			0.0035	-0.0385
			(0.0994)	(0.0890)
Log (Total Funds Raised)			0.3189***	0.3373***
			(0.0771)	(0.0544)
First Stage				
State-Pension Excess Returns (3-Years)	0.0069***	0.0077***	0.0092***	0.0121***
	(0.0012)	(0.0013)	(0.0030)	(0.0029)
F-Stat	34.856	36.096	9.486	16.549
Partial R2	0.0100	0.0113	0.0163	0.0224
State FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
VC FE	Yes	No	Yes	No
Adj. R2	0.0941	0.0718	0.376	0.406
Obs.	21800	25867	1569	2194

Table 3.5: Ex Ante Analysis.

This table reports the results of a linear regression of whether a VC invested in a risky company on the instrumented level of venture capital supply and various round and company controls. Venture capital supply is instrumented with historical excess state-level pension returns as described in the text and done in Tables 3.2-3.4. The unit of observation is at the VC-Company Level. High R&D industries are those with above-median Industry R&D-to-Asset ratios in the prior quarter using the historical time frame given. High volatility industries are those with above-median volatilities using the past 5-years of monthly returns. Betas are calculated using the method of Campbell, Lettau, Malkiel, and Xu (2001). Idiosyncratic volatility is the average monthly stock return volatility for each stock in the industry index over the previous 5-years. Public companies are mapped to VX industries using the method of Gompers and Lerner (2000). VCs are considered experienced if they have had at least 5 first-round investments over the prior 2-years. All remaining variables are as defined in Tables 3.1 - 3.3. VC fixed effects are run at the VC-firm level. Standard errors are double clustered on the company and quarter the company received its first VC financing.

Panel A: VC FE

Dep. Var	High R&D Ind.		High Ind. Return Vol.		
	5-Years	Hist.	Beta	Total	Idiosyncratic
	(1)	(2)	(3)	(4)	(5)
Log (No. of VC Investment in Qtr. & State) - Instr.	0.1850*	0.1983*	0.2083**	0.2417**	0.186*
	(0.1086)	(0.1075)	(0.0989)	(0.1057)	(0.102)
Log (Amount Raised in First Round)	-0.0313***	-0.0319***	-0.0096	-0.0052	-0.0332***
	(0.0076)	(0.0076)	(0.0069)	(0.0063)	(0.00688)
Log (No. Investors in Syndicate)	0.0325***	0.0347***	-0.0197*	-0.0101	0.0253**
	(0.0117)	(0.0117)	(0.0100)	(0.0099)	(0.0119)
Log (Age at First Round)	0.0359***	0.0349***	-0.0726***	-0.0731***	0.0213*
	(0.0106)	(0.0111)	(0.0164)	(0.0171)	(0.0112)
Log (Amount Invested by VC prior 2-Years)	-0.0174*	-0.0184*	-0.0200*	-0.0167	-0.0244**
	(0.0102)	(0.0102)	(0.0105)	(0.0113)	(0.0101)
Home Price Index	-0.1323	-0.1118	0.6088**	1.0815***	0.362**
	(0.1691)	(0.1726)	(0.2458)	(0.1875)	(0.143)
Local-Pension Return (3-Years)	-0.0017	-0.0018	0.0007	-0.0006	-0.00238*
	(0.0013)	(0.0013)	(0.0012)	(0.0013)	(0.00120)
First Stage					
State-Pension Excess Returns (3-Years)	0.0068***				
	(0.0014)				
F-Stat	25.232				
Partial R2	0.0086				
State FE	Yes	Yes	Yes	Yes	Yes
Industry FE	No	No	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes
VC FE	Yes	Yes	Yes	Yes	Yes
Adj. R2	0.100	0.0958	0.271	0.240	0.0681
Obs.	19817	19817	19817	19817	19817

Table 3.5 Continued

Panel B: VC Experience

Dep. Var	High R&D Ind.		High Ind. Return Vol.		
	5-Years	Hist.	Beta	Total	Idiosyncratic
	(1)	(2)	(3)	(4)	(5)
Log (No. of VC Investment in Qtr. & State) - Instr.	0.1319	0.1470	0.2371**	0.2473**	0.0862
	(0.0960)	(0.0964)	(0.0968)	(0.1035)	(0.0870)
Experienced VC	0.0198***	0.0197***	0.0339**	0.0277**	0.0207***
	(0.0061)	(0.0063)	(0.0074)	(0.0084)	(0.0061)
Log (Amount Raised in First Round)	-0.0302***	-0.0311***	-0.0018	0.0028	-0.0274***
	(0.0055)	(0.0056)	(0.0055)	(0.0053)	(0.0049)
Log (No. Investors in Syndicate)	0.0533***	0.0553***	-0.0410***	-0.0297***	0.0437***
	(0.0113)	(0.0114)	(0.0117)	(0.0112)	(0.0118)
Log (Age at First Round)	0.0147	0.0129	-0.0916***	-0.0859***	-0.0023
	(0.0123)	(0.0127)	(0.0173)	(0.0183)	(0.0116)
Home Price Index	-0.0494	-0.0116	0.4012	0.8218***	0.3339**
	(0.1810)	(0.1841)	(0.2490)	(0.1972)	(0.1554)
Local-Pension Return (3-Years)	-0.0011	-0.0013	-0.0003	-0.0012	-0.0010
	(0.0014)	(0.0014)	(0.0014)	(0.0015)	(0.0012)
First Stage					
State-Pension Excess Returns (3-Years)	0.0067***				
	(0.0014)				
F-Stat	23.980				
Partial R2	0.0092				
State FE	Yes	Yes	Yes	Yes	Yes
Industry FE	No	No	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes
VC FE	No	No	No	No	No
Adj. R2	0.0595	0.0558	0.124	0.115	0.0412
Obs.	23578	23578	23578	23578	23578

Table 3.6: Proxies for Asymmetric Information.

This table reports the results of a two-stage least squares regression of the degree of IPO undervaluation (1), or if the VC invested in a company that was in an industry with above median IPO undervaluation (2), analyst forecast dispersion (3), or error (4). Venture capital supply is instrumented with historical excess state-level pension returns as described in the text and done in Tables 3.2-3.4. The unit of observation is at the VC-Company Level. IPO undervaluation is the percentage change in the IPO price relative to the closing price on the day of the IPO. High forecast dispersion (error) industries are those with above-median average company level forecast dispersion (error) in the prior quarter using the previous 5-years of data. Public companies are mapped to VX industries using the method of Gompers and Lerner (2000). All remaining variables are as defined in Tables 3.1 - 3.3. VC fixed effects are run at the VC-firm level. Standard errors are double clustered on the company and quarter the company received its first VC financing.

	IPO Undervaluation		Analyst	
	Company	Industry	Dispersion	Error
	(1)	(2)	(3)	(4)
Log (No. of VC Investment in Qtr. & State)	0.9381**	0.2346**	0.1931**	0.2498**
	(0.4654)	(0.0895)	(0.0778)	(0.1001)
Log (Total Unique Investors)	0.1668***			
	(0.0618)			
Log (First Round to IPO - Months)	-0.1107			
	(0.0668)			
Log (Total Funds Raised)	-0.0756			
	(0.0572)			
Log (Amount Invested by VC prior 2-years)	-0.1436**	-0.0229**	-0.0219**	-0.0249**
	(0.0695)	(0.0093)	(0.0089)	(0.0106)
Home Price Index	0.4169	-0.5394***	0.0125	-0.3418**
	(0.9272)	(0.1889)	(0.1554)	(0.1681)
Local Pension Return (3-Years)	-0.0109*	-0.0004	-0.0021*	-0.0025*
	(0.0060)	(0.0011)	(0.0011)	(0.0013)
Log (Amount Raised in First Round)		-0.0227***	-0.0190***	-0.0116
		(0.0070)	(0.0064)	(0.0082)
Log (No. Investors in Syndicate)		-0.0175	-0.0053	-0.0358***
		(0.0113)	(0.0097)	(0.0108)
Log (Age at First Round - Months)		0.0299**	-0.0003	-0.0008
		(0.0132)	(0.0126)	(0.0130)
First Stage				
State Pension Excess Returns (3-years)	0.0089***	0.0074***	0.0070***	0.0070***
	(0.0029)	(0.0012)	(0.0012)	(0.0012)
F-Stat	9.378	36.278	31.403	31.403
State FE	Yes	Yes	Yes	Yes
Industry FE	Yes	No	No	No
Year FE	Yes	Yes	Yes	Yes
VC FE	Yes	Yes	Yes	Yes
Adj. R2	0.171	0.282	0.129	0.247
Obs.	1578	21773	20531	20531

Appendices

Appendix A

Proofs

A.1 Proof of Proposition 1.

I first derive the proposed equilibrium by assuming pooling among entrepreneurs with a given project. I then show that there is no other equilibrium that is an undefeated pure-strategy equilibrium. Finally, I show that the proposed equilibrium is undefeated since it gives the highest expected payoff to the high-type entrepreneur among all pure-strategy equilibria for a given VC expected market payoff U.

Step 1 (Deriving Proposed Equilibrium.).

Using the described refinement the focus is on deviations from high-type entrepreneurs. Therefore, I can just focus on the expected payoffs for high-types and then check that low-types will not have an incentive to deviate given the off-equilibrium beliefs of the VCs and that VCs make optimal decisions.

Assuming pooling implies that $\mu(\alpha_i^*, i) = p_i$, where α_i^* is the proposed equilibrium. I assume that for all $\alpha' \neq \alpha_i^*$ VC beliefs are $\mu(\alpha', i) = \psi_L$. I now solve for the α_i^*, among all potential α that support pooling, which maximizes the expected payoff for high-types. Solving the VC constraint, Eq. 2.14, for α

in terms of θ yields

$$\alpha = \frac{U\theta}{(1-e^{-\theta})pR} + \frac{I}{pR}. \tag{A.1}$$

Substituting α into the entrepreneur's problem, Eq. 2.13, for high-types yields

$$\max_{\theta} \frac{\psi_{i,H}}{p_i}[(p_i R_i - I)(1-e^{-\theta}) - U\theta - p_i \Omega(i,H)]. \tag{A.2}$$

Taking first-order conditions over θ and solving yields

$$U = e^{-\theta}[p_i(R_i - \Omega(i,H)) - I]. \tag{A.3}$$

Second-order conditions can be easily verified. Thus, the optimal level of θ for a high-types with project i must satisfy Eq. A.3 or be a corner solution with $\alpha = 0$ and high-types not entering the VC market.

To solve for U, use Eq. A.3 and that U must be the same across all active sub-markets. If there is entry into both sub-markets, then $\theta_r = \sigma V$ and $\theta_s = (1-\sigma)V$, which yields

$$\{\alpha_r^*,\ \alpha_s^*\} = \left\{\frac{U\theta_r^*}{(1-e^{-\theta_r^*})p_r R_r} + \frac{I}{p_r R_r},\ \frac{U\theta_s^*}{(1-e^{-\theta_s^*})p_s R_s} + \frac{I}{p_s R_s}\right\} \tag{A.4}$$

$$\{\theta_r^*,:\ \theta_s^*\} = \left\{\frac{V-\gamma}{2},\ \frac{V+\gamma}{2}\right\} \tag{A.5}$$

$$\sigma^* = \frac{V-\gamma}{2V} \tag{A.6}$$

$$U^* = e^{-(V+\gamma)/2}[p_s(R_s - \Omega(s,H)) - I] \tag{A.7}$$

$$\text{where } \gamma = \log\left(\frac{p_s(R_s - \Omega(s,H)) - I}{p_r(R_r - \Omega(r,H) - I}\right). \tag{A.8}$$

This is an SCSE if VCs' off-equilibrium beliefs are defined such that for any deviation $\alpha' \neq \alpha_i^*$, $\mu(\alpha, i) = \psi_{i,L}$. Clearly, a low-type will not deviate since his expected payoff is higher in the pooling equilibrium than 0, his payoff from deviating. A high-type will not deviate since his expected payoff from the proposed equilibrium is higher than his outside option. If not, then the high-type's maximization problem would be a corner solution since $\alpha_i^* = 0$ is in the possible action space. A VC is guaranteed her expected market payoff U and has no incentive to deviate. Beliefs of VCs and entrepreneurs are consistent with strategies, and strategies are symmetric. Thus, the proposed equilibrium is an SCSE.

This SCSE yields an expected payoff for high-types of

$$\pi^*_{E,i,H} = \frac{\psi_{i,H}}{p_i}[p_i R_i - I - U^*(1 + \theta_i^*)] \tag{A.9}$$

If $V < \gamma$, then entrepreneurs with risky projects do not post in the VC market and risky high-types get their outside option. Assuming there is entry by safe high-types, then $\theta_s = V$ and the remaining equilibrium conditions are

$$\alpha_s^* = \frac{UV}{(1 - e^{-V})p_s R_s} + \frac{I}{p_s R_s} \tag{A.10}$$

$$\theta_s^* = V \tag{A.11}$$

$$\sigma^* = 0 \tag{A.12}$$

$$U^* = e^{-V}[p_s(R_s - \Omega(s, H)) - I]. \tag{A.13}$$

Posting in the VC market is not an equilibrium for risky high-types. If a high-type posts and matches with probability 1, then his expected value from matching, assuming that low-types would mimic in equilibrium, is less than his outside option. To see this, use U^* defined above and substitute into the risky high-type's expected payoff

$$\frac{\psi_{r,H}}{p_r}(p_R(R_r - \Omega r, H) - I - e^{-V}[p_s(R_s - \Omega(s, H)) - I]). \tag{A.14}$$

This is negative since at $V = \gamma$, the above is positive and decreasing in V, so it must be negative for all $V < \gamma$.

The above is an SCSE if off-equilibrium beliefs are defined such that for any deviation $\alpha' \neq \alpha_i^*$, $\mu(\alpha, i) = \psi_{i,L}$. Clearly safe high-types and low-types have no incentive to deviate for reasons similar to above. Risky high-types will also not deviate given the off-equilibrium beliefs above. VCs receive their expected market payoff and have no incentive to deviate. Beliefs are consistent, and strategies are symmetric.

Step 2 (No other SCSE is an undefeated pure-strategy equilibrium.).

Claim 1 (No fully separating SCSE exists.).

Proof. Suppose that a fully separating SCSE exists with entrepreneur entry such that high-types play $\alpha_{i,H}^* < 1$, low-types stay out of the VC market or equivalently post but never receive VC funding, and VC beliefs are $\mu(\alpha_{i,H}^*, i) = \psi_{i,H}$. By Assumption 1 (A), the expected value of a low-type's outside option is 0. By Assumption 2, the low-type can never get VC funding under separation. Therefore, in this separating equilibrium the low-type entrepreneur's payoff is

0. If a low-type deviates to $\alpha = \alpha^*_{i,H}$, then his expected payoff is

$$\psi_{i,L}(1-\alpha_{i,H})R_i(1-e^{-\theta_{\alpha_{i,H},i}}) > 0. \tag{A.15}$$

Therefore, low-type entrepreneurs will always have an incentive to deviate and this cannot be an equilibrium.

If $\alpha^*_{i,H} = 1$, then a low type's expected payoff is 0, but a high-type's expected payoff is also 0 if he enters the VC market. By Assumption 1, the high-type's outside option is always positive. Therefore, a high-type will never enter the market, which is inconsistent with beliefs $\mu(\alpha^*_{i,H}, i) = \psi_{i,H}$. Therefore, no separating equilibrium with entry is an equilibrium. □

Claim 2 (No other pooling SCSE with entrepreneur entry can be an undefeated equilibrium.).

Proof. A continuum of other pooling SCSE exist with entrepreneur entry depending on VCs' off-equilibrium beliefs. Let $\alpha' \neq \alpha^*_i$ and $\alpha' \in (0,1)$ be the candidate equilibrium posting. If off-equilibrium beliefs are such that for all $\alpha \neq \alpha'$ VC beliefs are $\mu(\alpha, i) = \psi_{i,L}$, then the candidate equilibrium is a potential SCSE as long as the expected payoff is greater than the expected payoff from a high-type's outside option.

Suppose that an alternative pooling SCSE with $\alpha' \neq \alpha^*_i$ yields a higher expected payoff to a high-type entrepreneur. Since the entrepreneur's problem is a twice-differentiable continuous concave function over $\alpha \in [0,1]$, the first-order condition (FOC) is necessary for any interior optimal solution. This means that for α' to yield a higher payoff it must satisfy the FOC when on-equilibrium beliefs are $\mu(\alpha', i) = p_i$. However, α_i^* satisfies the FOC when $\mu(\alpha', i) = p_i$, which means that $\alpha' = \alpha_i^*$. This contradicts $\alpha' \neq \alpha_i^*$. Therefore, any pooling equilibrium with $\alpha' \neq \alpha_i^*$ cannot have a higher expected payoff for the high-type VC. In return, the off-equilibrium beliefs of VCs for any alternative pooling equilibrium must assign beliefs of $\mu(\alpha_i^*, i) = p_i$ after observing a deviation α_i^*. Given these off-equilibrium beliefs, high-types will always have an incentive to deviate to α_i^*. Thus, the proposed alternative equilibrium is not an SCSE with the refined beliefs.

Therefore, the pooling equilibrium with α_i^* defeats any other alternative pooling equilibrium under Assumptions 1-3 and $p_i[R_i - \Omega(i, H)] - I > U$. $\square$

All pooling equilibria are defeated by the proposed pooling equilibrium with α_i^*. Further, the pooling equilibrium with α_i^* yields the highest expected payoff for the high-type entrepreneur for a given U, which implies it will also yield the highest expected payoff for the high-type entrepreneur for U^*. Therefore, the equilibrium with α_i^* is the unique undefeated pure strategy equilibrium under Assumptions 1-3 and $p_i[R_i - \Omega(i, H)] - I > U$

If $p_i[R_i - \Omega(i, H)] - I \leq U$, then a high-type entrepreneur prefers his outside option to any equilibrium that involves posting. This is because the highest payoff that he can expect to receive among any potential equilibrium with a positive probability of attracting a VC is using the proposed pooling equilibrium strategy. However, this has a lower expected payoff than that of his outside option $\psi_{i,H}\Omega(i,H)$ when $p_i(R_i - \Omega(i,H)) - I < U$. To see this, set $U = p_i(R_i - \Omega(i,H)) - I$ and substitute into Eq. A.9 and compare to $\psi_{i,H}\Omega(i,H)$. This is only $> \psi_{i,H}\Omega(i,H)$ if $\theta < 0$, which cannot occur. Therefore, if $p_i(R_i - \Omega(i,H)) - I < U$, then the only SCSE is a pooling equilibrium with neither type of entrepreneur entering the VC market. Since this is the only SCSE, it will also be the unique undefeated pure strategy equilibrium.

A.2 Proof of Proposition 2.

I first prove that $\theta_s > \theta_r$ for any $V > 0$ assuming some entry occurs for either project and then show that this means an entrepreneur with a safe project always has a higher likelihood of attracting funding than an entrepreneur with a risky project.

Proof. If $V \leq \gamma$, then $\theta_s^* > 0 = \theta_r^*$.

If $V > \gamma$, then using Eq. A.3 $\theta_s^* > \theta_r^*$ if

$$p_s(R_s - \Omega(s,H)) > p_r(R_r - \Omega(r,H)) \tag{A.16}$$

since U^* is the same across sub-markets. This is satisfied given the limiting condition on the relative gains from trade for risky high-types — that is, $\frac{p_s}{p_r} > \frac{R - r - \Omega(r,H)}{R_s - \Omega(s,H)}$.

□

Because the probability of funding is $1 - e^{-\theta}$ and this is increasing in θ, safer projects will always have a higher probability of funding.

A.3 Proof of Proposition 3.

The ratio of risky to safe projects κ is

$$\kappa = \frac{X_r}{X_s}. \tag{A.17}$$

Because $X_r = 0$ when $V \leq \gamma$, κ is 0 and is non-decreasing in V.

I now show that the ratio of risky projects κ is increasing in V for $V > \gamma$ and that this implies the average failure rate and the average payoffs are increasing with V.

Proof. First note that $X_i = (1 - e^{-\theta_i})$. Substituting for X in Eq. 2.24 and taking the derivative of κ with respect to V yields

$$\frac{d\kappa}{dV} = \frac{(1 - e^{-\theta_s})e^{-\theta_r}\frac{d\theta_r}{dV} - (1 - e^{-\theta_r})e^{-\theta_s}\frac{d\theta_s}{dV}}{(X_s)^2}. \tag{A.18}$$

Using Eq. 2.20 and taking derivatives with respect to V, to substitute for $d\theta/dV$ and simplifying yields

$$\frac{d\kappa}{dV} = \frac{e^{-\theta_r} - e^{-\theta_s}}{2(X_s)^2}. \tag{A.19}$$

This is positive because by Proposition 2, $\theta_s > \theta_r$ for all $V > 0$. □

To see that an increase in the proportion of risky projects leads to an increase in the average failure rate of VC-backed projects, first denote the average failure rate as

$$\Delta = \frac{X_r(1-p_r) + X_s(1-p_s)}{X_s + X_r}. \tag{A.20}$$

Taking the derivative with respect to V and simplifying yields

$$\frac{d\Delta}{dV} = \frac{(p_s - p_r)\left(X_s \frac{dX_r}{dV} - X_r \frac{dX_s}{dV}\right)}{(X_r + X_s)^2}. \tag{A.21}$$

This has the same sign as $\left(X_s \frac{dX_r}{dV} - X_r \frac{dX_s}{dV}\right)$ because $p_s > p_r$, which will have the same sign as $\frac{d\kappa}{dV}$ because $\frac{d\kappa}{dV}$ is

$$\frac{d\kappa}{dV} = \frac{X_s \frac{dX_r}{dV} - X_r \frac{dX_s}{dV}}{(X_s)^2}. \tag{A.22}$$

Similar calculations can be done for the average VC-backed successful project payoff.

A.4 Proof of Proposition 4.

To see this effect, I show that κ only depends on I through its effect on γ, and that κ is decreasing in γ and γ is increasing in I.

Proof. Using Eq. 2.24, taking the derivative of κ with respect to γ simplifies to

$$\frac{d\kappa}{d\gamma} = -\frac{e^{\gamma}(-2 + e^{(V+\gamma)/2} + e^{(V-\gamma)/2})}{2(1 - e^{(V+\gamma)/2})^2}. \tag{A.23}$$

This is negative because $V - \gamma > 0$ if there is entry into the risky sub-market, $V + \gamma > 0$ if there is entry into the safe sub-market, and $e^x > 1$ for all $x > 0$ and $e^x > 0$ for all $x \in (-\infty, \infty)$.

Using Eq. 2.23 and taking the derivative w.r.t. I and simplifying yields

$$\frac{d\gamma}{dI} = \frac{p_s[R_s - \Omega(s,H)] - p_r[R_r - \Omega(r,H)]}{(p_r(R_r - \Omega(r,H)) - I)(p_s(R_s - \Omega(s,H)) - I)}. \tag{A.24}$$

This is positive because, first, the denominator is positive if there is entry into both sub-markets, and, second, the numerator is positive since $\frac{p_s}{p_r} > \frac{R_r - \Omega(r,H)}{R_s - \Omega(s,H)}$ if gains from trade are not too large. Therefore, because κ is decreasing in γ and γ is increasing in I, the proportion of funded risky projects will be decreasing in I. □

A.5 Proof of Proposition 5.

To see this effect, assume that $0 < \chi < \bar{\chi} = p_r\Omega(r,H) - p_s\Omega(s,H)$.

Proof. Taking the derivative of η with respect to V and simplifying yields

$$\frac{d\eta}{dV} = \frac{e^{(\gamma+V)/2}(e^{\gamma} - 1)\chi}{2I(1 - e^{(\gamma+V)/2} + e^{\gamma} - 2)^2}, \tag{A.25}$$

which is positive because $\gamma > 0$, from the proof of Proposition 2, as long as $0 < \chi < \bar{\chi}$. □

A.6 Proof of Proposition 6.

To prove that when $V_T < \overline{V}_T, \sigma_E$ is non-decreasing in V_T, I first solve for σ_E in terms of V_T and parameters while assuming that the high-ability VCs enter both sub-markets.

Using the FOC from Eq. 2.28-2.30, where there is no entry from the low-types into the risky sub-market because $V_T < \overline{V}_T$, yields the following conditions

$$
\begin{aligned}
U_E &= e^{-\sigma_E}[p_r(R_r - \Omega(r,H))(1-\delta(1-\lambda)) - I(1-\delta(1-h_r))] && \text{(A.26)} \\
U_E &= e^{-(1-\sigma_E)-V_T}[p_s(R_s - \Omega(s,H) - I)(1-\delta(1-\lambda)) + \delta I e^{V_T}(\lambda - h_s)] && \text{(A.27)} \\
U_T &= e^{-(1-\sigma_E)-V_T}[p_s(R_s - \Omega(s,H)) - I]. && \text{(A.28)}
\end{aligned}
$$

If an experienced VC is entering both sub-markets, then she must be indifferent between sub-markets. Setting Eq. A.26 equal to Eq. A.27 and solving for σ_E yields

$$
\sigma_e = \max\left\{\min\left\{\frac{1 + V_T - \log\left(\frac{(p_s(R_s-\Omega(s,H))-I)(1-\delta(1-\lambda))+\delta I e^{V_T}(\lambda-h_s)}{p_r(R_r-\Omega(r,H))(1-\delta(1-\lambda))-I(1-\delta(1-h_r))}\right)}{2}, 1\right\}, 0\right\}. \tag{A.29}
$$

When $V_T > \overline{V}_T$, the low-ability VCs enter both sub-markets. Using the FOC from Eq. 2.28 - 2.30 to solve for σ_T in terms of σ_E and parameters yields

$$
\sigma_T = \frac{1 + V_T - \gamma - 2\sigma_E}{2V_T}, \tag{A.30}
$$

where γ is defined by Eq. 2.23.

Using Eq. A.30 and Eq. 2.31 and given that $\sigma_E = \theta_{E,r}$ and $1 - \sigma_E = \theta_{E,s}$ to solve for σ_E yields

$$
\sigma_E = \min\left\{\frac{1 + \log\left(\frac{\lambda - h_r}{\lambda - h_s}\right)}{2}, 1\right\}. \tag{A.31}
$$

Proof. Let $V_T < \overline{V}_T$. If σ_E is greater than 1, then the high-ability VC only enters the risky market and σ_E is unchanged by further increases in V_T.

If $0 < \sigma_E < 1$ then taking the derivative of σ_E with respect to V_T simplifies to

$$\frac{d\sigma_E}{dV_T} = \frac{1}{2} - \frac{\delta I e^{V_T}(\lambda - h_s)}{2[p_s(R_s - \Omega(s,H)) - I](1 - \delta(1-\lambda)) + 2\delta I e^{V_T}(\lambda - h_s)}. \quad \text{(A.32)}$$

The above is always positive because $p_s(R_s - \Omega(s,H)) - I > 0$ for there to be any entry by safe entrepreneurs and $\lambda > h_s$, so the second term is always less than 1/2.

If $\sigma_E = 0$ when $V_T = 0$, then initially the high-type will not post in the VC market. However, eventually it will be profitable for the high-type entrepreneurs to post and at least some high-ability VC to enter the risky sub-market such that I can use Eq. A.32.

If $V_T > \overline{V}_T$, then using Eq. A.31 the derivative of θ_E with respect to V_T is

$$\frac{d\theta_E}{dV_T} = 0 \quad \text{(A.33)}$$

because σ_E does not depend on V_T. This is because any gain from the high-type entrepreneur posting a higher share in the risky sub-market is perfectly offset by the share posted in the safer sub-market and thus the relative expected value for an experienced VC from choosing one sub-market over the other does not change. Further, using Eq. A.31 we can see that $\sigma_E > 1/2$ since $h_s > h_r$.

To see that σ_T is increasing in V_T, use Eq. A.30 to take the derivative with respect to V_T, which yields

$$\frac{d\sigma_T}{dV_T} = \frac{-1 + 2\sigma_E + \gamma}{2V_T^2}. \tag{A.34}$$

This is always positive because $\sigma_E \in (.5, 1]$ and $\gamma > 0$.

Finally, using Eq. A.30 verifies that $\sigma_T \to 1/2$ as $V_T \to \infty$. Therefore, $\sigma_E \geq \sigma_T$ for all V_T. $\square$

Appendix B

Additional Theoretical Detail

B.1 Micro-Foundations of Urn-Ball Matching Function.

I closely follow the framework of Burdett, Shi, and Wright (2001) and Shi (2002). Entrepreneurs post shares for sale (α) that are observed by VCs, who can then choose which project to approach. A selected VC invests I for share α.

VCs of measure V apply to a sub-markets indexed by $j \in \{1, .., N\}$ with probability σ_i, where $\sum_{j=1}^{N} \sigma_j = 1$. Sub-markets are defined by the posted α, the belief $\mu(\alpha)$, and the project $i \in \{r, s\}$. There are E_j entrepreneurs in a sub-market. Because I require equilibria to be symmetric, then within a sub-market VCs apply to each project with the same probability $(1/E_j)$. The ratio of VCs to entrepreneurs in a sub-market is $\theta_j = \frac{\sigma_j V}{E_j}$. The probability of an entrepreneur matching is

$$\left[1 - \left(1 - \frac{1}{E_j}\right)^{V\sigma_j}\right].$$

This can be rewritten in terms of θ_j:

$$\left[1 - \left(1 - \frac{\theta_j}{V\sigma_j}\right)^{V\sigma_j}\right].$$

Given that E_j and V represent a continuum, taking the limit as $E_j, V \to \infty$, while keeping θ constant yields

$$(1 - e^{-\theta}),$$

which is the probability of the entrepreneur matching with a VC for a given θ. Likewise, the probability of a VC matching is $\frac{1-e^{-\theta}}{\theta}$.

B.2 Introducing Entrepreneur Mixed-Strategies Does not Change the Equilibrium Outcomes of the Model

In the following analysis, I show that allowing entrepreneurs to play mixed strategies does not change the equilibrium outcomes of the model if I add an additional component to the undefeated refinement. First, to allow for mixed strategies let an entrepreneur with project i and type Z strategy consist of a probability distribution $a_{i,Z}(\alpha_i)$ over share postings $\alpha_i \in [0, 1]$. Let $A_{i,Z}$ represent the set of all share postings by the entrepreneur with project i and type Z that have a positive probability and $E_{i,Z}(\alpha_i)$ represent the expected mass of entrepreneurs with project i and type Z that play α_i. I redefine the equilibrium as follows:

Definition 2 (Symmetric Competitive Search Equilibrium). *A Symmetric Competitive Search Equilibrium (SCSE) consists of entrepreneur posting strategies $a_{i,Z}$, VC strategies $\sigma(\alpha_i)$, market tightness θ_{α_i}, VC beliefs $\mu(\alpha_i)$, and entrepreneur beliefs on θ_{α_i} such that*

1. ***Entrepreneurs' optimal choices:*** *For a given $i \in \{r, s\}$ and $Z \in$*

$\{L, H\}$, if $\alpha_i \in A_{i,Z}$ then

$$\max_{\alpha' \in [0,1]} \pi_{E,i,Z}(\alpha') \leq \pi_{E,i,Z}(\alpha_i).$$

2. ***VCs' optimal choices:*** *$U^* = \max\{0, \max_{\alpha_i \in A} \pi_V(\alpha_i)\}$. VCs only enter a sub-market with posting α_i if the expected value from doing so is the market payoff U^*. That is, for all $\alpha_i \in [0,1]$ and $i \in \{r, s\}$*

$$\pi_V(\alpha_i) = U^* \text{ if } \theta_{\alpha_i} > 0$$
$$\pi_V(\alpha_i) < U^* \text{ if } \theta_{\alpha_i} = 0.$$

3. ***Consistent beliefs:*** *For all $\alpha_i \in A$*

$$\mu(\alpha_i) = \frac{\psi_{i,H} E_{i,H}(\alpha_i) + \psi_{i,L} E_{i,L}(\alpha_i)}{E_{i,H}(\alpha_i) + E_{i,L}(\alpha_i)}.$$

4. ***Probabilities integrate to one*** *For all $i \in \{r, s\}$ and $Z \in L, H$*

$$\int_{\alpha_i \in A_{i,Z}} a_{i,Z}(\alpha_i) d\alpha_i = 1$$
$$\int_{\alpha_i \in A} \sigma(\alpha_i) d\alpha_i = 1.$$

5. ***Symmetry**: Entrepreneurs of a given type Z and project i have the same strategy $a_{i,Z}(\alpha_i)$. All VCs have the same strategy $\sigma(\alpha_i)$.*

The entrepreneur's problem is now to choose the strategy $a_{i,Z}$ to maximize his expected value given his beliefs of VCs' best responses and other entrepreneurs' actions:

$$\max_{a_{i,Z}(\alpha_i)} \quad \pi_{E,i,Z}(\alpha_i) \tag{A.1}$$

$$s.t. \quad (\mu(\alpha_i)\alpha_i R_i - I)\frac{1-e^{-\theta_{\alpha_i}}}{\theta_{\alpha_i}} = U. \tag{A.2}$$

Given that $a_{i,Z}$ can have a continuous support over all-potential share postings that are part of other equilibria, it is possible that no deviation exists that is an on-equilibrium action in another equilibrium. Therefore, the undefeated refinement as currently applied cannot refine these equilibria.

To give the refinement additional power, I add a second condition that corresponds with the lexicographical maximum (lex-max) sequential equilibrium (LMSE) described in Mailath, Okuno-Fujiwara, and Postlewaite (1993). This equilibrium is the equilibrium that maximizes the payoff to the highest sending type and conditional on maximizing the payoff for the highest sending type, maximizes the payoff of other types. Formally, if multiple undefeated equilibria exist, then I select the LMSE. Since an LMSE always exists, this additional condition will always refine equilibria. I refer to this equilibrium as the lex-max undefeated equilibrium.

I now show that no semi-pooling SCSE with entrepreneur entry can be the lex-max undefeated equilibrium. Combining this with the proof of Proposition 1 shows that the only lex-max undefeated equilibrium is the proposed pooling equilibrium with $a_{i,Z}(\alpha_i^*) = 1$. Therefore, allowing mixed strategies for entrepreneurs will not yield different equilibrium outcomes.

Claim 1 (No semi-pooling SCSE with entrepreneur entry can be a lex-max undefeated equilibrium.).

Proof. Suppose there exists a semi-pooling equilibrium that is an SCSE and all equilibrium postings for entrepreneurs with project i are denoted A_i. In this mixed strategy equilibrium, both types play some set of $\alpha \in (0, (R_i - \Omega(i, H))/R_i]$ with probability distributions given by $a_{i,Z}(\alpha_i)$, where i denotes the project and Z the entrepreneur type. The restriction on α is necessary for a high-type to have an incentive to enter; if not, then he would prefer his outside option to posting and matching with probability 1. For all $\alpha \in A_i$, if $a_{i,H}(\alpha) = 1$, then $a_{i,L}(\alpha) = 1$ because no fully-separating SCSE exists.

For this to be a mixed-strategy equilibrium both types must be indifferent over potential equilibrium α given the updating of VCs using the proposed equilibrium strategies $a_{i,L}$ and $a_{i,H}$. Denote the set of all equilibrium postings in this mixed-strategy equilibrium as $\hat{A}_i$. There must exist at least one $\alpha \in A_i$ such that $\mu(\alpha) \leq p$ because the expectation of $\mu(\alpha)$ over all $\alpha \in A_i$ conditional on $a_{i,L}$ and $a_{i,H}$ must be p. Denote this as $\hat{\alpha}$, a VC's beliefs as $\hat{\mu}$, and the resulting market tightness as $\hat{\theta}$. Note that given $\hat{\mu}$, the minimum associated $\hat{\alpha}$ must be $> \frac{U+I}{\hat{\mu} R_i}$ or VCs will never fund even if they have a probability 1 of matching. Because entrepreneurs must be indifferent across all potential equilibrium α given VC beliefs, the problem reduces to checking whether a high-type would prefer the payoff from α^* to that of $\hat{\alpha}$.

First, assume that $\alpha_i^* \notin \hat{A}_i$. Because $\hat{\alpha}$ is an equilibrium action, there exists another pooling equilibrium with $a_{i,Z}(\hat{\alpha}) = 1$ supported by beliefs $\mu(\hat{\alpha}) = p_i$ and $\mu(\alpha \neq \hat{\alpha}) = \psi_{i,L}$. This must exist because the share given up by the high-type is the same, but the distribution is better from a VC's perspective, which results in a $\theta > \hat{\theta}$ for the same U. To see this, rearranging the constraint with U yields

$$\frac{1 - e^{-\theta}}{\theta} - \frac{U}{\mu R_i \alpha - I} = 0. \tag{A.3}$$

Applying the Implicit Function Theorem, and noting that $e^x > (1 + x)$ for all $x > 0$, θ is increasing in μ. Therefore, if high-types did not want to deviate when beliefs were $\hat{\mu}$, they will not deviate from this alternative pooling equilibrium. Further, low-types and VCs will also not deviate. However, it is immediate that the expected payoff for high-types must be strictly greater in the alternative pooling equilibrium than the payoff from the proposed mixed strategy equilibrium. This is because high-types are giving up the same share of the project but have a strictly higher probability of VC funding due to the higher θ.

Using the result from Claim 2 of the proof of Proposition 1, the pooling equilibrium with α^* will always yield a higher payoff for a high-type entrepreneur than the alternative pooling equilibrium referenced above. Therefore, it will defeat the proposed mixed-strategy equilibrium since the high-type has a higher payoff in the proposed pooling equilibrium than the proposed mixed-strategy equilibrium and the proposed mixed-strategy equilibrium is not consistent with $\mu(\alpha_i^*) = p_i$.

Now assume that $\alpha_i^* \in \hat{A}_i$. The argument used above does not apply to this case because playing α_i^* is no longer a deviation and therefore cannot be used as a signal by the high-type. Therefore, it is possible that this equilibrium will not be defeated by the proposed pooling equilibrium. However, using the second part of the refinement it will not be the lex-max undefeated equilibrium if the proposed pooling equilibrium yields a higher payoff to the high-type.

Let $\hat{\alpha} \in \hat{A}_i$ represent the share posted in the proposed semi-pooling equilibrium that has the lowest associated μ. By similar arguments to those above there exists a pooling equilibrium with $a_{i,Z}(\hat{\alpha}) = 1$ that will yield a higher payoff to the high-type entrepreneur. Further, the proposed semi-pooling equilibrium must also have a lower expected payoff for high-types than the proposed pooling equilibrium with $a_{i,Z}(\alpha_i^*) = 1$ because the proposed pooling equilibrium yields the highest payoff among all pooling equilibria. Therefore, because this holds for any semi-pooling equilibria, the proposed pooling equilibrium with $a_{i,Z}(\alpha_i^*) = 1$ must yield a higher expected payoff to the high-type than any semi-pooling equilibrium.

Therefore, no semi-pooling equilibrium can be a lex-max undefeated equilibrium under Assumptions 1-3 and $p_i[R_i - \Omega(i,H)] - I > U$. □

All semi-pooling equilibrium are defeated by some pooling equilibrium and all pooling equilibrium are defeated by the proposed pooling equilibrium with α_i^*. Further, the pooling equilibrium with α_i^* yields the highest expected payoff for the high-type entrepreneur for a given U, which implies it will also yield the highest expected payoff for the high-type entrepreneur for U^*. Therefore, the equilibrium with α_i^* is the unique lex-max undefeated equilibrium under Assumptions 1-3 and $p_i[R_i - \Omega(i, H)] - I > U$

All remaining parts of the analysis are the same as restricting entrepreneurs to pure strategies and will provide the same equilibrium outcomes.

B.3 No Equilibrium with Entry Survives the Spirit of the Intuitive Criterion.

To show that no equilibrium with entrepreneur entry into the VC market survives the Intuitive Criterion, first note that from the proof of Proposition 1 no fully separating SCSE exists with entrepreneur entry. Therefore, I just need to show that any semi-pooling or pooling SCSE with entrepreneur entry will fail the spirit of the Intuitive Criterion.

Claim 2 (No Semi-Pooling or Pooling SCSE with Entry Survives the Spirit of the Intuitive Criterion.).

Proof. Without loss of generality suppose that some semi-pooling or pooling equilibrium exists, where for all equilibrium postings $\alpha < 1$ for all $\alpha \in A_i$ and $\theta(\alpha) > 0$. Then the equilibrium payoff for the high and low-type can be defined by $\mu \in (\psi_L, \psi_H]$ and θ. If it is a semi-pooling equilibrium, then each type is indifferent among their strategies such that, dropping the project sub-scripts, the expected equilibrium payoffs can be characterized for high and low-types respectively as

$$\frac{\psi_H}{\mu^*}\left[(\mu^* R - I)(1 - e^{-\theta_{\alpha_i^*}}) - U\theta_{\alpha_i^*} + \mu^*\Omega(i,H)e^{-\theta_{\alpha_i^*}}\right] \tag{A.4}$$

$$\frac{\psi_L}{\mu^*}\left[(\mu^* R - I)(1 - e^{-\theta_{\alpha_i^*}}) - U\theta_{\alpha_i^*}\right]. \tag{A.5}$$

Denote $(\mu^* R - I)(1 - e^{-\theta_{\alpha_i^*}}) - U\theta_{\alpha_i^*})$ as Γ^*.

Now suppose a deviation $\alpha' \notin A$ exists, such that the VC assigns beliefs of $\mu(\alpha') = \psi_H$ and results in θ'. If a low-type's payoff to deviating to α' is less than his equilibrium payoff and the payoff of the high-type to deviating to α' is greater than his equilibrium payoff, then the proposed equilibrium fails the Intuitive Criterion. To see that such a α' exists, set α' such that the low type's payoff from deviating is

$$\frac{\psi_L}{\psi_H}\left[(\psi_H R - I)(1 - e^{-\theta_{\alpha'}}) - U\theta_{\alpha'}\right] \quad <= \quad \frac{\psi_L}{\mu^*}\Gamma^*. \tag{A.6}$$

Denote $\left[(\psi_H R - I)(1 - e^{-\theta_{\alpha'}}) - U\theta_{\alpha'}\right]$ as Γ'. This implies that at equality $\frac{\psi_H}{\mu^*}\Gamma^* = \Gamma'$. Substituting for Γ^*, then the high-type's equilibrium expected payoff and expected payoff from deviating to the θ for which Eq. A.6 holds at equality are respectively

$$\Gamma' + \psi_H e^{-\theta_{\alpha'}}\Omega(i,H) \tag{A.7}$$

$$\Gamma' + \psi_H e^{-\theta_{\alpha^*}}\Omega(i,H). \tag{A.8}$$

The high-type has a higher payoff from deviating if $\theta_{\alpha'} < \theta_{\alpha^*}$. Therefore, if there exists $\theta' \in (0, \theta_{\alpha^*})$ such that Eq. A.6 holds, then the equilibrium will fail the spirit of the Intuitive Criterion.

To see that such a $\theta_{\alpha'}$ exists note that at $\theta_{\alpha'} = 0$ Eq. A.6 holds since the LHS is zero and the RHS is positive. Also, note that at $\theta_{\alpha'} = \theta_{\alpha^*}$ the LHS is greater than the RHS. Because the LHS is a continuous function in θ for all $\theta \in (0, \theta_{\alpha^*})$, by the Intermediate Value Theorem there must exist some $\theta_{\alpha'} \in (0, \theta_{\alpha^*})$ such that Eq. A.6 strictly holds. Therefore, the proposed equilibrium fails the spirit of the Intuitive Criterion.

This holds for any semi-pooling or pooling SCSE. Thus no semi-pooling or pooling SCSE survives the spirit of Intuitive Criterion. □

B.4 Allowing for Separation

I now show that the central predictions of the model can still hold if I relax Assumption 2 such that entrepreneurs with low-quality projects have positive NPV. Relaxing this assumption allows for separation to be supported in equilibrium. For ease of exposition, I will focus on the least cost separating equilibrium (LCSE) that provides the highest payoff for the high-type entrepreneur.

In addition, I will make a simplifying assumption that instead of directly varying the supply of venture capital, I will allow for free entry of VCs and allow the entry costs of VCs to vary. This is isomorphic to the original model but maintains tractability. Formally denote C as the cost a VC must pay to pursue an entrepreneur. Free-entry ensures that VCs will continually enter a sub-market until the expected value of entering is equal to the entry cost. Therefore, for any sub-market the following free-entry condition must hold:

$$[\mu(\alpha, i)R_i\alpha - I]\frac{F(\theta)}{\theta} = C \tag{A.9}$$

Using this condition, I can solve for the low-type entrepreneur's first best expected payoff and market tightness, which I denote as $FB_{i,L}$ and $\theta^*_{i,L}$, and is

$$\begin{aligned} FB_{i,L} &= \psi_{i,L}R_i - I - C(1+\theta_{i,L}) && \text{(A.10)} \\ \theta_{i,L} &= \log\left(\frac{\psi_{i,L}R - I}{C}\right) && \text{(A.11)} \end{aligned}$$

For a separating equilibrium to exist, a low-type entrepreneur must be at least indifferent between mimicking the high-type or receiving his first-best payoff. Applying the free-entry condition for VCs and simplifying, yields the low-type's IC

$$(\psi_{i,H}R_i - I)F(\theta) - C\theta \leq \frac{\psi_{i,H}}{\psi_{i,L}}FB_{i,L} \tag{A.12}$$

The high-type signals by posting a share that is sufficiently costly for the low-type to mimic. Similar to previous results in Chapter 2, there is a one-to-one mapping between the posted share and the market tightness. The high-type's problem is then

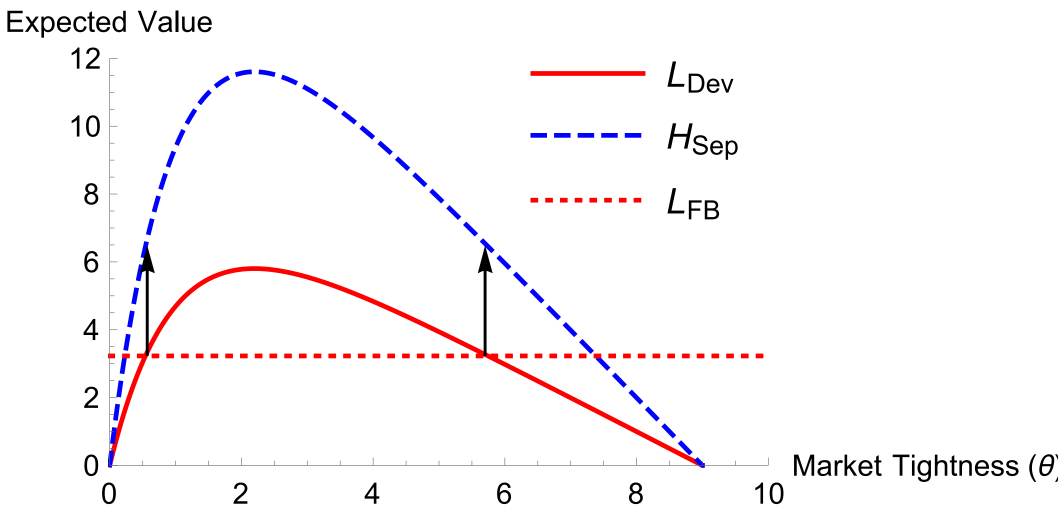
$$\begin{aligned} \max_{\theta} \quad & F(\theta)(\psi_{i,H}R_i - I) - C\theta + (1-F(\theta))\psi_{i,H}\Omega_{i,H} && \text{(A.13)} \\ \text{s.t.} \quad & (\psi_{i,H}R_i - I)F(\theta) - C\theta \leq \tfrac{\psi_{i,H}}{\psi_{i,L}}FB_{i,L} && \text{(A.14)} \end{aligned}$$

Similar to the intuition of Cho and Kreps (1987), one can easily check that the LCSE will occur when the IC of the low-type binds. Using the binding

IC of the low-type, and that $F(\theta)$ is concave, implies there are two potential θ for which the IC of the low-type will bind. Moreover, given that any θ away from the first-best θ for the high-type reduces the high-type's expected value, then there are only two potential levels of market tightness that will maximize the high-type's expected value. Finally, using Eq. **??**, we can see that the high-type will always prefer the lower of the two potential levels of market tightness. This because the expected value from receiving VC funding will be the same (i.e., $\frac{\psi_{i,H}}{\psi_{i,L}} FB_{i,L}$). However, the high-type prefers to choose the market tightness which has a lower probability of funding and a higher share retained. This is because they have a positive outside option and thus retaining the higher share associated with a lower probability of funding is less costly. This is illustrated in Figure B.1.

Figure B.1: Example of Separating Equilibria.

This figure plots the expected payoff for a low-type from deviating (L_{Dev}), the expected payoff for the high-type assuming separation occurs (H_{Sep}), and the low-type's first-best payoff (L_{FB}). The arrows define where the low-types' first-best payoffs intersect with their payoffs from deviating. Parameter values are: $\psi_H = .4$, $\psi_L = .2$, $R = 50$, $I = 2$, and $C = 2$.

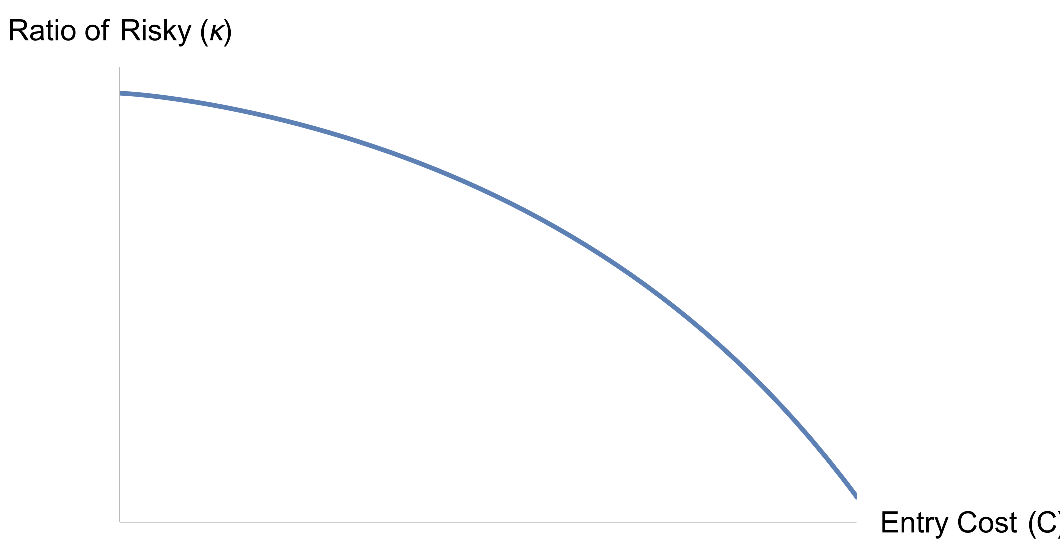


As can be seen in Figure B.1, there are two potential levels market tightness that will allow the IC of the low-type to bind. For any level of market tightness outside of these bounds, the high-type could increase (reduce) his posted share increasing his expected value and still being able to separate. For any level of market tightness within these bounds, the low-type will deviate from the separating equilibrium. Thus, the LCSE must be at either one of these two points. However, the lower level of market tightness has a higher expected value to the high-type because they have a positive outside option that is received if no match occurs, which is with probability (1-θ). Therefore, the high-type will always choose the lower level of market tightness for it has the same expected value from funding but a higher expected value from the outside option. Said differently, it is more efficient for the high-type to separate by choosing to retain a high share that is associated with a lower probability of funding.

In order to analytically solve for the equilibrium value of $\theta_{i,sep}$, I would need to use Eq. A.12. However, this involves using a product log function (Lambert-W function) that is not well-defined. Therefore, I show that the main predictions of the model hold by solving for $\theta_{i,sep}$ numerically for each project variety, and then plotting how the ratio of risky to safe projects changes with entry costs C. I show an example of this in Figure B.2.

Figure B.2: Ratio of Risky to Safe for Separating Equilibria.

This figure plots the ratio of risky to safe projects funded in the economy for varying levels VC entry costs. The parameters assumptions are $I = 15$, $R_r = 500$, $R_s = 100$, $\Omega(r, H) = 180$, $\Omega(s, H) = 20$, $p_r = 0.1$, $p_s = 0.5$, and $\lambda = 0.9$. I allow C to vary between 0.1 and 4.



As can be seen in Figure B.2 as entry costs fall (i.e., increased entry of VCs), the ratio of risky to safe projects increases in the economy. The intuition for this result is similar to before. The equilibrium market tightness of safe projects is higher than for risky projects. Thus a shock to VC entry has a bigger effect on the sub-markets with lower market tightness because there is less competition among VCs in these sub-markets. Therefore, in equilibrium these sub-markets have a greater proportional response to the shock and the projects probability of funding increases by a larger relative amount.

Overall, the results of this extension show that the model's key predictions are not driven by the assumption in the baseline version that low-type entrepreneurs have negative NPV. Instead, it shows that similar to the baseline version the information asymmetry is most costly to the entrepreneurs with high-quality risky projects and thus in equilibrium their equilibrium outcome faces the most distortion. Moreover, this distortion is reduced when there is increased VC entry and thus entrepreneurs with risky projects see a larger proportional increase in their probability of funding.

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