Endogenous Networks in Investment Syndication*

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Abstract: As an effective investment strategy, investors often invest jointly in a company by forming a syndicate. The unique feature of this paper is that it endogenizes the formation of an investment syndicate. We provide a theory on the endogenous formation of networks in investment syndication and analyze how several key factors such as risk aversion, productivity, risk and cost affect incentive and syndicated investment. We also apply the theory to venture capital investment and identify empirical evidence in support of it.

Keywords: investment syndication, endogenous network, investment risk, risk aversion, project productivity

JEL Classification: G30

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1. Introduction

Risk-averse investors demand large compensation for investing in highly risky projects. One effective strategy for investors to deal with risks is to form a group to invest jointly in a firm. This way a number of investors can share the risks, especially when investing in a highly risky firm. This group of investors is referred to as an investment syndicate and the company being invested in is referred to as a portfolio company. An investment syndicate is a form of interfirm alliances in which two or more venture capital firms or investment banks (investors) co-invest in a portfolio company and share a payoff (Wright and Lockett, 2003). Investment syndicates are very popular in reality. For example, Wright and Lockett (2003) reported that 63.6% of U.S. and 29.5% of European venture capital (VC) investments were syndicated in 2000. Brander et al. (2002) found that 60% of Canadian VC investments in 1997 involved more than one VC investor. Lerner (1994) suggested that syndication is commonplace even in first-round investments. In practice, an investment syndicate is typically led by one of the investors, who actively invites other investors to join in and coordinates investment deals between the company and the investors. This lead investor typically makes the largest investment among the group and is involved throughout the whole investment phase.

In the beginning, the entrepreneur (EN) of the portfolio company initiates an investment syndicate by inviting and appointing a lead investor. When deciding on whom to appoint as the lead investor, the EN must take into account two major factors: (1) the lead investor’s ability in organizing a syndicate to satisfy the needs of the company; and (2) the bargaining power of this syndicate for a share of company profits. One crucial determinant of the lead investor’s ability to organize a syndicate is her business connections, which determines her ability in inviting suitable investors to join her syndicate. Such personal business connections are known as the lead investor’s network capital. A well organized syndicate can provide the necessary funding for the company. At the same time it is also in a good position to bargain for a large share of company profits. For example, Hochberg et al. (2010) argued for the value of networks in restricting the entry of outside venture capitalists (VCs), thus improving the incumbents’ bargaining power with the EN. Hence, when choosing a suitable lead investor, the EN needs to strike a balance between a syndicate’s ability in providing funding to satisfy the company’s needs and its potential to bargain for company profits. For this reason, an equilibrium theory should be developed on the level of the lead investor’s network capital or more generally on the composition of an investment syndicate in equilibrium.
Although syndication is very important in venture capital, little is known about the motives of syndication. Lerner (1994) pointed out that “Syndication has been little scrutinized in the corporate finance literature. The reason may lie in the difficulty of analyzing syndication patterns empirically and the complexity of motives behind syndication.” More recently, Brander et al. (2002) claimed that “Aside from Lerner (1994), we are unaware of any published academic papers in which the rationale for VC syndication is the central focus, although some of the existing literature on VC finance does bear on the syndication question”. In this study, we provide a theory on the endogenous formation of an investment syndicate. The theoretical model has three stages. In the first stage, the EN of the portfolio company selects a lead investor. In the second stage, the lead investor coordinates the formation of a syndicate. In the third stage, the EN and the syndicate or the lead investor bargain for output shares. Most of the existing studies have focused on the second stage. Our analysis shows the impact of network endogeneity. In particular, we show opposite effects of productivity on effort if a network is treated as exogenous instead of endogenous.

This study is related to two streams of literature. The first stream is on investment syndication. Existing studies on investment syndication have focused on two questions: what is the rationale behind investment syndication and how are investment syndicates formed? There are many theoretical studies on the rationale behind syndication. In theoretical studies, Wilson (1968), Sah and Stiglitz (1986) and Pichler and Wilhelm (2001) suggested that syndication is an efficient way to share risks among partners and gather additional information about a startup’s value and can also be a way of colluding tacitly. Admati and Pleiderer (1994) provided an implicit rationale for syndication based on information asymmetry between VCs and the EN. They suggested that the only optimal financial contract that can mitigate overinvestment and other agency problems is a fixed-fraction contract. This is when the VCs receive a fixed fraction of the project’s payoff and finance the same fraction of future investments. Their theoretical model implies that the VCs’ syndication decision in later rounds would ensure the optimality of a financial contract. Casamatta and Haritchabalet (2007) suggested that VC syndication improves the screening process of VCs and prevents competition among investors after investment opportunities are disclosed. They also highlighted the importance of experience to the formation and efficiency of investment syndicates, which suggests that experienced VCs should syndicate with experienced VCs. Huang and Xu (2003) provided a contractual foundation that solves a class of commitment problems in R&D financing and argued that syndicated VC financing can be deployed as a commitment device to terminate bad projects promptly. Fluck et al. (2006) provided an explanation to the popular co-existing phenomena of staged financing and syndication in VC investments. They found that ex ante commitment to syndicate investments in later stages protects the EN from po-
potential hold-up problems arising from staged financing. Dorobantu (2006) suggested that a VC can use syndication in the second or a later financing round as a signaling device to credibly communicate private information about her project-selection ability to potential investors in a follow-on round.

The most related empirical works on the rationale of investment syndication are those of Brander et al. (2002) and Ozdemir (2006). Brander et al. (2002) examined two conjectures: the venture selection and value-added hypotheses. Using Canadian VC investment data, they found that syndicated VC investments have higher returns, which supports the value-added interpretation. A similar result was found by Cumming and Walz (2010). Ozdemir (2006) discussed “how social structure and a VC firm’s position within it affect the propensity of syndication.” Ozdemir confirmed that “uncertainty and risk associated with investing in a particular target company increase the likelihood of syndication.” De Clercq and Dimov (2004) investigated the realized investment strategies of 200 U.S.-based VCs over a twelve-year period. Their findings suggested that syndication is a mechanism for VCs to share complementary knowledge and financial risks among syndicate partners.

Unlike the rationale behind investment syndication, there are few theoretical studies on the formation of investment syndicates. To our knowledge, the only related studies to our work are those of Cestone et al. (2007) and Tykovová (2007). Cestone et al. (2007) focused on contract design to induce VCs to truthfully disclose investment opportunities. Their findings suggest that more experienced lead VCs should select more experienced partners. This conclusion is consistent with the implications of the theoretical work of Casamatta and Haritchabalet (2007) and is supported by the empirical works of Lerner (1994) and Du (2009). In contrast, Tykovová (2007) showed in a complete information setting that VCs may choose to syndicate with less experienced partners if the latter are willing to accept comparably worse payoffs after taking into account the benefits of reputation building and the transfer of know-how among partners.

The second stream of literature related to this study consists of recent studies on the application of network theory in finance, especially VC investments. Network structure is known to be important in determining the outcome of many important social and economic relations.3 In finance, network theory is mainly applied to financial stability and contagion.

3 Examples of the effects of social networks on economic activity are abundant, including their effects on transmitting information about job availability, new products, technologies and political opinions. They also serve as channels for informal insurance and risk sharing. The network structure influences patterns of decisions regarding education, career, hobbies, criminal activity and even participation in micro-finance. Durlauf (2004)

In empirical studies, Ozdemir (2006) showed that “those VC firms deeply embedded in the VC industry syndication and social networks are more likely to initiate syndicates, although the more experienced VC firms prefer going solo.” Hochberg et al. (2007) investigated the effect of networks on VC investments. They looked at VCs who are connected through a network of syndicated investments. They found that better-networked VCs experience significantly better fund performance, as measured by the proportion of investments that are successfully exited through IPOs and sales to other companies. Hochberg et al. (2010) further showed that VC syndication presents a potential barrier to entry for new VCs, and incumbents appear to have benefited from this reduced entry because they show the willingness to accept lower compensation for their deals. Hochberg et al.’s (2007, 2010) works agree with the earlier work of Seppä and Jääskeläinen (2003), who explored 54,700 VC investments in 10,057 portfolio companies by 100 of the largest private U.S. VCs during 1986–2000. Sorenson and Stuart (2001) explored how interfirm networks in the U.S. VC market affect spatial patterns of exchange. Empirical evidence suggests that social networks in the VC market—built up through the extensive use of syndicated investments—transfer information across boundaries and therefore expand the spatial radius of exchange. Sorenson and Stuart (2008) proposed a theory to explain the formation of distant ties in VC investment networks and suggested that VCs form relations with distant partners when they participate in two types of settings: unusually faddish ones and those with limited risks to participants.

This paper examines a different aspect of the formation of investment syndicates. Previous theoretical and empirical studies have emphasized relational ties among investors but reviewed theoretical models on neighborhood effects. Allen and Babus (2009) reviewed the application of network theory in finance. Jackson (2005, 2010) gave a survey of theoretical works on network formation and provided an overview of social networks in economic applications.
ignored the role of the EN. In other words, they have focused on how the lead investor chooses syndication partners, with the EN playing no role in the process. We, however, take into account the role of the EN in the formation of the investment syndicate. We propose a theoretical model to explain how the syndicate is determined through a process involving choices and bargaining between the EN and the syndicate and among the syndicate members. In our theoretical model, the syndication process involves three stages: the EN first chooses the lead investor; then the lead investor chooses syndication partners; and finally the EN and the syndicate bargain to determine their output shares. The first and final stages have so far been ignored in the existing literature on the formation of investment syndicates. Our three-stage syndication process endogenously determines the lead investor's network capital in equilibrium.

This paper contributes to the literature on the networks of investment syndicates. Our model suggests that when choosing the lead investor, the EN will take into account the lead investor’s network capability as a key factor. This is quite consistent with existing empirical evidence. For example, Gulati (1999) found that accumulated network resources (or what we refer to as network capital in this paper) arising from the history of participation in the network of alliances are influential in a firm’s decision to join new alliances. More direct evidence came from Smith (2001), who found that the factors the EN considers when evaluating VCs include network capital, such as “co-investing with other investors”, “interfacing with the investor group” and “obtaining alternate sources of financing.” A lead investor’s network capital affects her ability to organize a sizable syndicate, which is proven to be valuable to project efficiency (Brander et al., 2002). We conclude that the tradeoff between syndicated funding and profit sharing determines the optimal choice of the EN, by which the lead investor’s network capital is endogenously determined in the process. Endogenously determined networks can be found in the existing studies on financial networks. For example, Babus (2009) found that a financial network of banks emerges endogenously. In equilibrium, with endogenous networks, the degree of systemic risk is significantly reduced. Further, in certain equilibria, contagion does not occur.

Our theoretical model shows that the determinants of the syndicate size or the lead investor’s network capital include the investors’ risk aversion, project productivity and investors’ output share. We further provide empirical evidence to support our theoretical findings using 40,395 identified domestic VC investment rounds made in 15,264 portfolio companies by U.S. VCs during 1985–2005. After controlling for the type of lead VC firm (lead VC type) and the fixed effects of funding year, industry and round sequence, we found that investment risk and portfolio company quality had a significant positive effect on the syndicate size. This empirical finding is consistent with our theoretical results.
This paper is organized as follows. In Section 2, we set up the model. In Section 3, we solve for the equilibrium solution and provide a theoretical analysis of our solution. In Section 4, we apply our theory to VC investments and present an empirical analysis using data from the U.S. VC industry. We conclude in Section 5 with a summary of our main results and remarks. The derivations are given in the Appendix.

2. The Model

In this section, we develop a theory on the formation of an investment syndicate supplying funds to a target company.

Consider an EN who seeks investment from investors for a project. Funding is provided through a syndicate. The syndicate is organized by a lead investor, who is invited and appointed by the EN. The syndicate is defined by a vector \( (n, \alpha_1, \ldots, \alpha_n) \), where \( n \) is the number of investors in the syndicate and is called the lead investor’s network capital, and \( \alpha_i \) is a measure of the risk aversion of investor \( i \) in the syndicate. This \( n \) is endogenous. For the investors, a larger \( n \) implies more investors to share risk and increases the bargaining power of the syndicate for a share of output; for the EN, a larger \( n \) means more funding but reduces the EN’s bargaining power. An optimal \( n \) will be chosen by the EN when she selects the lead investor.

The EN is risk neutral, and the investors are risk averse. Each investor has utility function:

\[
u_i(x) = \frac{1}{1-\alpha_i} x^{1-\alpha_i}.
\]  

Output is determined jointly by investment from investors and effort from the EN. The EN has an incentive problem since her effort \( a \) is unverifiable. Specifically, output ex ante is a lottery \( \tilde{x} \) defined by

\[
\tilde{x} \equiv (x(I), p(a); 0,1 - p(a)),
\]

where \( I \) is the total investment from the investors, \( x(I) \) is the output ex post when the project is successful, \( p(a) \) is the probability of success, and both \( x(I) \) and \( p(a) \) are assumed to be increasing functions. We assume \( p(a^*)x(I^*) > I^* \) in equilibrium \( (a^*, I^*) \), implying a profitable project.

The EN bargains with the lead investor over how to divide the output after it is produced. Let \( \lambda(n) \) be the output share for the syndicate. Hence, \( \lambda(n) \) represents the bargain-
ing power of the lead investor. We assume that $\lambda(n)$ is increasing in $n$, meaning that the larger the syndicate, the more bargaining power the lead investor has.

We take the same incomplete contract approach as Hart and Moore (1990) did. In our model setting, there is no contract ex ante at $t = 0$ and the two parties, the EN and the syndicate (SN), bargain for output shares ex post at $t = 1$. However, the equilibrium solution is implementable by a complete contract ex ante. If $n^*$ is the equilibrium solution, the complete contract is an upfront equity-sharing agreement that gives an equity share of $\lambda(n^*)$ to the syndicate and an equity share of $1 - \lambda(n^*)$ to the EN. Our model setting ensures our solution to be bargaining-proof or renegotiation-proof.

We solve the problem backwards in three steps as indicated by the following figure.

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**Step 1: The EN’s Effort**

After output is produced, the two parties bargain for a share. We assume that when bargaining for a share of output, the lead investor representing the syndicate behaves as a risk-neutral agent. This is symmetric to the setting on the EN’s side, where the risk-neutral EN also represents a group of agents in reality, including managers, entrepreneurs and the original owners (insiders) of the firm. Only when each investor considers her own investment does she behave as a risk-averse agent. We use the Nash bargaining solution to define their output shares. If no agreement is made, both parties get nothing; if there is an agreement, they share output $x$. The Nash bargaining solution implies the following ex post payoffs for the EN and the syndicate, respectively,

$$
\Pi_{EN} = [1 - \lambda(n)] \bar{x}, \quad \Pi_{SN} = \lambda(n) \bar{x},
$$

where the subscript $SN$ stands for the syndicate, random output $\bar{x}$ takes either $x(I)$ or 0, and $\lambda(n)$ represents the lead investor’s bargaining power, which is assumed to be increasing in $n$. With private cost $c(a)$ and risk neutrality, the EN’s ex ante payoff is\(^4\)

$$
U_{EN} = [1 - \lambda(n)] p(a)x(I) - c(a),
$$

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\(^4\) We can also assume that the EN is risk averse, which does not add much complexity to our analysis nor change our conclusions.
where $c(a)$ is the EN’s private cost of effort. Then, the EN chooses $a$ according to the following first-order condition (FOC):

$$[1 - \lambda(n)] p'(a)x(I) = c'(a).$$  

(2)

By assuming concave $p(a)$ and convex $c(a)$, the second-order condition (SOC) for the choice of $a$ is satisfied.

**Step 2: The Investors’ Investment**

Consistent with reality, assume that the expected return is the same among all the investors in a syndicate. This means that each investor’s income from investment is proportional to her investment. That is, investor $i$ with investment $I_i$ receives a share $I_i/I$ from the syndicate’s total income $\lambda(n)x$. With the coordination of the lead investor, the investors form a cooperative group. Suppose that the total investment $I$ is to be determined by social welfare maximization in the syndicate. Then, assuming $u_i(0) = 0$, the syndicate’s investment decision is determined by the following problem:

$$U_{SN} \equiv \max_{\{I_i\}} \sum_{i=1}^{n} \left\{ p(a)u_i \left[ \sum_{j} \frac{I_j}{I} \lambda(n)x \left( \sum_{j} I_j \right) \right] - I_i \right\}.$$

This problem implies the total investment $I$. That is, it is not the lead investor who decides $I$; instead, it is the syndicate that determines this $I$ together. Based on the existing literature, we assume homogeneity among the investors in a syndicate; specifically, we assume that all the investors in a syndicate have the same risk aversion $\alpha$. Hence, we must have $I_i = I/n$ for all $i$ in equilibrium. Then, the FOC for the above problem is (see the Appendix for the derivations):

$$1 = p(a)n \left[ \frac{\lambda(n)x(I)}{n} \right]^{\frac{1}{1-\alpha}} \frac{x'(I)}{x(I)}.$$

(3)

This equation determines the optimal funding $\hat{I}(a,n)$. That is, the investment is affected by the EN’s incentive and the lead investor’s network capital.

Our assumption of homogenous investors is well justified by the literature. Casamatta and Haritchabalet (2007) studied the rationale behind syndication. They indicated that syndication can improve the screening process (gather information) and prevent competition among investors. They highlighted the importance of experience to the formation and efficiency of a syndicate and suggested that experienced VCs syndicate exclusively with experienced partners because they possess good assessment skills. Cestone, Lerner, and White (2007) studied the formation of VC syndicates. They also found that more experienced VCs
select more experienced partners. Du (2009) examined VCs’ preferences for syndication partners in an empirical study. She found that VCs are less likely to syndicate with partners who are different from themselves.

**Step 3: The EN’s Choice of Network Capital**

The EN selects a lead investor with a certain network capital $n$. Given equations (2) and (3), the EN’s problem is

$$\max_{n,a,I} [1 - \lambda(n)] p(a)x(I) - c(a)$$

s.t. $IC_1: [1 - \lambda(n)] p'(a)x(I) = c'(a),$  \hspace{1cm} (4)

$$IC_2: p(a)n\left(\frac{\lambda(n)x(I)}{n}\right)^{\frac{1}{1-\alpha}} \frac{x'(I)}{x(I)} = 1.$$  

Notice that we do not include individual rationality (IR) conditions in the problem, which can be expressed as

$$[1 - \lambda(n)] p(a)x(I) - c(a) > 0, \quad \sum_{i=1}^{n} \left[ p(a)u_i \left( \frac{I_i}{\sum_{j} I_j} \right) - I_i \right] > 0.$$  

We have no need for the IR conditions in problem (4) since we have implicitly allowed the bargaining process to include a monetary transfer between the two parties to ensure both IR conditions are satisfied for the EN and the syndicate. It turns out that such a transfer is unnecessary in our model since for the set of functions we choose later in (5), the solution of (4) automatically satisfies the two IR conditions.

To gather a group of investors to satisfy a company’s needs for funding, the lead investor must have many network connections in the investor community. On the one hand, a well-connected investor is able to gather a proper and sufficiently large group of investors to provide sufficient funding and to spread risks among the investors. On the other hand, such a well-connected lead investor has more bargaining power against the portfolio company. Through Nash bargaining, a well-connected investor obtains a large income share from a deal, which reduces the EN’s incentive to work. Hence, the EN needs to balance between these two factors when she appoints a lead investor. The optimal network capacity of this lead investor is the key in our model.

Most existing theoretical studies on investment syndication have focused on how a lead investor chooses partners but ignored the role of the EN. Our model lets the EN choose a lead investor with a certain network capital. This is consistent with the study by Smith (2001), whose survey data suggests that companies in need of investment actively choose
investors. He found a number of network factors to be important in this choice, including “co-investing with other venture capitalists,” “interfacing with the investor group” and “obtaining alternate sources of financing.”

Theoretical and empirical studies have suggested that both the EN and the lead investor are important to the project. In existing theoretical studies, either the EN or the investors have been assumed to be the principal in their relationship. For example, in a study by Admati and Pfleiderer (1994), the EN determines the initial financing agreement in order to maximize the net surplus of the project, while in another study by Amit et al. (1990) the VCs determine the manager’s profit share in order to maximize their own profits. We assume that the EN chooses a lead investor to initiate the syndication process, which is quite consistent with the empirical evidence in the survey by Smith (2001). Smith (2001) indicated that around 71% of ENs in his sample had a choice on which VCs should be allowed to invest in their companies.

3. Theoretical Analysis

3.1. The Cooperative Investment Solution

To analyze the solution, we must use parametric functions. Parametric functions allow a few parameters to represent the key aspects of the issue at hand. We choose the following parametric functions:

\[
u_i(x) = \frac{1}{1 - \alpha} x^{1-\alpha}, \quad p(a) = a^\gamma, \quad c(a) = a^\delta, \quad x(I) = I^\delta, \quad \lambda(n) = \rho n, \quad (5)
\]

where \(\alpha, \gamma, \delta, \rho \in (0, 1)\) and \(\beta \geq 1\). These parameters represent the key factors of the problem and allow us to analyze various aspects of the solution. Here, \(\alpha\) is a measure of risk aversion, \(\delta\) represents the productivity of investment (effective use of investment), and \(\rho\) is an investor’s output share. For our equilibrium solution \((n^*, a^*, I^*)\), since \(a^* < 1\) with reasonable parameter values, an increase in \(\beta\) tends to reduce the cost of effort \(c(a^*)\). Hence, \(\beta\) represents easiness of effort. Similarly, an increase in \(\gamma\) tends to reduce the chance of

\[\text{-------------}
\]

5 The results do not change if we use the following more general functions:

\[
u_i(x) = Ax^{1-a}, \quad p(a) = Ba^\gamma, \quad c(a) = Ca^\delta, \quad x(I) = Dl^\delta, \quad \lambda(n) = E\rho n,
\]

where \(A, B, C, D\) and \(E\) are arbitrary constants.
success \( \rho(a^*) \). Hence, \( \gamma \) represents project riskiness. Since the ratio \( \gamma / \beta \) often appears in our formulas, we denote \( \theta \equiv \gamma / \beta \).

Given the above parametric functions, we can solve for a closed-form solution of problem (4). The derivations are in the Appendix. The solution of the network capital is:

\[
n^* = \frac{\delta}{\rho(1 + \alpha \delta)}.
\]

Then,

\[
I^* = \left(1 + \alpha \delta - \frac{\delta \gamma}{\beta}\right)^{ \frac{\gamma}{(\beta - \gamma)(1 + \alpha \delta) - \beta \delta} } \left(\rho^{\alpha \delta - \beta} \frac{\delta^2}{1 + \alpha \delta}\right)^{ \frac{\beta - \gamma}{(\beta - \gamma)(1 + \alpha \delta) - \beta \delta} },
\]

\[
a^* = \left(1 + \alpha \delta - \frac{\delta \gamma}{\beta}\right)^{ \frac{1 + \alpha \delta - \beta}{(\beta - \gamma)(1 + \alpha \delta) - \beta \delta} } \left(\rho^{\alpha \delta - \beta} \frac{\delta^2}{1 + \alpha \delta}\right)^{ \frac{\delta}{(\beta - \gamma)(1 + \alpha \delta) - \beta \delta} }.
\]

The syndicate’s output share is

\[
\lambda^* = \frac{\delta}{1 + \alpha \delta}.
\]

In contrast, if the network capital is exogenous (i.e., \( n \) is a given constant), with a corresponding change to problem (4), the solutions of effort and investment are

\[
\hat{\theta} = \left[(1 - \rho \eta) \gamma \right]^{ \frac{\gamma}{(\beta - \gamma)(1 + \alpha \delta) - \beta \delta} } \left(n \delta \rho^{\alpha - \beta} \right)^{ \frac{\beta - \gamma}{(\beta - \gamma)(1 + \alpha \delta) - \beta \delta} },
\]

\[
\hat{a} = \left[(1 - \rho \eta) \gamma \right]^{ \frac{1 + \alpha \delta - \beta}{(\beta - \gamma)(1 + \alpha \delta) - \beta \delta} } \left(n \delta \rho^{\alpha - \beta} \right)^{ \frac{\delta}{(\beta - \gamma)(1 + \alpha \delta) - \beta \delta} }.
\]

### 3.2. The Nash Investment Solution

In the above solution, the investors in the syndicate decide their investments cooperatively. Hence, we call the above solution the cooperative investment solution. Alternatively, the investors in the syndicate may play a Nash game to determine their investments.\(^6\) The solution in this case is called the Nash investment solution and investor \( i \)’s investment is determined by

\(^6\) We would like to acknowledge and thank an anonymous referee for proposing this alternative solution and for suggesting that we compare syndicated investment with solo investment.
\[ U_i \equiv \max_{i_j} p(a) u_i \left[ \sum_{i_j} \frac{I_j}{\lambda(n) x \left( \sum_{i_j} I_j \right)} - I_i \right]. \]

The FOC is
\[ 1 = p(a) \left[ \frac{\lambda(n) x(I)}{n} \right]^{1-\alpha} \left[ \frac{n-1}{I} + \frac{x'(I)}{x(I)} \right]. \tag{10} \]

Then, the EN’s problem becomes
\[
\max_{n, a, I} [1 - \lambda(n)] p(a) x(I) - c(a) \\
\text{s.t.} \quad IC_1: \quad [1 - \lambda(n)] p'(a) x(I) = c'(a), \tag{11} \\
IC_2: \quad p(a) \left[ \frac{\lambda(n) x(I)}{n} \right]^{1-\alpha} \left[ \frac{n-1}{I} + \frac{x'(I)}{x(I)} \right] = 1.
\]

Its solution is
\[ n^* = \frac{\delta + \rho (1 - \delta)(1 + \alpha \delta - \delta)}{\rho (1 + \alpha \delta)}. \]

Then,
\[
I^* = \left(1 - \rho n^* \right) \frac{\gamma}{\beta} \left[ \frac{\beta - \gamma}{(1 + \alpha \delta - \delta)} \right] \left[ \rho^{1-\alpha} (n^* + \delta - 1) \right]^{\frac{\beta - \gamma}{(1 + \alpha \delta - \delta)}}, \\
a^* = \left(1 - \rho n^* \right) \frac{\gamma}{\beta} \left[ \frac{1 - \delta + \alpha \delta}{(1 + \alpha \delta - \delta)} \right] \left[ \rho^{1-\alpha} (n^* + \delta - 1) \right]^{\frac{\delta}{(1 + \alpha \delta - \delta)}}.
\]

If the network capital is exogenous, with a corresponding change to problem (11), the solutions of effort and investment are
\[
\hat{I} = \left(1 - \rho n \right) \frac{\gamma}{\beta} \left[ \frac{\beta - \gamma}{(1 + \alpha \delta - \delta)} \right] \left[ \rho^{1-\alpha} (n + \delta - 1) \right]^{\frac{\beta - \gamma}{(1 + \alpha \delta - \delta)}}, \\
\hat{a} = \left(1 - \rho n \right) \frac{\gamma}{\beta} \left[ \frac{1 + \alpha \delta - \delta}{(1 + \alpha \delta - \delta)} \right] \left[ \rho^{1-\alpha} (n + \delta - 1) \right]^{\frac{\delta}{(1 + \alpha \delta - \delta)}}.
\]

### 3.3. Analysis

We analyze the solutions in this section. It turns out that the results derived from the two alternative solutions are very similar. Hence, we present the results for the cooperative
investment solution only. Due to the space limit, we have only included the proof of Proposition 1 in the Appendix; other proofs are available upon request.

**Syndication versus Solo**

Is it possible to have a syndicated investment that is smaller than solo investment (i.e. underinvestment)? Is it possible that incentive is worse under syndication? By denoting \( \hat{I} \) and \( \hat{a} \) in (9) respectively as functions \( \hat{I}(n) \) and \( \hat{a}(n) \) of \( n \), we can compare solo investment \( \hat{I}(1) \) with syndicated investment \( I^* = \hat{I}(n^*) \), and compare effort \( \hat{a}(1) \) under solo investment with effort \( a^* = \hat{a}(n^*) \) under syndication. The question is: is it possible to have \( \hat{I}(n^*) < \hat{I}(1) \) and \( \hat{a}(n^*) < \hat{a}(1) \) when \( n^* \geq 1 \)? It turns out that it is.

**Proposition 1** (Syndication vs. Solo). Given condition \( n^* \geq 1 \), i.e., \( \rho \leq \frac{\delta}{1 + \alpha \delta} \), for the cooperative investment solution,

(a) Solo investment is larger than syndicated investment if and only if

\[
\rho \leq 1 - \theta \leq \frac{\delta}{1 + \alpha \delta},
\]

where \( \theta = \gamma / \beta \).

(b) Incentive under solo investment is better if and only if

\[
1 - \theta \leq \frac{\delta}{1 + \alpha \delta}.
\]

For example, if \( \alpha = 0.1, \beta = 1.5, \gamma = 0.8, \rho = 0.2 \) and \( \delta = 0.8 \), the cooperative solution indicates underinvestment with syndication: \( n^* = 3.7, \hat{I}(n^*) = 4.9 \) and \( \hat{I}(1) = 5.1 \). Similarly, for the same parameter values, the Nash investment solution also indicates underinvestment with syndication: \( n^* = 3.8, \hat{I}(n^*) = 50.5 \) and \( \hat{I}(1) = 64.7 \).

There are two inequality conditions in (12):

\[
\rho \leq 1 - \theta \quad \text{and} \quad 1 - \theta \leq \frac{\delta}{1 + \alpha \delta}.
\]

If and only if one of these inequality conditions fails will syndicated investment be larger. The second inequality condition is the same as (13). This means that if the first inequality condition holds, the EN’s incentive and investors’ investment are strategic complements in equilibrium with respect to syndication; if the first inequality condition fails but the second one holds, incentive and investment are strategic substitutes. In the latter case, solo invest-
ment is smaller, but incentive under solo investment is better. In the following, we provide intuition for the results in Proposition 1. We focus on investment only; intuition for incentive is similar.

On the one hand, with a solo investor, although sources of funding are limited, her incentive is good since she is the sole recipient of the income share for investors and hence may invest a lot. On the other hand, with syndication, although there are multiple sources of funding, each investor’s willingness to invest is low since the investors have to share the benefits and hence the total investment may be low. Both the EN and the investors care about output shares, but while the EN welcomes more investment, the investors prefer to invest less. Depending on project risk, risk aversion, productivity and cost of effort, each party may have a tendency towards one objective or the other. In cases where the EN does not care so much about the investment amount, for example, if productivity is high (in terms of effective use of funding), solo investment may be larger than syndicated investment. Our theory indeed suggests this. Condition (12) is more likely to hold if \( \delta \) is large; if so, solo investment is larger than syndicated investment.

One important function of the syndicate is to share risk. If risk aversion is low, the syndicate’s role of risk sharing is reduced, while output sharing within the syndicate will still have a negative effect on investment. Hence, if risk aversion is low, solo investment may be larger than syndicated investment. Our theory indeed confirms this. Condition (12) is more likely to hold if \( \alpha \) is small; if so, solo investment is larger than syndicated investment. On the other hand, if risk aversion is high, a solo investor will invest conservatively, while syndication allows risk sharing so that investors will be more willing to invest. In this case, we expect syndicated investment to be larger than solo investment. Indeed, when \( \alpha \) is large, condition (12) is more likely to fail; if so, our theory predicts that syndicated investment is larger.

If each investor only has a small output share \( \rho \), each will invest a small amount. Then, for a given required amount of investment, the syndicate will need to be large. Such a syndicate tends to bargain for a large share of output, causing a negative effect on incentive, which in turn reduces investment. Hence, in this case, solo investment is likely to be larger than syndicated investment. Our theory indeed confirms this. Condition (12) is more likely to hold if \( \rho \) is small; if so, solo investment is larger than syndicated investment.

When the project is highly risky, we expect a preference for syndication on both sides. Indeed, when the project is risky as represented by a large \( \gamma \), condition \( \rho \leq 1 - \theta \) in (12) tends to fail, implying a larger syndicated investment.
If effort is costly, the EN will rely more on investment than her own effort, in which case she is likely to go for syndication. Indeed, if \( \beta \) is small, condition \( \rho \leq 1 - \theta \) in (12) tends to fail; if so, syndicated investment is larger.

**Proposition 2** (The Gap between Syndicated and Solo Investments). *Given condition \( n^* \geq 1 \), for the cooperative investment solution,*

(a) If \( 1 - \theta > \frac{\delta}{1 + \alpha \delta} \) or \( \rho \leq 1 - \theta \leq \frac{\delta}{1 + \alpha \delta} \), higher productivity implies a larger gap between syndicated investment and solo investment.

(b) If \( 1 - \theta > \frac{\delta}{1 + \alpha \delta} \) or \( \rho \leq 1 - \theta \leq \frac{\delta}{1 + \alpha \delta} \), higher risk aversion implies a smaller gap between syndicated investment and solo investment.

(c) If \( \rho \geq 1 - \theta \), a larger \( \rho \) implies a larger gap between syndicated investment and solo investment; otherwise the gap is smaller.

**Network Capital**

Interestingly, \( \gamma \) and \( \beta \) are irrelevant to the equilibrium network capital, even though the equilibrium investment and effort are dependent on these two factors. Here, \( \beta \) represents easiness of effort and \( \gamma \) represents project riskiness, both of which depend crucially on the EN’s effort. This suggests that those factors directly related to the EN’s effort do not have an effect on network capital.

In contrast, the network capital is heavily dependent on the risk aversion \( \alpha \) and productivity \( \delta \) of investment, both of which depend crucially on investors and investment. This suggests that those factors directly related to investment influence network capital strongly.

**Proposition 3** (Network Capital).

(a) The syndicate size or network capital is diminishing in risk aversion, and this negative effect of risk aversion on syndicate size is also diminishing in risk aversion:

\[
\frac{\partial n^*}{\partial \alpha} < 0, \quad \frac{\partial^2 n^*}{\partial \alpha^2} > 0. \tag{14}
\]

(b) The syndicate size or network capital is increasing in productivity, and this positive effect of productivity on syndicate size is also diminishing in productivity:
Proposition 3 suggests that more risk aversion implies a smaller syndicate. This result makes sense since highly risk-averse investors demand high compensation for their investment. Consequently, the EN prefers a small syndicate to reduce the investors’ bargaining power for compensation. Proposition 3 also indicates that for a project with high return potential, the EN will pick a lead investor to organize a large syndicate. This result is fairly intuitive.

**Output Sharing**

We now investigate how the two parties share output.

**Proposition 4 (Sharing).** Regarding the syndicate’s output share \( \lambda^* \), we have

\[
\frac{\partial \lambda^*}{\partial \alpha} < 0, \quad \frac{\partial^2 \lambda^*}{\partial \alpha^2} > 0; \quad \frac{\partial \lambda^*}{\partial \delta} > 0, \quad \frac{\partial^2 \lambda^*}{\partial \delta^2} < 0.
\] (16)

That is, the more risk averse the investors are, the smaller the output share they will collectively get; and the more productive the investment is, the larger the output share the investors will collectively get.

A smaller output share for more risk-averse investors is a consequence of less bargaining power implied by (14). At the same time, a larger output share for the EN induces the EN to invest more effort. This suggests that providing better incentive for the EN is an effective strategy to cope with investor risk aversion. Further, if investment is more productive (more effective use of investment), the investors are given a larger output share, which encourages them to invest more in the project.

**Investment and Incentives**

We now investigate the effects of risk aversion, productivity and an investor’s output share on incentive and investment.

While \( \lambda \) is the output share of the syndicate, \( \rho \) is the output share of each investor. For example, if the syndicate has a 50\% share of the output and there are five investors \( (n^* = 5) \), each investor is entitled to \( \rho = 50\% / n^* = 10\% \) of the output. This \( \rho \) reflects each investor’s bargaining power, which tends to have a negative effect on the EN’s incentive. The effect of \( \rho \) is clear from (6) and (7): an increase in the investor share \( \rho \) reduces the syndicate size,
effort and investment. The reason is that a larger investor share reduces the EN’s incentive, which in turn reduces investment; consequently the EN will choose a smaller syndicate size.

The effects of risk aversion and productivity are summarized by the following two propositions.

**Proposition 5** (The Effect of Risk Aversion on Investment and Incentive).

(a) Investment generally increases with risk aversion. Specifically, investment increases with risk aversion if and only if

\[ \rho^\frac{1}{1-\theta} \leq \delta^{-2} (1 + \alpha \delta)^{1-\theta} \left[ (1 + \alpha \delta - \delta) \theta \right]^{\theta} \frac{1}{(1 + \alpha \delta - \delta)(1 + \alpha \delta)}. \]

(b) Incentive generally improves with risk aversion. Specifically, incentive improves with risk aversion if and only if

\[ \rho^\frac{1}{1-\theta} \leq \delta^{-2} (1 + \alpha \delta)^{1-\theta} \left[ (1 + \alpha \delta - \delta) \theta \right]^{\theta} \frac{1}{(1 + \alpha \delta - \delta)(1 + \alpha \delta)}. \]

Typically \( \theta \equiv \gamma / \beta \) is small since \( \beta \) is larger than 1. Hence, we will generally have \( \delta < 1 - \theta \). If so, Proposition 5(a) can be expressed as \( \frac{\partial I^*}{\partial \alpha} \geq 0 \) if and only if

\[ \rho \leq \left[ \delta^{-2} (1 + \alpha \delta)^{1-\theta} \left[ (1 + \alpha \delta - \delta) \theta \right]^{\theta} \frac{1}{(1 + \alpha \delta - \delta)(1 + \alpha \delta)} \right]^{\frac{1}{1-\theta}}. \]

With reasonable parameter values (where \( \alpha \) assumes values between 0 and 1), the right-hand side of the above inequality is above 70. Hence, condition (17) generally holds. This means that investment generally increases with risk aversion. By the same reasoning, incentive generally improves with risk aversion.

The explanation is that risk aversion puts pressure on performance, which improves incentive and in turn induces more investment. Higher risk aversion also reduces the syndicate size and hence results in a larger output share for the EN, which also improves incentive. One interesting observation here is that more risk-averse investors end up investing more in equilibrium.

**Proposition 6** (The Effect of Productivity on Investment and Incentive).

(a) Investment increases with productivity if and only if \( \rho \) is small. Specifically, investment increases with productivity if and only if
\[
\rho \leq \left( \frac{1 + \alpha \delta - \delta}{1 + \alpha \delta} \right)^\theta \frac{\delta^2}{1 + \alpha \delta} e^{\frac{1}{\alpha(1-\theta)} \frac{1 - \alpha(1 + \alpha \delta)}{1 + \alpha \delta}}. \tag{19}
\]

(b) Incentive is generally decreasing in productivity. Specifically, incentive is decreasing in productivity if and only if

\[
\rho \geq \left( \frac{\delta^2}{1 + \alpha \delta} \right)^\theta \frac{1 + \alpha \delta - \delta}{1 + \alpha \delta} e^{\frac{\delta}{\alpha(1-\theta)} \frac{1}{1 + \alpha \delta}}. \tag{20}
\]

For reasonable parameter values, the right-hand side of (19) is between 0 and 10, and the right-hand side of (20) is less than 0.17. Hence, investment is increasing in productivity if and only if \( \rho \) is small, and incentive is generally decreasing in productivity. There are two reasons for these results. On the one hand, since a larger investor output share \( \rho \) has a negative effect on incentive, \( \rho \) cannot be too large for the EN to have enough incentive. If the investor share is small, with sufficient incentive, the EN welcomes higher productivity and applies more effort, which in turn induces investors to invest more. On the other hand, a large investor share sufficiently dampens the EN’s incentive; in this case, with insufficient incentive, higher productivity puts less pressure on the EN to perform, which implies less incentive and investment.

**Cost of Effort and Project Risk**

We now investigate the effects of easiness of effort and project riskiness on investment and incentive.

**Proposition 7** (The Effects of Easiness of Effort and Project Riskiness).

(a) Investment is generally positively associated with easiness of effort and negatively associated with project riskiness. Specifically, an increase in easiness of effort \( \beta \) or a decrease in project riskiness \( \gamma \) raises investment if and only if

\[
\rho \geq \left( \frac{1 + \alpha \delta - \delta}{1 + \alpha \delta} \right)^\theta \left( \frac{\delta^2}{1 + \alpha \delta} \right)^\theta e^{\frac{\delta}{\alpha(1-\theta)} \frac{1}{1 + \alpha \delta}}. \tag{21}
\]

(b) Incentive is generally negatively associated with project riskiness. Specifically, a decrease in project riskiness \( \gamma \) improves incentive if and only if

\[
\rho \geq \left( \frac{1 + \alpha \delta - \delta}{1 + \alpha \delta} \right)^\theta \left( \frac{\delta^2}{1 + \alpha \delta} \right)^\theta e^{\frac{1 + \alpha \delta - \delta(1 + \alpha \delta)}{\alpha(1-\theta)} \frac{1}{1 + \alpha \delta}}. \tag{22}
\]
(c) Incentive is generally positively associated with easiness of effort. Specifically, an increase in easiness of effort $\beta$ improves incentive if and only if (21) holds.

For reasonable parameter values, the right-hand sides of (21) and (22) are less than 0.02 and 0.06, respectively. Hence, these two conditions generally hold. Since $a^* < 1$ with reasonable parameter values, if $a^*$ is fixed, an increase in $\beta$ will reduce the cost of effort $c(a^*)$. Hence, we expect an increase in $\beta$ to raise effort, which in turn encourages more investment. There is a second effect: an increase in effort will raise the cost of effort $c(a^*)$. In fact, $c(a^*)$ does increase with $\beta$ when $a^*$ is allowed to change with $\beta$. However, this second effect is a consequence of the first effect. This means that the second effect cannot change the fact that $a^*$ is increased; it can only reduce the extent of this increase. The net effect (the total of the two effects) is indicated in Proposition 7, i.e., an increase in $\beta$ raises effort and investment.

Similarly, since $a^* < 1$, if $a^*$ is fixed, an increase in $\gamma$ will reduce the chance $p(a^*)$ of project success. In fact, $p(a^*)$ is still decreased when $a^*$ is allowed to change with $\gamma$. Hence, as indicated in Proposition 7, a decrease in $\gamma$ improves the chance of success or reduces project riskiness, which in turn boosts investment and improves incentive.

So far, we have considered the usual circumstances for the results in Propositions 5–7. Under some unusual circumstances, when the inequality conditions fail, the conclusions can be reversed. For example, for Proposition 7(b), if $\rho$ is sufficiently small, condition (22) fails, so that incentive is positively associated with project riskiness $\gamma$. To explain this result, we need to understand the three underlying forces at work. First, an increase in project riskiness $\gamma$ has a negative effect on incentive. Second, a small $\rho$ (a small investor output share) has a positive effect on incentive. Third, as indicated in Proposition 7(a), an increase in project riskiness implies less investment, which may put pressure on the EN to perform, implying a positive effect on incentive. Here, we cite the fact that incentive and investment may be strategic substitutes in equilibrium. In aggregate, when $\rho$ is small enough, the positive effect from a small $\rho$ and/or from the pressure of reduced investment may dominate, which leads to an improvement in incentive. Hence, in Proposition 7(b), a positive association between incentive and project riskiness is possible. Similar situations apply to the other results too.
Endogenous vs Exogenous Networks

One natural question to ask is whether the type of networks, either endogenous or exogenous, is important in our results. In Figure 1, we graph investment by arbitrarily setting $\rho = 0.2$, $\gamma = 0.5$, $\beta = 2$ and allowing risk aversion to change; in Figure 2, we regraph investment with the same parameter values except a fixed $n_0$ at an equilibrium value. Comparing Figures 1 and 2, we find that productivity has opposite effects on investment in the two figures. In other words, with an endogenous network in Figure 1, productivity has a positive effect on investment; but with an exogenous network in Figure 2, productivity has a negative effect on investment. Hence, the endogeneity of network is important in our conclusions.

4. Empirical Evidence from VC Investments

Our theory is applicable to many kinds of investments. With the guidance of our theory, in this section, we conduct an empirical analysis of the determinants of the syndicate size using U.S. VC investment data.

Syndication is widely observed in VC investments. In fact, VCs typically syndicate their investments with other VCs, rather than investing alone (Lerner, 1994). The role of syndication has been investigated theoretically and empirically in the literature. Casamatta and Haritchabalet (2007) suggested in theory that syndication improves the screening process of VC deals and prevents competition among investors after investment opportunities are disclosed. Using a sample of Canadian companies, Brander et al. (2002) provided evidence that syndicated VC investments have higher returns. Our theory focuses on the endogenous
formation of investment syndicates in equilibrium. It is unique in that it determines the lead investor’s network capital endogenously, implying a testable formula for network capital.

We focus mainly on the determinants of network capital or syndicate size, which is the key in our theoretical model. As shown in equation (6), the determinants of the syndicate size or the lead VC’s network capital \( n \) include the lead VC’s risk aversion \( \alpha \), productivity \( \delta \) and the lead VC type \( \rho \). Based on this, we formulate the following regression model:

\[
Dependent \ Variable = \alpha_0 + \alpha_1Investment \ Risk + \alpha_2Portfolio \ Company \ Quality + \alpha_3Controls.
\]

Here, the dependent variable is the syndicate size or the lead VC’s network capital. Our theoretical model indicates that the lead VC’s network capital is endogenously determined in the syndication process. In other words the EN chooses the optimal syndicate size as well as the lead VC with a certain network capital which is in fact a tradeoff between future funding and profit allocation. We take the ex post “Investment Risk” as a proxy for the lead VC’s risk attitude. The higher the lead VC’s risk aversion, the lower the ex post investment risk. “Portfolio Company Quality” is taken to be a proxy for productivity. The higher the portfolio company quality, the greater the productivity. “Controls” include lead VC type plus a set of other control variables.

Equation (6) implies a negative relationship between the syndicate size and the lead VC’s risk aversion, and a positive relationship between the syndicate size and the firm’s productivity. Hence, we expect both investment risk and portfolio company quality to be positively related to the syndicate size.

4.1. Data and Variables

Our sample was obtained from the SDC VentureXpert database, which is the main public database for academic research on VC. We collected data on all the VC investments by U.S. VCs in U.S. portfolio companies that received their initial VC funding during the period 1985–2005. We focused on VC investments that were made in the development stage of a portfolio company. Therefore, we excluded those investments made in the mature stages, including investments in “Buyouts/Acquisitions,” “unknowns” and those made by private equity, such as angel or buyout funds. We also excluded those observations without regression variables. We eventually identified 40,395 VC investment rounds in 15,264 portfolio companies.

Table 1 presents the distribution of our sample by funding year and the industry, location and development stage of the portfolio company. The number of observations and the corresponding percentages are also given. As observed, VC investments increased rapidly.
since 1994, peaked in year 2000, and slowed down considerably following the “bubble burst” of the dot-com era. The sample covered the following 18 industries based on the venture economics industry classification (VEIC) code in the VentureXpert database: agriculture/forestry/fishing, biotechnology, business services, communications, computer hardware, computer other, computer software, construction, consumer related, financial services, industrial/energy, internet specific, manufacturing, medical/health, semiconductor/electronics, transportation, utilities, and other. Clearly, VC investments were concentrated in high-technology industries. In particular the computer software, internet specific, medical/health, and communications industries constituted respectively 23.0%, 18.3%, 12.9% and 11.3% of the whole sample.

Regarding the locations of the portfolio companies, we can see a clear trend of geographic clustering in VC investments. For this reason, we report only the top 20 states in which VC investment rounds have been made. The other 30 states constituted only 7.2% of the sample. We found that most VC investments occurred in California, Massachusetts, Texas and New York, which constituted respectively 36.8%, 11.4%, 5.8% and 4.5% of the sample. That’s a total of almost 60% of our sample. Also, about 40% of the VC investment rounds were made in the seed or early development stage of a portfolio company, which is comparable with the 39% reported by Gompers (1995).

The definitions and measures of all the variables are defined and explained in Table 2. The variables are defined in the remainder of this section.

**Dependent Variables**

Our unit of analysis is a VC investment round. The dependent variable is the logarithm of the number of VCs participating in an investment round and is named **Syndicate Size**. For each VC investment round, we identified the lead VC as the VC firm that injected the largest funding. In practice, the lead VC is typically the most active investor and plays a leading role in monitoring and professionalizing a portfolio company. Our definition of the lead VC is similar to those of Sørensen (2007), Hochberg *et al.* (2007) and Nahata (2008). In total, there were 2,373 lead VCs in our sample.

The network capital in our theoretical model can be in many forms, including other VCs, head hunters, patent lawyers and investment bankers. In the spirit of Hochberg *et al.* (2007), we focused on the most important co-investment network. We measured a lead VC’s network capital in a given investment round by the number of VCs that she had syndicated with during the five years prior to the investment round, normalized it by the number of active VCs participating in at least one investment round during the five-year span and named it
Network Degree. Network Degree is an indirect measure of a lead VC’s network capital. The more coinvestment ties a lead VC has, the more opportunities exist for exchange and so the more influential the lead VC. A lead VC who has many coinvestment ties with other VCs may have access to a wide range of experts, contacts and pools of capital. To further analyze a lead VC’s direct relationships with other VCs, we constructed two alternative variables indicating the lead VC’s network capital in a given investment round. Specifically Network Outdegree and Network Indegree are measured respectively as the normalized number of VCs a lead VC had invited into her syndicates and the number of VCs who had invited the lead VC into their syndicates in the five years prior to the investment round. These three measures representing the lead VC’s network capital are the same as those used by Hochberg et al. (2007). For example, if a lead VC had syndicated with 10 different VCs, had invited five different VCs into her syndicates and had been invited into four different VCs’ syndicates during 2000–2004, and if there were a total of 21 active VCs participating in at least one investment deal during 2000–2004, the values of Network Degree, Network Outdegree and Network Indegree of the lead VC for those investment rounds occurring in 2005 would respectively be 50% (10/(21-1)), 25% (5/(21-1)) and 20% (4/(21-1)).

Investment Risk

Investment risk was used to represent a lead VC’s risk version (\(\alpha\)). The first measure of investment risk in an investment round, named Company Age, is the logarithm of the age of a portfolio company at the time of the investment round, while the age of a portfolio company at the time of the investment round is the number of years between its founding and the year of the investment round. Hence, a younger company is likely to be riskier.

It is widely observed that VCs typically target certain industries, certain development stages of the portfolio companies, or certain local geographical areas (Bygrave, 1987; Gupta and Sapienza, 1992; Norton and Tenenbaum, 1993). This may help them control risk when identifying, evaluating and monitoring projects and prevent competition from other VCs and other types of financial institutions. Our sample distribution in Table 1 also implies such investment clustering. In the spirit of Sorenson and Stuart (2001), investment risk was determined by industry distance, stage distance and geographic distance between a lead VC and her portfolio company. A lead VC who makes an investment in a faraway portfolio company, a new industry, or a new development stage of a portfolio company is bearing more investment risk than most and so she must be less risk averse.

We measured the Industry Distance of a given investment round by the percentage of investment rounds a lead VC had made from 1980 to the year prior to the given investment
round that were not in the same industry as the portfolio company. There are totally 18 industry groups based on the VEIC code. This measure incorporates at least five years of VC investment experience. For a VC investment round that occurred in 2000, this measure of industry distance incorporates 20 years of VC investment experience during 1980–1999. For example, if the SDC VentureXpert database shows that a lead VC had made a total of 100 rounds of investment during 1980–1999 and 15 of those were in the “Computer Hardware” industry, the **Industry Distance** of this lead VC for an investment round made in 2000 and in a portfolio company in the “Computer Hardware” industry would be 85% \((\frac{100-15}{100})\).

Similar to **Industry Distance**, we measured the **Stage Distance** of a given investment round by the percentage of investment rounds a lead VC had made from 1980 to the year prior to the given investment round that were not in the same development stage as the portfolio company in the given round. We covered four development stages: seed stage, early stage, expansion stage and later stage. As a robustness check, we also measured **Industry Distance** and **Stage Distance** by past investment amount rather than by the number of past investment rounds. All the results are similar. Finally, we measured **Geographic Distance** directly by the logarithm of the physical distance between the state in which the lead VC is located and her portfolio company.

**Portfolio Company Quality**

We took the quality of a portfolio company as a proxy for project productivity \((\delta)\) in the theoretical model. The greater the total VC investment, the higher the portfolio company quality is likely to be, and the higher the likelihood of good performance. Gompers (1995) proposed that funding in follow-on rounds is given only if a portfolio company does well in earlier rounds. Also, specific milestone-contingent clauses are contained in most VC financing contracts, by which VCs automatically cease to provide further funding to weak ventures (Wang, 2009). Hence, a larger VC funding reflects better quality of the portfolio company. Following Nahata (2008), we used the logarithm of the total VC funding amount in a portfolio company across all financing rounds as a proxy for its quality and named it **Total VC Funding**.

We also defined an indicator variable on whether a portfolio company has successfully exited through an IPO or acquisition as a proxy for its quality and named it **Quality Indicator**. In practice, observable VC returns are mainly made from successful exits, such as if the portfolio company goes public or is acquired (Cumming and MacIntosh, 2003; Cochrane, 2005). The larger the number of successful exits a VC makes from its portfolio companies, the larger its internal rate of return from investments. Hence, we also used **Quality Indicator**
to represent portfolio company quality. We traced the exits of portfolio companies until the end of 2009, which provides a minimum of four years for a successful exit.

These two measures of company quality are by no means perfect and involve a look-ahead bias since the cumulative funding and a successful exit are unknown at the time of early financing rounds. However, considering that VentureXpert provides little information on portfolio companies other than financing rounds, funding amount, investors and exits, these two measures have been well adopted in the literature and have been considered to reflect many unobservable factors that determine a portfolio company’s prospects at the time of funding.

**Control Variables**

Other than the explanatory variables indicating investment risk and portfolio company quality, we also needed to control for lead VC type based on its organizational structure. There is a distinction between traditional VCs and the so-called captive VCs. The latter are affiliated with corporations, financial institutions or governments (Bottazzi et al., 2008; Nahata, 2008; Hellmann et al., 2008). Different types of VCs may have different resources and connections with other institutions and emphasize different strategic objectives. To control for lead VC type, we created three dummy variables indicating whether a lead VC was affiliated with a corporation, an institution, or a government, and named them *Corporate VC Indicator*, *Institutional VC Indicator* and *Government VC Indicator*, respectively.

We also included industry indicators based on the VEIC code to partially account for technological and industrial characteristics of portfolio companies. We further included funding year indicators as additional control variables. Considering the possible effect of an early choice of syndication on later rounds, we further controlled for the round sequence effects based on the sequencing of investment rounds in each portfolio company (being in the first, second or third round, etc.).

**4.2. Summary Statistics and Correlations**

Table 3 presents summary statistics of all the regression variables. The quartiles, means, standard deviations and the number of observations are presented. As indicated, about 2.4 VCs formed a syndicate in an investment round on average, suggesting the popularity of

\footnotesize 7 We reported raw values for all the variables in Table 3, even though some of them were used in their natural logarithm form in our regressions (as indicated by "***" in Table 2).
syndication in VC investment. About 54% of VC investment rounds were syndicated (not tabulated). A typical lead VC syndicated with 7.48% of all active VCs (Network Degree) on average, invited 4.71% of all active VCs to her syndicates (Network Outdegree), and was invited by 1.37% of all active VCs to their syndicates (Network Indegree) in the five years prior to the current investment round. The lead VCs in our sample had higher network capital on average than those reported by Hochberg et al. (2007). In particular, Hochberg et al. (2007) reported the averages of Network Degree, Network Outdegree and Network Indegree to be 4.24%, 1.20% and 1.00%, respectively. The reason for the difference is that we measured the network capital for the lead VCs only, who tend to have more network capital and their network capital tends to be more influential than an average VC.

Table 3 indicates high investment risk in the VC market. On average, a portfolio company was less than five years old with the median being only three years old. A trend in specialization is clear. In an investment round, on average 20% (or 32.5%) of a lead VC’s investment experience was in the industry (or in a development stage) of the portfolio company. In other words, the average Industry Distance was 80% (with a standard deviation of 24%), which is very close to the 77% (with a standard deviation of 21%) reported by Sorenson and Stuart (2001). The distribution of Stage Distance was similar to that of Industry Distance, whose mean and standard deviation were 67.54% and 21%, respectively. The average geographic distance between a lead VC and her portfolio company was about 1,208 kilometers with the median being only 363.9 kilometers. Also, 41% of VC investment rounds were made in the same state as the lead VC’s (unreported). For portfolio companies, the total VC fund inflows across all rounds were 22.27 million dollars on average, which is comparable with the 24 million dollars reported by Nahata (2008). As observed, 38% of VC investments made successful exits through IPOs or acquisitions by the end of 2009, which is slightly higher than the 35% reported by Gompers (1995) for the period 1961–1992. Finally, the probabilities that a lead VC was affiliated with a corporation, a financial institution and a government were respectively 3%, 4% and 11%.

The Spearman and Pearson correlation matrices are tabulated respectively in the upper and lower diagonals of Table 4. The correlations among all the variables were small, except for those among the three alternative measures of the network capital of the lead VC, namely Network Degree, Network Outdegree and Network Indegree, which suggests the absence of severe multicollinearity in our regression model.

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8 The value of Total VC Funding reported in Table 3 was based on VC investment rounds, which is slightly different from the value based on portfolio companies.
4.3. Regression Results

We also investigated the impact of investment risk and portfolio company quality on the syndicate size (which also indicates the network capital of a lead VC in equilibrium in our theoretical model). Our unit of analysis was a VC investment round. The sample size was 40,395. We took Syndicate Size and the three alternative measures of the network capital of the lead VC, namely Network Degree, Network Outdegree and Network Indegree, as the dependent variables. We employed an OLS model to relate the dependent variables with the following primary explanatory variables: investment risk as measured/proxied by Company Age, Industry Distance, Stage Distance and Geographic Distance, and portfolio company quality as measured/proxied by Total VC Funding and Quality Indicator. We also controlled for lead VC type by including Corporate VC Indicator, Institutional VC Indicator and Government VC Indicator in all the regressions. Although not reported, in all the regressions, we also included 20 funding year indicators, 17 industry indicators based on the VEIC codes and 19 round sequence indicators based on the sequencing of investment rounds in each portfolio company (being in the first, second or third round, etc.) to control for the year, industry and round sequence fixed effects.

Table 5 reports the results. All the $t$-statistics have been adjusted for heteroskedasticity (White, 1980). In models 1 and 2, we took Syndicate Size as the dependent variable and separately included factors representing investment risk and portfolio company quality. In models 3 to 5, we separately took the three alternative measures of the network capital of a lead VC as the dependent variable and included all the explanatory variables. We found very similar results in all the models. Our empirical results are consistent with our theoretical findings.

Our theoretical model implies a negative relationship between a lead VC’s risk aversion ($\alpha$) and the syndicate size ($n$). Our regression results confirm this prediction by showing that investment risk had a positive impact on the syndicate size. Also, the coefficient of Company Age was negative at the 1% significance level and the coefficients of Industry Distance, Stage Distance and Geographic Distance were all significantly positive at the less than 5% significance level. These results are also consistent with the prediction of our theoretical model.

For the magnitude of the effects, we found that a one standard deviation increase in Company Age decreases Syndicate Size and its three alternative measures, Network Degree, Network Outdegree and Network Indegree, by 1.83%, 48.31%, 22.82% and 8.97%, respectively. Also, a one standard deviation increase in Industry Distance (Stage Distance, Geographic Distance) increases Syndicate Size and its three alternative measures, Network
Degree, Network Outdegree and Network Indegree, by 3.29% (1.40%, 2.11%), 108.81% (12.10%, 37.13%), and 18.18% (3.08%, 1.49%), respectively.

Our theoretical model implies that productivity ($\delta$) has a positive impact on a lead VC’s equilibrium network capital ($n$). Hence, we expect a positive relationship between portfolio company quality and the syndicate size in our regressions. Indeed, the coefficients of Total VC Funding and Quality Indicator were both positive at the 1% significance level. Specifically, a one standard deviation increase in the total VC funding across all rounds for a portfolio company increases Syndicate Size and its three alternative measures, Network Degree, Network Outdegree and Network Indegree, by 19.91%, 108.42%, 64.07% and 15.02%, respectively. Also, a one standard deviation increase in the likelihood of a successful exit implies an increase in Syndicate Size and its three alternative measures, Network Degree, Network Outdegree and Network Indegree, of 6.05%, 32.83%, 22.46% and 4.08%, respectively.

Since lead VC type ($\rho$) in our theoretical model can be measured by a set of characteristics of the lead VC in our empirical model, our theory predicts an impact, but not the specific signs of the coefficients of those variables representing the lead VC’s characteristics. Indeed, as expected, our regressions indicate that both Corporate VC Indicator and Government VC Indicator had a negative impact, but Institutional VC Indicator had a positive impact, on Syndicate Size.

In summary, after controlling for lead VC type and the fixed effects of funding year, industry and round sequence, we found that both investment risk and portfolio company quality had a significant positive effect on syndicate size. This empirical finding is consistent with our theoretical finding.

4.4. Robustness Checks

To ensure the reliability of our empirical analysis, we conducted many robustness checks. Firstly, we investigated the impact of investment risk and portfolio company quality on the syndicate size at the portfolio company level to rule out the double counting problem. The unit of analysis became a portfolio company, rather than a VC investment round. We defined Syndicate Size as the number of VCs providing funding to a portfolio company. The lead VC was identified as the VC that participated in the initial round of financing and made the largest total investment in the portfolio company across all rounds. The lead VC’s network capital was measured similarly as before but this time we took its value at the time a portfolio company received initial VC funding. With a reduced sample size of 15,264, all our results remained qualitatively the same after these adjustments.
Secondly, we also tried many alternative measures of investment risk and portfolio company quality. For example, we measured *Industry Distance* and *Stage Distance* based on the past investment amount rather than the number of past investment rounds. We redefined *Geographic Distance* as a dummy variable indicating whether a lead VC and her portfolio company were located in the same state. We further included public companies’ risk as a proxy for the investment risk borne by these private companies. Specifically, we first identified the 4-digit SIC code for each portfolio company based on the VEIC-SIC concordance provided by Dushnitsky and Shaver (2009). Then we calculated the standard deviation of the ROA, ROE and stock returns of public companies using accounting and stock information from Compustat and CRSP with the same 2-digit SIC code of the portfolio company in the year prior to a VC investment round. Lastly we took these industry risk variables of the public companies as proxies for the investment risk of the VC investment round. All our findings remained unaltered.

On portfolio company quality, around 25% of the portfolio companies voluntarily reported their market valuation after an investment round, which is a good predictor of their quality. Even though we do not know exactly the reasons for disclosing company market valuation, we argue that portfolio companies with better quality are more likely to disclose their market valuation. It is widely suggested in the accounting literature that voluntary information disclosure plays a role in mitigating asymmetric information and agency problems (Myers and Majluf, 1984). This reduces the cost of capital (Botosan, 1997) and IPO underpricing (Leone, *et al*., 2007) and increases market capitalization of earnings (Piotroski, 1999). Therefore, we used a dummy variable indicating whether a portfolio company discloses its post-round market valuation as one more proxy for company quality. We found that this variable had a positive effect on *Syndicate Size* at the 1% significance level. Again, all our existing results remained unchanged.

Thirdly, to investigate further whether our results were unduly influenced by outliers, we re-ran our regressions after winsorizing the top and bottom 1%, 2% and 5% for each variable. The results remained largely similar.

Fourthly, considering the possible impact of the NASDAQ bubble during 1999–2000, we re-ran our regressions by excluding these two years. The sample size was reduced to 31,368. Our results were qualitatively unchanged.

Finally, as shown in Table 1, the computer software industry and the California state made the largest contributions to our dataset respectively in terms of the portfolio company industry and location. To examine whether the inclusion of these special subsamples influenced our results, we ran our regressions yet again after excluding the software industry or
the California state, which reduced the sample size respectively to 31,115 and 27,731. The results again remained qualitatively unchanged.

5. Conclusion

As an effective investment strategy, investors often form a syndicate to invest jointly in a company. The unique feature of this paper is that it endogenizes the formation of the investment syndicate. We provide a theory on endogenous networks in investment syndication and analyze how several key factors such as risk aversion, productivity, risk and cost affect the incentives for and the investments by managers and investors. Since investment syndication is very popular in VC investments, we also apply our theory to VC investments and identify empirical evidence in support of our theory.

Unlike previous empirical papers on investment syndication or investment networks which have mostly focused on the role of the lead investor (such as Brander et al., 2002; Hochberg et al., 2007, 2010; Casamatta and Haritchabalet, 2007), this paper focused instead on strategic interactions between managers and investors. In our model, investment decisions, together with syndication and network, are determined in equilibrium in three stages. Most of the existing studies have focused only on the second stage. In addition, we demonstrated that network endogeneity is crucial. For example, productivity can have opposite effects on investment if the network is treated as exogenous instead of endogenous (Figures 1 and 2).

We have also applied our theory to VC investments. Using 40,395 domestic VC investment rounds made in 15,264 U.S. portfolio companies by U.S. VCs during 1985–2005 and controlling for various factors, we found empirical support for our theory.

Syndication occurs in many domains, including the VC industry, IPOs, bond issuing, real estate development, and large infrastructure projects (subways, railways, roads and airports). Although our empirical work focuses on VC, insights from our study provide an understanding of syndication as a form of network in general.

Appendix

In this appendix, we give the derivations for the expressions in (3), (6)–(8) and (9).
A.1. Derivation of (3)

The FOC for $I_i$ is

$$1 = p(a)u_i \left[ \frac{I_i}{I} \lambda(n)x(I) \right] \left[ \frac{\sum_{j \neq i} I_j - I_i}{\left( \sum_{j} I_j \right)^2} \lambda(n)x(I) + \frac{I_i}{\sum_{j} I_j} \lambda(n)x'(I) \right]$$

$$+ p(a) \sum_{i=2}^{n} u_i \left[ \frac{I_i}{I} \lambda(n)x(I) \right] \left[ -\frac{I_i}{\left( \sum_{j} I_j \right)^2} \lambda(n)x(I) + \frac{I_i}{\sum_{j} I_j} \lambda(n)x'(I) \right].$$

With the same risk aversion $\alpha$ for all the investors, we must have $I = nI_i$ for all $i$ in equilibrium. Then,

$$1 = p(a)u_i \left[ \frac{1}{n} \lambda(n)x(I) \right] \left[ \frac{I - \frac{1}{n}I}{I^2} \lambda(n)x(I) + \frac{1}{n} \lambda(n)x'(I) \right]$$

$$+ p(a) \sum_{i=2}^{n} u_i \left[ \frac{1}{n} \lambda(n)x(I) \right] \left[ -\frac{1}{nI^2} \lambda(n)x(I) + \frac{1}{n} \lambda(n)x'(I) \right]$$

$$= p(a)u_i \left[ \frac{1}{n} \lambda(n)x(I) \right] \left[ \frac{n - 1}{nI} \lambda(n)x(I) + \frac{1}{n} \lambda(n)x'(I) \right]$$

$$+ p(a) \sum_{i=2}^{n} u_i \left[ \frac{1}{n} \lambda(n)x(I) \right] \left[ -\frac{1}{nI} \lambda(n)x(I) + \frac{1}{n} \lambda(n)x'(I) \right],$$

implying

$$nI = n\lambda(n)p(a)x(I)u_i \left[ \frac{1}{n} \lambda(n)x(I) \right] + p(a) \sum_{i=1}^{n} u_i \left[ \frac{1}{n} \lambda(n)x(I) \right] [I\lambda(n)x'(I) - \lambda(n)x(I)].$$

With the same utility function for all, we have

$$nI = n\lambda(n)p(a)x(I)\left[ \frac{1}{n} \lambda(n)x(I) \right]^\alpha + p(a)n\left[ \frac{1}{n} \lambda(n)x(I) \right]^\alpha [I\lambda(n)x'(I) - \lambda(n)x(I)],$$

implying

$$\frac{I}{p(a)n} = \left[ \frac{\lambda(n)x(I)}{n} \right]^{-\alpha} + \left[ \frac{\lambda(n)x(I)}{n} \right]^{-\alpha} \left[ \frac{Lx'(I)}{x(I)} - 1 \right],$$

which implies (3).

A.2. Derivation of the Solution (6)–(8)

Condition $JC_2$ implies
\[
\left[ \frac{\lambda(n)}{n} \right]^{1-\alpha} a^n n^\delta = I^{1-\delta+\alpha \delta}.
\]  
(23)

By this, condition \( IC \) implies
\[
[1 - \lambda(n)] \gamma \left[ \frac{\lambda(n)}{n} \right]^{1-\alpha} a^n n^\delta = \beta a^{\beta - \gamma},
\]
implying
\[
a = \left[ 1 - \lambda(n) \right] \frac{\gamma}{\beta} \left[ \frac{\lambda(n)}{n} \right]^{1-\alpha} n^\delta \left[ \frac{\delta}{(\beta - \gamma)(1+\alpha \delta) - \beta} \right]^{1-\delta+\alpha \delta}.
\]  
(24)

By (23) and (24), we find
\[
I^{1-\delta+\alpha \delta} = \left( \frac{\lambda(n)}{n} \right)^{1-\alpha} n^\delta \left[ 1 - \lambda(n) \right] \frac{\gamma}{\beta} \left[ \frac{\lambda(n)}{n} \right]^{1-\alpha} n^\delta \left[ \frac{\delta}{(\beta - \gamma)(1+\alpha \delta) - \beta} \right]^{1-\delta+\alpha \delta}.
\]  
(25)

Then, the objective function in problem (4) becomes
\[
[1 - \lambda(n)] a^{\beta} I^{\delta} - a^{\delta} = \left[ \frac{\gamma}{\beta} \right]^{(1+\alpha \delta)} \frac{(\beta - \gamma)(1+\alpha \delta) - \beta}{(\beta - \gamma)(1+\alpha \delta) - \beta} - \left[ \frac{\gamma}{\beta} \right]^{(1-\delta+\alpha \delta)} \frac{(\beta - \gamma)(1+\alpha \delta) - \beta}{(\beta - \gamma)(1+\alpha \delta) - \beta}
\]
\[
\cdot [1 - \lambda(n)] \gamma \left[ \frac{\lambda(n)}{n} \right]^{1-\alpha} n^\delta \left[ \frac{\delta}{(\beta - \gamma)(1+\alpha \delta) - \beta} \right]^{1-\delta+\alpha \delta}.
\]  
(26)

Since \( \gamma < \beta \), we have
\[
\left[ \frac{\gamma}{\beta} \right]^{(1+\alpha \delta)} > \left[ \frac{\gamma}{\beta} \right]^{(1-\delta+\alpha \delta)},
\]
which guarantees a positive payoff for the EN. Then, problem (4) becomes
\[
\max_n \left\{ \frac{\lambda(n)}{n} \right\}^{(1-\alpha \delta)} [1 - \lambda(n)] \gamma \left[ \frac{\lambda(n)}{n} \right]^{1-\alpha} n^\delta \left[ \frac{\delta}{(\beta - \gamma)(1+\alpha \delta) - \beta} \right]^{1-\delta+\alpha \delta}.
\]

With \( \lambda(n) = \rho n \), the above problem becomes
\[
\max_n \rho^{(1-\delta+\alpha \delta)} n^{\beta} \frac{(\beta - \gamma)(1+\alpha \delta) - \beta}{(\beta - \gamma)(1+\alpha \delta) - \beta}.
\]

The first-order condition (FOC) then implies
\[ n^* = \frac{\delta}{(1 + \alpha \delta) \rho}. \]

The second-order condition (SOC) is satisfied. Hence, we are sure that the solution in (6) is correct. Then from (24), we find

\[
a^* = \left[ (1 - \rho n^*) \frac{\gamma}{\beta} (\rho^{1 - \alpha} n^* \delta)^{\frac{\delta}{(1 - \delta + \alpha \delta)}} \right]^{\frac{1 - \delta + \alpha \delta}{(\beta - \gamma)(1 + \alpha \delta) - \delta \rho}} = \frac{1 + \alpha \delta - \delta \gamma}{1 + \alpha \delta} \left( \rho^{\frac{\alpha}{\beta}} \frac{\delta^2}{1 + \alpha \delta} \right)^{\frac{1 - \delta + \alpha \delta}{(\beta - \gamma)(1 + \alpha \delta) - \delta \rho}}.
\]

By (25), we have

\[
I^{1 - \delta + \alpha \delta} = \rho^{(1 - \alpha) \frac{\gamma}{(\beta - \gamma)(1 + \alpha \delta) - \delta \rho}} \left( 1 + \alpha \delta - \delta \gamma \right)^{\frac{1 - \delta + \alpha \delta}{(\beta - \gamma)(1 + \alpha \delta) - \delta \rho}} \left( \rho^{\frac{\alpha}{\beta}} \frac{\delta^2}{1 + \alpha \delta} \right)^{\frac{1 - \delta + \alpha \delta}{(\beta - \gamma)(1 + \alpha \delta) - \delta \rho}},
\]

implying

\[
I^* = \left( 1 + \alpha \delta - \delta \gamma \right)^{\frac{\gamma}{(\beta - \gamma)(1 + \alpha \delta) - \delta \rho}} \left( \rho^{\frac{\alpha}{\beta}} \frac{\delta^2}{1 + \alpha \delta} \right)^{\frac{\beta - \gamma}{(\beta - \gamma)(1 + \alpha \delta) - \delta \rho}}.
\]

A.3. Derivation of (9)

With a fixed \( n \), (24) and (25) imply

\[
\hat{a} = \left( 1 - \rho n \right) \frac{\gamma}{\beta} (\rho^{1 - \alpha} n \delta)^{\frac{\delta}{(1 - \delta + \alpha \delta)}} \left( \frac{1 - \delta + \alpha \delta}{(\beta - \gamma)(1 + \alpha \delta) - \delta \rho} \right),
\]

\[
\hat{I}^{1 - \delta + \alpha \delta} = \rho^{(1 - \alpha) \frac{\gamma}{(\beta - \gamma)(1 + \alpha \delta) - \delta \rho}} \left( 1 - \rho n \right) \frac{\gamma}{\beta} (\rho^{1 - \alpha} n \delta)^{\frac{\delta}{(1 - \delta + \alpha \delta)}} \left( \frac{1 - \delta + \alpha \delta}{(\beta - \gamma)(1 + \alpha \delta) - \delta \rho} \right),
\]

which in turn imply the solution in (9).

A.4. Derivation of (10)

The FOC is
\[
\frac{1}{p(a)} = u \left[ \frac{\lambda(n)I_i}{\sum_j I_j} x \left( \sum_j I_j \right) - \frac{\lambda(n)I_i}{\sum_j I_j} x' \left( \sum_j I_j \right) \right]
\]
or
\[
\frac{1}{p(a)} = \lambda(n)u' \left[ \frac{\lambda(n)I_i}{I} x(I) - \frac{1}{I} x(I) + \frac{I}{I^2} x'(I) \right].
\]

Since we must have \( I_i = I / n \) for all \( i \) in equilibrium, this FOC becomes
\[
\frac{1}{p(a)} = \lambda(n) \left[ \frac{\lambda(n)x(I)}{n} \right] ^{-\alpha} \left[ \frac{n-1}{nI} x(I) + x'(I) \right],
\]
which implies (10).

A.5. Derivation of the Nash Investment Solution

Condition \( IC_2 \) implies
\[
1 = a^\gamma \left( \rho I^\delta \right)^{1-\alpha} \left[ \frac{n-1}{I} + \frac{\delta}{I} \right],
\]
implying
\[
I^{1-\delta+\alpha \delta} = a^\gamma \rho^{1-\alpha} (n + \delta - 1).
\] (27)

By this, condition \( IC_1 \) implies
\[
(1 - n\rho)^\gamma \left[ a^\gamma \rho^{1-\alpha} (n + \delta - 1) \right]^{\frac{\delta}{1-\delta+\alpha \delta}} = \beta a^{\beta-\gamma},
\]
implying
\[
(1 - n\rho)^\gamma \beta^\alpha \left[ \rho^{1-\alpha} (n + \delta - 1) \right]^{\frac{\delta}{1-\delta+\alpha \delta}} = a^\frac{\beta-\gamma}{\beta} \left[ \frac{\delta}{1-\delta+\alpha \delta} \right],
\]
implying
\[
\hat{a} = \left\{ \frac{\gamma}{\beta} (1 - n\rho) \left[ \rho^{1-\alpha} (n + \delta - 1) \right]^{\frac{\delta}{1-\delta+\alpha \delta}} \right\} \left( \frac{1-\delta+\alpha \delta}{(\beta-\gamma)(1+\alpha \delta) - \beta \delta} \right).
\] (28)

By (27) and (28),
\[ I^{1-\delta+\alpha\delta} = \rho^{1-\alpha}(n + \delta - 1) \frac{\gamma}{\beta} \left[ (1 - n\rho)\left(\rho^{1-\alpha}(n + \delta - 1)\right)\right]^{\frac{\delta}{(1-\delta+\alpha\delta)}} \left(\frac{(1-\delta+\alpha\delta)\gamma}{(\beta-\gamma)(1+\alpha\delta)-\beta}\right) \]

(29)

Then,

\[ \hat{I} = \left[\rho^{1-\alpha}(n + \delta - 1)\right]^{\frac{(1-\delta+\alpha\delta)\gamma}{(\beta-\gamma)(1+\alpha\delta)-\beta}} \left[1 - n\rho\right]^{\frac{\gamma}{\beta}} \left[\left(\rho^{1-\alpha}(n + \delta - 1)\right)\right]^{\frac{\delta}{(1-\delta+\alpha\delta)}} \]

Then, the objective function in problem (11) becomes

\[ (1 - \rho n)\alpha^\gamma I^\delta - a^\beta = (1 - \rho n) \left[ \frac{\gamma}{\beta} \left[ (1 - n\rho)\left(\rho^{1-\alpha}(n + \delta - 1)\right)\right]^{\frac{\delta}{(1-\delta+\alpha\delta)}} \right]^{\left(\frac{(1-\delta+\alpha\delta)\gamma}{(\beta-\gamma)(1+\alpha\delta)-\beta}\right)} \]

\[ \cdot \left[\rho^{1-\alpha}(n + \delta - 1)\right]^{\frac{(1-\delta+\alpha\delta)\gamma}{(\beta-\gamma)(1+\alpha\delta)-\beta}} \left[1 - n\rho\right]^{\frac{\gamma}{\beta}} \left[\left(\rho^{1-\alpha}(n + \delta - 1)\right)\right]^{\frac{\delta}{(1-\delta+\alpha\delta)}} \]

(30)

\[ - \left[\frac{\gamma}{\beta} \left(1 - n\rho\right)\left[\rho^{1-\alpha}(n + \delta - 1)\right]^{\frac{\delta}{(1-\delta+\alpha\delta)}} \right]^{\frac{\gamma}{\beta}} \left[\left(\rho^{1-\alpha}(n + \delta - 1)\right)\right]^{\frac{\delta}{(1-\delta+\alpha\delta)}} \]

Since \( \gamma < \beta \), we have

\[ \left[\frac{\gamma}{\beta}\right]^{\frac{(1+\alpha\delta)\gamma}{(\beta-\gamma)(1+\alpha\delta)-\beta}} > \left[\frac{\gamma}{\beta}\right]^{\frac{(1-\delta+\alpha\delta)\gamma}{(\beta-\gamma)(1+\alpha\delta)-\beta}} \]

which guarantees a positive payoff for the EN. Then, problem (11) becomes

\[ \max_n \left[ (1 - n\rho)\left(\rho^{1-\alpha}(n + \delta - 1)\right)\right]^{\frac{\delta}{(1-\delta+\alpha\delta)}} \]

The first-order condition (FOC) is

\[ \frac{\delta}{n + \delta - 1} = \rho \frac{1-\delta + \alpha \delta}{1-\rho n} \]

implying

\[ n^* = \frac{\delta + \rho(1-\delta)(1+\alpha\delta - \delta)}{(1+\alpha\delta)\rho}. \]

The second-order condition (SOC) is satisfied. Hence, we are sure that this solution is correct.
A.6. Proof of Proposition 1

Part (a)

We have

\[(\beta - \gamma)(1 + \alpha\delta) - \beta\delta > 0 \iff 1 - \frac{\gamma}{\beta} > \frac{\delta}{1 + \alpha\delta} \quad (31)\]

If \(1 - \frac{\gamma}{\beta} > \frac{\delta}{1 + \alpha\delta}\), then

\[I^* \geq \hat{I}(1) \iff \left(1 + \alpha\delta - \delta\right)^{\gamma - \gamma} \left(1 + \alpha\delta\right)^\beta \geq \frac{\delta}{1 + \alpha\delta} \quad (32)\]

or

\[(1 - \rho)\left(\frac{\beta - \gamma}{\delta}\right)\left(1 + \alpha\delta\right)^\gamma \leq 1 + \alpha\delta - \delta. \quad (33)\]

Hence, if \(1 - \frac{\gamma}{\beta} > \frac{\delta}{1 + \alpha\delta}\), then

\[I^* \geq \hat{I}(1) \iff (1 - \rho)\left(\frac{\beta - \gamma}{\delta}\right)\left(1 + \alpha\delta\right)^\gamma \leq 1 + \alpha\delta - \delta; \]

and if \(1 - \frac{\gamma}{\beta} < \frac{\delta}{1 + \alpha\delta}\), then

\[I^* \leq \hat{I}(1) \iff (1 - \rho)\left(\frac{\beta - \gamma}{\delta}\right)\left(1 + \alpha\delta\right)^\gamma \leq 1 + \alpha\delta - \delta. \quad (33)\]

We also have

\[\frac{\partial}{\partial \rho}\left[(1 - \rho)^{\beta - \gamma}\right] = \frac{\beta - \gamma}{\gamma} (1 - \rho)^{\beta - 2} - \rho^{\beta - \gamma} \geq 0 \iff \rho \leq 1 - \frac{\gamma}{\beta}. \]

Therefore, if \(\rho \leq 1 - \frac{\gamma}{\beta}\), then \(\rho \leq \frac{\delta}{1 + \alpha\delta}\) implies

\[(1 - \rho)\left(\frac{\beta - \gamma}{\delta}\right)\left(1 + \alpha\delta\right)^\gamma \leq \left[1 - \frac{\delta}{1 + \alpha\delta}\right]^\gamma \left(1 + \alpha\delta\right)^\gamma = 1 + \alpha\delta - \delta. \]

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That is, if $\rho \leq 1 - \frac{\gamma}{\beta}$ and $1 - \frac{\gamma}{\beta} > \frac{\delta}{1 + \alpha \delta}$, given the condition $\rho \leq \frac{\delta}{1 + \alpha \delta}$ (i.e., $n^* \geq 1$), we have $I^* \geq \hat{I}(1)$. But, if $\rho \leq 1 - \frac{\gamma}{\beta}$ and $1 - \frac{\gamma}{\beta} \leq \frac{\delta}{1 + \alpha \delta}$, given the condition $\rho \leq \frac{\delta}{1 + \alpha \delta}$, we have $I^* \leq \hat{I}(1)$.

On the other hand, if $\rho \geq 1 - \frac{\gamma}{\beta}$, then $\rho \leq \frac{\delta}{1 + \alpha \delta}$ implies

$$
(1 - \rho)\left(\frac{\beta}{\delta}\right)^{\gamma}(1 + \alpha \delta)^{\beta} \geq \left[1 - \frac{\delta}{1 + \alpha \delta}\right] \left(\frac{1}{1 + \alpha \delta}\right)^{\gamma}(1 + \alpha \delta)^{\beta} = 1 + \alpha \delta - \delta. \quad (34)
$$

Given $\rho \leq \frac{\delta}{1 + \alpha \delta}$, if $\rho \geq 1 - \frac{\gamma}{\beta}$ then we have $1 - \frac{\gamma}{\beta} \leq \frac{\delta}{1 + \alpha \delta}$. By (33) and (34), we then have $I^* \geq \hat{I}(1)$. Part (a) is proven.

**Part (b)**

We have

$$
(\beta - \gamma)(1 + \alpha \delta) - \beta \delta > 0 \quad \Leftrightarrow \quad 1 - \frac{\gamma}{\beta} > \frac{\delta}{1 + \alpha \delta}. \quad (35)
$$

If $1 - \frac{\gamma}{\beta} > \frac{\delta}{1 + \alpha \delta}$, then

$$
a^* > \hat{a}(1) \quad \Leftrightarrow \quad \left(1 + \alpha \delta - \frac{\delta}{\beta}\right)^{1+\alpha \delta} \left(\frac{\rho}{\delta}\right)^{1+\alpha \delta} \left(\frac{1}{1 + \alpha \delta}\right)^{\delta} \left(1 - \rho\right)^{\gamma} \left(\frac{\gamma}{\beta}\right)^{1+\alpha \delta} \left(\delta \rho^{1 - \alpha}\right)^{\delta},
$$

or

$$
(1 - \rho)\left(\frac{\rho}{\delta}\right)^{1+\alpha \delta} (1 + \alpha \delta)^{1+\alpha \delta} < 1 + \alpha \delta - \delta.
$$

Hence, if $1 - \frac{\gamma}{\beta} > \frac{\delta}{1 + \alpha \delta}$, then

$$
a^* \geq \hat{a}(1) \quad \Leftrightarrow \quad (1 - \rho)\left(\frac{\rho}{\delta}\right)^{1+\alpha \delta} (1 + \alpha \delta)^{1+\alpha \delta} \leq 1 + \alpha \delta - \delta; \quad (36)
$$

and if $1 - \frac{\gamma}{\beta} \leq \frac{\delta}{1 + \alpha \delta}$, then
We also have
\[
\frac{\partial}{\partial \rho} \left[ (1 - \rho)^{\delta} (1 + \alpha \delta)^{\frac{1 + \alpha \delta}{1 - \delta + \alpha \delta}} \right] = \frac{\delta}{1 - \delta + \alpha \delta} (1 - \rho) \rho^{\delta} (1 + \alpha \delta)^{-\delta} - \rho^{\delta} (1 + \alpha \delta)^{-\delta} \geq 0 \iff \rho \leq \frac{\delta}{1 + \alpha \delta}.
\]  

The given condition is \( n^* \geq 1 \) or \( \rho \leq \frac{\delta}{1 + \alpha \delta} \), which ensures that \( (1 - \rho) \rho^{\delta} (1 + \alpha \delta)^{\frac{1 + \alpha \delta}{1 - \delta + \alpha \delta}} \) is increasing in \( \rho \). Then, \( \rho \leq \frac{\delta}{1 + \alpha \delta} \) implies
\[
(1 - \rho)^{\delta} (1 + \alpha \delta)^{\frac{1 + \alpha \delta}{1 - \delta + \alpha \delta}} \leq \left( \frac{1 - \delta}{1 + \alpha \delta} \right)^{\delta} (1 + \alpha \delta)^{\frac{1 + \alpha \delta}{1 - \delta + \alpha \delta}} = 1 + \alpha \delta - \delta.
\]

Hence, if \( 1 - \frac{\gamma}{\beta} > \frac{\delta}{1 + \alpha \delta} \), by (36), we have \( a^* \geq \hat{a}(1) \); and if \( 1 - \frac{\gamma}{\beta} < \frac{\delta}{1 + \alpha \delta} \), by (37), we have \( a^* \leq \hat{a}(1) \). Part (b) is proven.

References


Table 1. The Sample Distribution

The sample consisted of 40,395 VC investment rounds led by 2,373 lead VCs and made in 15,264 portfolio companies that received their initial VC funding during 1985–2005 and for which there were relevant data in the database. The table presents the distribution of VC investment rounds by funding year and the industry, location and development stage of the portfolio company. The number of observations and the corresponding percentages are listed.

<table>
<thead>
<tr>
<th>Year</th>
<th>Obs.</th>
<th>Percent</th>
<th>Industry</th>
<th>Obs.</th>
<th>Percent</th>
<th>Location</th>
<th>Obs.</th>
<th>Percent</th>
<th>Stage</th>
<th>Obs.</th>
<th>Percent</th>
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<td>Agriculture/Forestry/Fishing</td>
<td>70</td>
<td>0.17</td>
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<td>36.79</td>
<td>Seed Stage</td>
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<td>Biotechnology</td>
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<td>4605</td>
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<td>Early Stage</td>
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<td>Texas</td>
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### Table 2. Variable Definitions, Measures and Data Sources

The table presents definitions and measures for the dependent, independent and control variables. Dummy variables are indicated by *. Variables used as the natural logarithm are indicated by **.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Definition and Measurement</th>
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<tr>
<td><strong>Dependent Variables</strong></td>
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<tr>
<td>Syndicate Size**</td>
<td>The logarithm of the number of VCs participating in an investment round.</td>
</tr>
<tr>
<td>Network Degree</td>
<td>The normalized number of VCs that a lead VC had syndicated with in the 5 years prior to the current investment round.</td>
</tr>
<tr>
<td>Network Outdegree</td>
<td>The normalized number of VCs that a lead VC had invited into her syndicates in the 5 years prior to the current investment round.</td>
</tr>
<tr>
<td>Network Indegree</td>
<td>The normalized number of VCs that a lead VC had been invited into their syndicates in the 5 years prior to the current investment round.</td>
</tr>
<tr>
<td><strong>Investment Risk:</strong></td>
<td></td>
</tr>
<tr>
<td>Company Age**</td>
<td>The logarithm of the age of a portfolio company at the current investment round. The age of a portfolio company is the number of years between its founding and the year of the current investment round.</td>
</tr>
<tr>
<td>Industry Distance (%)</td>
<td>The proportion of investment rounds made previously by a lead VC that were not made in the given portfolio company’s industry.</td>
</tr>
<tr>
<td>Stage Distance (%)</td>
<td>The proportion of investment rounds made previously by a lead VC that were not made in the same development stage as the given portfolio company.</td>
</tr>
<tr>
<td>Geographic Distance**</td>
<td>The logarithm of the geographic distance (in kilometers) between the resident state of a portfolio company and its lead VC.</td>
</tr>
<tr>
<td><strong>Portfolio Company Quality:</strong></td>
<td></td>
</tr>
<tr>
<td>Total VC Funding**</td>
<td>The logarithm of one plus the total VC funding across all financing rounds.</td>
</tr>
<tr>
<td>Quality Indicator*</td>
<td>A dummy variable indicating whether the VC-backed portfolio company went public or was acquired before the end of 2009.</td>
</tr>
<tr>
<td><strong>Lead VC Type:</strong></td>
<td></td>
</tr>
<tr>
<td>Corporate VC Indicator*</td>
<td>A dummy variable indicating whether a lead VC firm was affiliated with a corporation.</td>
</tr>
<tr>
<td>Institutional VC Indicator*</td>
<td>A dummy variable indicating whether a lead VC firm was affiliated with an institution.</td>
</tr>
<tr>
<td>Government VC Indicator*</td>
<td>A dummy variable indicating whether a lead VC firm was affiliated with a government.</td>
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</table>
Table 3. Summary Statistics of VC Investment Rounds

The table presents summary statistics describing 40,395 VC investment rounds made in those portfolio companies that received initial VC funding during 1985–2005 and for which there were relevant data in the database. The definitions, measures and data sources of the variables are described in Table 2. The quartiles, means, standard deviations and the number of observations are presented.

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<tr>
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<tr>
<td>Company Age (years)</td>
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<td>Industry Distance (%)</td>
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Table 4. Correlation Matrix

The table presents the Spearman and Pearson correlation matrices among all the variables respectively in the upper and lower diagonals. The sample consisted of 40,395 VC investment rounds made in those portfolio companies that received initial VC funding during 1985–2005 and for which there were relevant data in the database. The definitions, measures and data sources of the variables are described in Table 2. The significance level at 5% is indicated by *.

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<td>-0.03*</td>
<td>0.06*</td>
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<td>-0.09*</td>
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<td>-0.007</td>
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<td>0.004</td>
<td>0.04*</td>
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<td>13 Government VC Indicator</td>
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<td>0.02*</td>
<td>0.01*</td>
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<td>-0.04*</td>
<td>-0.06*</td>
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</table>
Table 5. Regression Results

The sample consisted of 40,395 VC investment rounds made in those portfolio companies that received initial VC funding during 1995–2005 and for which there were relevant data in the databases. The table presents OLS regression results relating the dependent variable ( Syndication Size, Network Degree, Network Outdegree or Network Indegree) to the factors including investment risk and portfolio company quality as well as other control variables. The definitions, measures and data sources of the variables are described in Table 2. Funding year, industry and round sequence fixed effects were included in all the regressions (not reported). Intercepts are not reported. Robust t-values are in parentheses. The significance levels at 1%, 5% and 10% are identified by ***, ** and *, respectively.

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<th>Network Indegree</th>
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<td>2</td>
<td>3</td>
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<td>(5.54)***</td>
<td>(4.68)***</td>
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<td>(10.73)***</td>
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<td>Total VC Funding</td>
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<td>(54.89)***</td>
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