Venture Capital Syndicate Network: 
A Game-theoretic Model

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Abstract

Venture capital has become a major funding vehicle for many start-up firms. The venture capital industry is characterized by the co-investment activities among the venture capital firms. The venture capital syndicates network is a byproduct of them. There have been several empirical papers that dealt with this syndicates network of venture capital industry. Yet a theoretical model of venture capital syndicates network is scanty. This paper tries to come up with a game-theoretical model that utilizes the results of the empirical studies on the venture capital network as adapting the network formation theories recently developed in economics. Following the Jackson-van den Nouweland network formation rules, we develop a sequential network formation game for the venture capital syndicates network. We show that a center-sponsored star is a subgame-perfect equilibrium network architecture for local networks. We conclude the paper as we discuss several future research topics.

1 Introduction

Venture capital has become a major funding source for many start-ups in the US and other developed countries. With the steady growth of venture capital industry\(^1\) and more crucial role played by this industry for the economic growth of the whole economy, literature on venture capital has flourished during the past two decades. While most of corporate governance and control issues due to severe informational asymmetry and high risks inherent in venture capital industry (or VC industry) have been studied extensively and almost completely analyzed so far, a less-studied control mechanism\(^2\) of this industry - syndication of investments - has begun to attract attentions from several financial economists. For example, Hochberg, Ljungqvist, and LU (2007) show that well-networked venture capital firms are more likely to exit successfully in terms of successful IPOs and sales of the start-ups. This correlation between the network and financial performance is one of the topics studied in literature on venture capital industry. Sorenson and Stuart (2001, 2005) deal with the venture capital industry in social network analysis perspective. Furthermore, Burt

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\(^1\)According to the MoneyTree Report, venture capital investment reached $29.4 billion in 2007, and all four quarterly investments have been above $7 billion for the first time since 2001.

\(^2\)Sahlman (1990) describes the three control mechanisms common to all the venture capital financing: the convertible securities, syndication of investments, and the staging of capital infusions.
(1992), Granovetter (1973, 1985) and Podolny (1993, 2001) have, to name a few, provided the sociological basis for many research papers on the venture capital industry.

Recently there appear several economics papers directly studying the venture capital networks. Zheng (2004) uses social network analysis method to extensively analyze the venture capital networks. Kuan (2005) and Barney and Hopp (2007) analyze the reciprocity of venture capital syndicates and the syndicate partner selection problem, respectively. Especially, Piskorski (2004) complements the Podolny’s papers on venture capital networks while decomposing the centrality of network positions into power and status. These papers significantly help us understand the network characteristics of the venture capital industry. Yet the industrial organization of the venture capital industry has not been studied much. Hochberg, Ljungqvist, and Lu (2007b) is the first research paper, to the best of my knowledge, that tackles the industrial organization issue of venture capital industry. They argue that networking in this venture capital industry works as a barrier to entry to new venture capital firms (VC firms) so that this networking feature of capital supply in this industry helps raise the bargaining power of incumbent venture capital firms against start-up entrepreneurs. Most of the above papers are empirical ones using rare data sets of venture capital industry. Yet there have been very scanty research papers that try to model theoretically the venture capital syndicates network. Existing papers usually adopt the principal-agent paradigm to analyze the venture capital syndicates. And a theoretical model of networking via syndicates is not easy to find.

While social network analysis has been long developed in sociology since 1930s, sociological approaches do not pay much attention to the strategic network formation. By the way, mathematicians and statisticians have studied the network formation; their research outcomes have played a crucial role in developing the network analysis of economists. According to these papers the network formation is a byproduct of sociological and physical interactions among players in a society or a system. And, in turn, the network position or connectedness of an economic agent in a network significantly affects her economic and social actions. It has not been long since the strategic network formation has been extensively studied among game theorists in economics. Jackson and Wolinsky (1996) is the first to study network formation as outcomes of individual incentives to form or sever a link in a game-theoretic perspective. This network literature in economics can be classified into two distinct groups: cooperative game-theoretic network formation models and noncooperative game-theoretic network architecture models. The first group of studies, following the Jackson-Wolinsky (1996)’s approach, tackles the problems of stability and efficiency of various networks. Jackson and van den Nouweland (2005) introduce more realistic network formation rules that are bilateral network formation and unilateral network deletion rules.
with the multiple network activities at a time. These two network formation rules share the same mutual-consents condition for adding a new network, which is a hurdle for using noncooperative game theories to study the network formation\textsuperscript{9}. Using a cooperative game approach, Slikker and van den Nouweland (2000) study the network formation with costs for establishing links. Yet this cooperative game framework does not provide any network architecture results.

Bala and Goyal (2000) is a representative paper in the second group of noncooperative endogenous network formation papers. Their paper uses a simultaneous move game with homogeneous players. Considering one-way flow and two-way flow of benefits through networking as well as models with decay or without decay, Bala and Goyal characterize the strict Nash networks for various specifications. Galeotti et. al. (2006) also follow the noncooperative network formation approach while introducing the value and cost heterogeneity\textsuperscript{10}. They show that the heterogeneous-agent model has a strict Nash network, which is a center-sponsored star and the insider-outsider model has a generalized center-sponsored star as a strict Nash network. Still the bilateral network formation framework is not adopted by these two papers\textsuperscript{11}. Hojman and Szeidl (2004) build a noncooperative model of network formation with network externalities exhibiting decreasing returns. With heterogeneity among players they find a interlinked stars or separation as an equilibrium network architecture. In their model, however, the network is a collection of ‘non-directed’ links, which is not relevant for venture capital syndicates network formation. Chowdhurry (2007) is closest to our model in that it is a sequential network formation model. But this model considers the sequential decision by each and every player in the network one by one. And the heterogeneity among players are not fully developed yet\textsuperscript{12}.

This paper tries to fill up the void - the lack of theoretical model of venture capital syndicates network. We adapt the theoretical models developed in network formation game literature in order to reflect the network characteristics of venture capital syndicates network. As mentioned above, our model incorporates the benefits and costs heterogeneity not just from agent types\textsuperscript{13} but also from partner-specific features (with which VC firm one would form a syndicate connection). These double-heterogeneity feature of syndicates network provides critical conditions for the network architecture of local VC syndicates network. In order to exploit the noncooperative game model as well as to maintain the bilateral network formation rule, we build a sequential network formation model with three stages. At stage 0, the Nature assigns each VC firm a start-up project with either higher expected payoff or lower expected payoff. This information (history) is common knowledge at the end of stage 0. At stage 1 all the VC firms simultaneously decide whether or not to extend a syndicate offer and, if so, which VC firm(s) one would extend syndicate invi-

\textsuperscript{9} Jackson (2005) mentions the problems in modeling this bilateral network formation via noncooperative game framework in detail.

\textsuperscript{10} These heterogeneous values and costs are dependent on the player’s types, not on syndicate partner. In this regard this paper extends the concept of heterogeneity among players since our model uses the partner-specific benefit- and cost- heterogeneity.

\textsuperscript{11} The two models are dealing with a directed network, which can be formed by the action of only one of two agents.

\textsuperscript{12} Chowdhurry assumes that there are two types of agent in a network: high type and low type in terms of degree of being connected. The proposition 4 (in p. 14) shows a similar result to our model - a complete star will be the equilibrium network structure.

\textsuperscript{13} These types are determined according to the profitability of a project assigned to the agent by the Nature at the beginning of the network formation game.
tation(s) to. To simplify the network formation process, we formulate the model to assure that every VC firm receives at least one offer from its neighboring VC firms at the end of stage 1. Thus, at stage 2, all the VC firms with at least one syndicate offer decides whether or not to accept the offer; that is, with which VC firm one would form a syndicate while managing together the inviting party’s start-up project. Using backward induction, we seek a subgame-perfect Nash network equilibrium from scratch. That is, at stage 2, all VC firms in an empty local network are already assigned a project with either high profitability or low profitability. Since a high-value project gives additional advantage in terms of the cost of network formation, all the VC firms with a lower-value project prefer to form a syndicate with the VC firm with a high-value project. Network formation process is unilateral at stage 2 given that all VC firms have at least one invitation offer from other. And if a VC firm decides to accept a syndicate invitation from one VC firm, there will be a syndicate connection at the end of stage 2. We note that this connection is essentially a bilateral-consent network. Since only one acceptance response is possible at stage 2, a VC firm with a low-value project will have only one network connection with some other VC firm at the end of the game. By the way, for the VC firm with a high-value project, it would extend the invitations to any VC firm in its neighborhood, knowing that no VC firm will ever decline its offer at stage 2. This high-project VC firm would not wait until stage 2 in order to accept the offers from one of the other low-value project VC firms. Since that action pair (or strategy) would only make it give up its high-value project while forcing it to manage the low-value projects from one of the low-value project VC firms. Thus, at stage 2, this high-value project VC firm would not accept any invitation offer and at stage 1, it will extend the invitation offer to all the VC firms in its neighborhood. At the end of the game, a local network reaches an equilibrium network architecture, which is a center-sponsored star. In this paper we show that the local venture capital syndicate network is a star structure. That is, one stellar performer (VC firm) is located at the center of the local network, and all the other VC firms are peripheral and directly connected only to the central VC firm. These peripheral VC firms are indirectly connected only through the central VC firm. This outcome is consistent with the empirical findings of Zheng(2004); Zheng shows that most of network connections among VC firms are indirect, and the prominent VC firm holds the 'structural hole' position, which emphasizes the brokerage function of a central player in a network. Even though our model is a simple sequential game, it is interesting because only with the heterogeneity among VC firms that are reflected in network benefits and costs can we show the emergence of a star structure in local VC networks. Yet we acknowledge the tradeoff we made in order to simplify the network formation game.

First of all, we introduced the Nature at stage 0 in order to simplify the start-up project selection process. In reality this process can be very costly, especially for inexperienced VC firms. For a more realistic model, we need to model the strategic behavior during this project

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14 And for VC firms with a lower-value project, the decision also involves ‘from which VC firm they would accept an invitation offer’.

15 Here we assume that every VC firm can accept only one offer.

16 We assume that there is only one VC firm that gets assigned this high-value project at stage 0.

17 We will use syndicate connections, connections and network connections interchangeably.

18 This bilateral agreement feature is difficult to model and we cannot easily find a model dealing with a network formation via this kind of connection (a directed and heterogeneous arc), especially among the noncooperative network formation game models.

19 This result is similar to that of Hojman and Szeidl (2004).
search process. It is plausible that the search cost may be introduced and the probability of locating a high-value project may be assumed to be a function of a VC firm’s effort level and one’s network position. In addition, the value of a project can be assumed to be stochastic so that we may modify the network payoff function as an expected payoff function including a search-cost function. Secondly, we deliberately choose a noncooperative game model in order to seek a network architecture problem in VC industry. This goal brought in the issue of how to model a bilateral-agreement network formation without relying on a cooperative game model. We evade this issue as introducing the multi-stage game with the assumption on the strategic situation of second stage game. That is, using the backward induction for our sequential game model, we assume that each and every VC firm in a local group has received at least one invitation offer at the beginning of stage 2. This assumption turns our second stage game into a noncooperative, directed network formation game under unilateral network formation rule. Thirdly, Another important assumption behind our model is about the causal relationship between how to take the central position in a network and to have power and status in a network and how to become financially successful in investing. One may think that the central position in a network gives that player power and status in the network and thus more chance to be a successful investor in this risky business. And the other may think of the causality in reverse; a VC firm that had managed start-up projects in the past was able to build a reputation and its local network as forming a syndicate in one or two start-up projects. Our choice in this paper is the latter one. And we begin seeking our network architecture of a local VC network from the scratch with the heterogeneity of start-up projects’ values.

Yet there are many research topics left for future research. For example, we still lack the proper network dynamic model of venture capital industry. Sorensen and Stuart (2005) empirically study the evolution of venture capital syndicates network and two exogenous factors could affect the evolution of the venture capital syndicate network; one is some attractive events (investment opportunities) and the other is experimentation by a central position VC firm to form a syndicate with a low-risk project VC firm in distance. Their results also call for a dynamic network formation model of venture capital industry, which incorporates both the bilateral network formation and general heterogeneity among venture capital firms in a dynamic setting.

The remainder of the paper proceeds as follows. In section 2 we review and summarize the network features of venture capital industry from the empirical VC studies and literature of the social network analysis in sociology. In section 3, we set up a basic model and in section 4 we seek the network architecture of local venture capital syndicates network. In section 5 we conclude the paper as suggesting a few future research topics for both of theoretical and empirical research.

2 Characteristics of Venture Capital Syndicate Network

From the literature in sociology and economics, we find a few important features of the venture capital co-investments network for our modeling purpose.

First, the VC syndicate network as a whole is a byproduct of all the individual venture capital firms’ strategic interactions. Thus, we need to apply noncooperative, strategic network formation rules to this network. However, this implies that we have to adopt a sequential game framework for the network architecture study since we must maintain the
bilateral network formation aspect of venture capital syndicates. Unlike the staging of
the capital infusions, the stages in our game-theoretic model do not exactly match with the
physical time.

Second, the venture capital syndicate network is characterized by its heterogeneity
among venture capital firms. Due to past track records there exist a smaller number of
stellar performers (or prominent venture capital firms). These venture capital firms enjoy
the status and the power in relationships with other local venture capital firms. This
heterogeneity in network positions among venture capital firms is reflected in the network
payoff function as the heterogeneity in values and costs of network formation. And ultimately,
the heterogeneity of VC firms in terms of network positions plays a critical role in
determining the network architecture of the venture capital industry. Third, the venture
capital co-investments are characterized by the reciprocity of deal flows. Barney and Hopp
(2007) find that previous relationships between two VC firms affect the likelihood of collabora-
tion positively. That is, the previous cooperation experience facilitate development of
trust among economic agents, which, in turn, provides the foundation for future cooperation.
Also this distinctive feature of VC co-investments has significant positive effects on
syndicate partner selection as observed by Kuan (2005). She adapts the hostage theory by
Williamson (1999) to this venture capital syndication context. A non-lead VC in a syndi-
cate differ from a limited partners in the typical limited partnerships in a fundamental way.
It is highly probable that non-lead VC firms in one project may lead another deal in the
near future. This reciprocity of deal flows mitigate the asymmetric information problems
greatly since this possibility of future role exchanges creates the symmetric vulnerability -
the hostage exchange. Another empirical support of this reciprocity is found in Hochberg,
Ljungqvist, and Lu (2007a). They also identify the prevalent reciprocity in venture capital
co-investments. The venture capital firms that invited many VC firms in the past are more
likely to be rewarded with more co-investment opportunities in the future.

corporate venture capital network is not cohesive in the sense that the network is strate-
gically constructed in order to benefit financially. It has been argued that cohesive social
networks severely limit the function of information sharing, which is one of the important
motivations to form a network. Accordingly, the venture capital network mainly consists
of “weak ties” among the VC firms. Furthermore prominent VC firms (that is VC firms
with power and status) hold “structural hole” position in the network. Therefore, the

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20 As discussed above, the cooperative game approach does not provide any results about the network architecture.
21 Admati and Pfleiderer (1994) analyze the rationale for the venture capital syndication and a later-
stage syndication helps the incumbent venture capitalist under the fixed-fraction contract make the optimal
continuation decision.
22 As discussed above, Piskorski (2004) differentiates the VC firms with the status from those with the
power according to their network positions. But, in this paper, the distinction is not relevant for our modeling
purpose. Thus, in this paper, we consider a VC firm with power and status equal to a prominent VC firm
or a powerful VC.
23 Co-investments and syndicates are interchangeably used in this paper.
25 This empirical study uses the data from early 1970s. See Kuan (2005) for details.
27 See Uzzi (1996, 1999); a cohesive network may potentially hurt its members financially
28 Burt (1992) describes the structural hole as “a relationship of non-redundancy between two contacts”; each structural hole is a path to control of resources and information benefits.
prominent VC firms also play a role of connecting other VC firms in the network. With these observations and results we build a sequential network formation game model in section 2.

3 Model

We note that a syndicate network is formed between two venture capital firms when a venture capital firm initiates a syndicate offer to other venture capital firms and one of the respondent venture capital firms accepts the invitation to form a syndicate. In order to model the mutual agreements to form a syndicate in this context, we consider a sequential network formation game. These multiple bilateral network-formation and unilateral network-deletion rules are so-called Jackson-van den Nouweland rules. As discussed in Jackson (2005), this bilateral network-formation rule is a hurdle for using “any off-the-shelf noncooperative game-theoretic approach.” Jackson (2005) suggests that either a coalitional equilibrium concept or an extensive-form game model is necessary to model this mutual-consent network formation situation. He also mentions the ad hoc nature of the extensive-form game and the inevitable dependency of the model outcome on the details of the protocol. However, we use an extensive-form game model. This is because, first, the primary goal of this paper is to find the network architecture of the venture capital industry. More importantly, in order to incorporate the particular network characteristics of venture capital syndicates, the model we study in this context will be inevitably seen as ‘ad hoc’ when compared to other theoretical network formation models. In this paper, we try to find out the network architecture of the venture capital industry, which have been empirically studied while providing specific restrictions on network formation game. Now we begin with the basic assumptions on this sequential network formation game model.

3.1 The Basic Environment

Here we assume that there is no pre-existing network in the venture capital industry. There are sufficiently large number of venture capital firms, and the set of nodes (\(D\)) are equal to the set of players, denoted by \(N = \{1, 2, \ldots, n\}\) with \(i\) and \(j\) being typical venture capital firms. The cardinality of the set, \(N\), is denoted by \(|N| = n\). We restrict our attention to a local network in the whole venture capital syndicate network. That is, we assume that there are several local groups of venture capital firms in the whole venture capital industry. Our main goal in this paper is to find out the network architecture of a local group of venture capital firms. A syndicate is formed as \(i\) and \(j\) reach a mutual agreement to form a co-investment partnership; then we denote a syndicate connection initiated by \(i\) and accepted by \(j\) as \(g_{ij}\). A local venture capital network, denoted by \(G^l\), is a collection of these syndicate connections formed by mutual consents. The set of whole venture capital

\(29\) In reality, the size of syndicate is usually greater than 3; that is, at least three venture capital firms co-invest in a start-up project. But here we focus on the first step of the whole syndication process - in which the lead venture capital invites its first syndicate partner. The sequential nature of our multi-stage game may allow us to modify our model to include this dynamic aspect and multi-lateral bargaining process, which we leave for future research.

\(30\) See pp. 26-27 in Jackson (2005)

\(31\) The order of the venture capital firms is critical in this game.

\(32\) Assuming no pre-existing network, we begin with an empty network in which no syndicate connections are formed and thus all the venture capital firms are isolated.
firms are partitioned into \( l \) local groups (subsets) so that \( N = \bigcup_{h=1}^{l} (N^h) \) and for any local group, \( h \), \( \bigcap_{k=1}^{h} N^h = \emptyset \), for \( k \in \{2, 3, \ldots, l\} \). And the size of a local group, \( h \), is denoted by \( |N^h| \geq 3 \). A neighborhood of a venture capital firm \( i \) is defined as other venture capital firms located close to a venture capital firm, \( i \). Formally, \( N_{i}^{bd} = \{j \in N^h | d_{ij} \leq 2\} \) where \( d_{ij} \) represents the distance between two VC firms. The distance between two venture capital firms is measured by the length of the shortest (possible) path between the two venture capital firms. A path may exist if a VC can reach another VC either by a direct syndicate connection or by an indirect syndicate connection. By definition, the distance between two directly-connected VC firms is 1 and the distance between two indirectly-connected VC firms is 2. If there are two or more VC firms (or nodes) between \( i \) and \( j \), i.e., \( d_{ij} \geq 3 \), then the connection is called a ‘farthest’ connection. Also, all the VC firms are classified into two groups according to their assigned project’s prospects. The first group of VC firms get assigned a more profitable start-up project while the second group of VC firms get assigned a low-profitability project. We denote these two groups as \( N^S \) and \( N^P \), respectively. Accordingly, \( N = N^S \cup N^P \) and \( N^S \cap N^P = \emptyset \). Let \( t \) represents a VC’s group type; \( t \in \{S, P\} \). All the VC firms’ membership will be given at the beginning of the stage 1 and will remain the same until the end of the game.

### 3.2 A Sequential Network Formation Game

Our sequential game consists of three stages; i.e. \( t \in \{0, 1, 2\} \). At stage 0, Nature assigns each and every VC in the network a start-up project with either high-profitability \((V^H)\) or low-profitability \((V^L)\). That is, there are only two types of start-up projects available. And all the start-up projects have initially the same success probability of \( P^L \). This probability of success will be enhanced as a syndicate is formed and two member VC firms work together as sharing information and managerial talents and so on. Which VC firm is assigned the former type and which VC firms are assigned the latter type is common knowledge. Thus, at the beginning of stage 1, every VC firm knows its own type as well as all the other VC firms’ types.

At stage 1, \( \forall i \in N \) may initiate an offer to form a syndicate with another venture capital firm. However, we assume the cost heterogeneity in our network formation game. This cost heterogeneity will play a crucial role in determining the network architecture of the venture capital industry. By the way, we allow multiple offers at stage 1 in order to guarantee that at the end of stage 1, (almost) all the venture capital firms in a local group will have received at least one syndicate offer from other VC firms. Given these offers, the network architecture evolves according to the rules below.

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\( ^{33} \)It is possible that a local group is a little bit dense in the sense the longest distance between any two VC firms in it is just 2; in this case, we have \( N_{i}^{bd} = N^l \), where \( i \in N^l \).

\( ^{34} \)The indirect connection exists between \( i \) and \( j \), if \( \forall i, \exists a k \) between \( i \) and \( j \) such that \( i \) has a syndicate connection with \( k \), \( k \) has a syndicate connection with \( j \) and no direct syndicate connection exists between \( i \) and \( j \).

\( ^{35} \)In our model, the first group of VC firms will become a central venture capital firm in its local network. We assume that there is only one VC firm in each local group that gets assigned the higher-profitability project at stage 0. VC firms in the second group will become peripheral VC firms after the game ends. A peripheral VC firm may be indicated as a peri-VC firm from now on.

\( ^{36} \)Since there is only one VC firm with a \( V^H \)-project, every VC firm only needs to know which firm is of the \( V^H \)-type in one’s local network.

\( ^{37} \)We will discuss these costs of extending an invitation offer and of extending an acceptance offer in detail below.
architecture will be determined at stage 2 in which all the VC firms determine ‘whether or not to form a syndicate’ and ‘with whom to form a syndicate’\(^{38}\). At the end of stage 2, a local syndicate network is formed and all the VC firms receive their network payoffs - net value after costs of initiating and accepting the syndicate offer.

This setup is needed to get around the difficulty inherent in this mutual-consent situation as discussed above. That is, given the syndicate offers from other venture capital firms at the end of the first stage, the subgame at stage 2 becomes a noncooperative, directed-network formation game\(^{39}\). More importantly, if a VC firm, \(i\), initiates a syndicate offer and another VC firm, \(j\), accepts the offer, then the \(j\)’s start-up project will not be managed by the syndicate formed. That is, the initiating party’s project will be taken care of by both of syndicate members so that the network payoffs from this initiating party’s project will be shared according to some allocation rule\(^{40}\). And the invited party (that accepted the syndicate offer) may obtain some net payoff from managing independently its originally-assigned project\(^{41}\).

The Strategy\(^{42}\) Basically, each venture capital firm is assumed to be able to offer a syndicate partnership to any venture capital firm in its local network while incurring some offering costs. Therefore, the action set of each VC firm at stage 1 is \(A^1 = \{\text{Offer, Not-offer}\}\), and that of venture capitals at stage 2 is \(A^2 = \{\text{Accept, Decline}\}\), for \(\forall i \in N^l\). The strategy of each VC firm is contingent not only on its types (the profitability of its own project) but also on “from which VC firm the invitation offer to this VC firm originated at stage 1”. Thus, the strategy of \(i\) at stage 1, indicated by \(s^1_i\), is a vector, \(s^1_i = (s^{1}_{i,1}, s^{1}_{i,2}, \ldots, s^{1}_{i,i-1}, s^{1}_{i,i+1}, \ldots, s^{1}_{i,n})\) where \(s^{1}_{i,j} \in \{O, N\}\) for each \(j \in N^l \setminus \{i\}\). At stage 2, all the venture capital firms know what happened at stage 1. That is, the history available at stage 2, denoted by \(h^2\), includes the action profile of all the venture capital firms at stage 1, which is also assumed to be common knowledge. With this given information, each VC with at least one syndication offer determines whether or not to accept an offer and/or which VC firm’s offer to accept under the restriction that at stage 2, all the VC firms can accept only one offer, according to its strategy, which can be denoted by, for example, \(s^2_i\) for a venture capital firm \(i\). Here again the strategy is a vector, \(s^2_i = (s^{2}_{i,1}, s^{2}_{i,2}, \ldots, s^{2}_{i,i-1}, s^{2}_{i,i+1}, \ldots, s^{2}_{i,n})\) where \(s^{2}_{i,j} \in \{A, R\}\) for each \(j \in N^l \setminus \{i\}\). Therefore, \(g_{ij} = 1\) if \(s^{1}_{ij} = O\) and \(s^{2}_{ji} = A\), and \(g_{ji} = 1\) if \(s^{1}_{ji} = O\) and \(s^{2}_{ij} = A\). Otherwise, \(g_{ij} = g_{ji} = 0\).

Value and Cost Heterogeneity\(^{43}\) In our model, the value heterogeneity is two-fold; one is from the type of one’s own project and the other comes from whether or not a syndicate

\(^{38}\) Accepting an invitation offer also incurs some costs, which are assumed to be identical across all the VC firms. But we assume that at stage 2, all the VC firms are allowed to extend only one acceptance offer to one of the VC firms that have offered the syndicate invitation at stage 1.

\(^{39}\) This noncooperative directed network formation game with heterogeneous players is studied by Galeotti, et al. (2006).

\(^{40}\) We do not specify any particular allocation rule and the sharing percentages will be endogenously determined from the assumptions of our model. See below for details.

\(^{41}\) Below we assume that only a VC firm with the \(V_H\)-project can have a positive net payoff from this independent action. This setting is less realistic given that usual venture capital firms manage a big portfolio comprised of several start-up projects at the same time. But for analytical simplicity we need this unrealistic assumption.

\(^{42}\) The ‘O’ represents the action of ‘offer’ and the ‘N’ represents that of ‘not offer’.
is formed. At stage 0, all the VC firms are assigned a start-up project either with the higher value, \(V^H\) or with the lower value, \(V^L\). Furthermore it is assumed that syndication gives a higher chance of success; i.e., \(P^L\) becomes \(P^H\) as a syndicate is formed where \(P^x, x \in \{L, H\}\) is the success probability of a start-up project\(^{43}\). Venture capital firms earn values or benefits from forming a syndicate, which are comprised of two parts. The first one is the value of the current start-up project - the initiator’s project - assigned at stage 0\(^{44}\). The second one is the present value of future deal flows. All of these values are a function of one’s syndicate partner selection and the project type of the initiator. Let \(i\) be a VC with the start-up project of \(V^H\) and, \(j\) and \(k\) represent the VC firms with a project of lower value, \(V^L\). Ex-ante value of the current project of \(VC_i\) is equal to \(P^L V^H\) while that of other VC firms is \(P^L V^L\). If a syndicate is formed between \(i\) and \(j\), the ex-post value of the project of \(i\) would be \(P^H V^H\) when \(i\) initiated the syndication offer at stage 1 and that offer was accepted by \(j\) at stage 2. However, the ex-post value from current project to \(i\) could be \(P^H V^L\) if \(j\) initiated at stage 1 and \(i\) accepted the offer at stage 2. Yet \(i\) keeps its own project given at stage 0, which generates additional net payoff of \(P^L V^H - C^0_i\), which is assumed to be positive. The syndication between \(j\) and \(k\) just enhances the success probability from \(P^L\) to \(P^H\) while the syndicate’ project is one of the two VC firms so that its value remains the same as before: \(V^L\). And the invitee’s project generates its own net payoff of \(P^L V^H - C^0_i\), which is assumed to be zero for simplicity\(^{46}\). The bargaining power over the value of the current start-up project between two VC firms in a syndicate is determined by the assumption to be analyzed below\(^{47}\). That is, if a VC firm with a \(V^L\)-project tries to initiate a syndication offer, it would incur much higher costs in the sense that its bargaining power is weaker and thus, has to offer a bigger share of the value from the current project\(^{48}\).

By the way, the present value of future deal flows from forming a syndicate also depends on the partner selection in the sense that a VC firm with a more valuable start-up project is more likely to take a central position in a new local network after stage 2. And this centrality of a VC firm implies higher volume of future deal flows to this central VC firm. This centrality may be interpreted as the network characteristics of power/status. Without forming a syndicate, there is no future deal flows\(^{49}\). And we note that there is symmetry in this present value of future benefits. That is, regardless of the initiator’s project type, a syndicate between \(i\) with a \(V^H\)-project and \(j\) (or \(k\)) with a \(V^L\)-project generates the

\(^{43}\) Mathematically, the success probability, \(P^x, x \in \{L, H\}\) is a function of \(g_{ij} = g(s^1_i, s^1_j, s^2_i, s^2_j)\).

\(^{44}\) This value will be shared between two syndicate members. This assumption explains why a venture capital firm with a \(V^H\)-project does not want to extend a syndicate offer at stage 1.

\(^{45}\) Without any further indication, these notations for the types of VC firms will remain the same throughout this paper.

\(^{46}\) Therefore, the VC firms with a low-value project would give up its originally-assigned project as it accepts a syndicate offer from the VC firm with the \(V^H\)-project.

\(^{47}\) We do not attempt to formally model this bargaining process. Yet it is plausible that the VC firm with the \(V^H\)-project has a greater bargaining power than any other VC firms in a local group given that all the other VC firms with a \(V^L\)-project seek to form a syndicate initiated by the former VC firm with the \(V^H\)-project.

\(^{48}\) Piskorski (2004) mentions this point in terms of the opportunity costs of initiating VC firm with weaker network position. It will turn out that this smaller portion for each VC firm with a \(V^L\)-project is inevitable since all the firms would form a syndicate with the VC firm with the \(V^H\)-project. Thus, the current net payoff from this \(V^H\)-project will be divided among the VC firms that were invited at stage 1. It may be interpreted as adopting the egalitarian distribution rule among these VC firms only.

\(^{49}\) Again, we assume the present value of future deal flows of a solely-operating VC firm to be zero.
same present value of future deal flows to both members: \(B^F_i(g_{ij}) = B^F_i(g_{ji}) = B^F_j(g_{ij}) = B^F_j(g_{ji}) > 0\). Moreover, \(B^F(g_{jk}) = B^F(g_{kj})\), which is assumed to be zero for simplicity.\(^{50}\) Thus, we have the following order: \(B^F_j(g_{ij}) > B^F_j(g_{kj})\) for \(\forall i\) with a \(V^H\)-project and \(\forall j, k\) with a \(V^L\)-project.\(^{51}\)

The cost heterogeneity comes from the distance between two VC firms involved in a syndicate, the strategies to form a syndicate and the type of one’s initial project. If one VC does invite, but no syndication is formed, then its total cost in the game will be just the initiating costs from stage 1. If one VC does not initiate a syndicate but accepts an offer at stage 2, its total cost of the game will be just the accepting costs incurred at stage 2. And actually any VC firms will not extend an offer to a distant neighbor VC at stage 1 given that the indirect or farthest invitation offer costs them much more at stage 1. However, the multiple offers to neighboring VC firms are allowed by the assumption that the VC firm with the \(V^H\)-project has cost advantage in initiating syndicate offers to other VC firms while its acceptance cost is higher than the other VC firms’ costs.\(^{52}\) We also assume that the costs of solely managing the start-up project is higher than the initiating cost regardless of one’s type. And this initiating cost for the VC firms with the \(V^H\)-project is yet low enough to make the net payoff from multiple syndicates - if it ever happens - still sufficiently big. Formally, at stage 1, \(C^1_i = f(d_{ij}, s'_{ij}, V^t)\) with \(t \in \{1, 2\}\) for \(\forall i, j \in N\) where \(b \in \{1, 2\}\) from \(C^b\), represents the stage of a game, \(d_{ij}\) is the distance between \(i\) and \(j\), which is symmetric; (i.e.) \(d_{ij} = d_{ji}\). And given that there is an indirect connection which is initiated by \(i\) and then accepted by \(j\) through \(k\), denoted by \(g^k_{ij} = 1\), and a direct tie, \(g_{ij} = 1\), we have \(0 < C^1[d(g_{ij}) = 1] < C^1[d(g^k_{ij}) = 2]\); also we have \(C^1_i(g_{ij}) < C^1_j(g_{ji})\). Note that the assumption of smallest initiating costs for the VC firm with the \(V^H\)-project reflect power (or status) of the VC firm in the sense that this VC firm has many alternative VC firms from which it may choose as a syndicate partner.\(^{53}\)

The second part of the costs is acceptance/maintenance costs, which also include the syndicate maintenance costs as well as the monitoring costs. For simplicity, here we assume only one type of cost heterogeneity among all the VC firms in a local group. That is, the VC firm with \(V^L\)-project has smaller acceptance costs than a VC firm with the \(V^H\)-project as discussed above.

Now equipped with both values and costs heterogeneity, we build the network payoff function for all venture capital firms below.\(^{54}\)

**Payoff Functions** Recall that the network payoffs to each VC are mainly determined by two factors - one’s project type (profitability) and one’s syndicate partner selection. The

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\(^{50}\) So far we implicitly consider the case when \(g_{ij} = g_{ji} = g_{jk} = g_{kj} = 1\). And if \(g_{ij} = 0\), then \(B^F_m(0) = 0\) for \(\forall m \in N\).

\(^{51}\) The difference, \(B^F_j(g_{ij}) - B^F_j(g_{kj})\) is assumed to be sufficiently large so that the tiny portion of the current project’s value to each VC firm with a \(V^L\)-project does not induce this low-value project VC firms to deviate from its equilibrium strategy. See below for details.

\(^{52}\) In the end, this higher acceptance cost may be interpreted as implying the equilibrium outcome of this game. That is, the VC firm with the \(V^H\)-project will have many syndicate partners so that it has a greater maintenance and monitoring cost.

\(^{53}\) This is how Piskorski identifies a VC firm with power. See Piskorski (2004), pp. 11-13.

\(^{54}\) Galeotti et al. (2006) show that the value heterogeneity has limited effect on the network formation while the cost heterogeneity is crucial not only in determining a network architecture but also in shaping the level of connectedness.
former is given at the beginning of the game and remains the same through out the stages and the latter is endogenously determined at stage 2. The information about the type of each VC is assumed to be common knowledge. In other words, when a VC with a start-up project of \( V^H \) offers a syndicate partnership, the recipient of the offer knows that the invitation offer is from a venture capital firm with a high-value \( (V^H) \) project. Furthermore, we assume that these invitation-acceptance actions by any pair of venture capital firms are also observed by all the other VC firms in the network.

For simple exposition, we assume a linear network payoff function for all the venture capital firms.

\[
\pi_i(s^1_i, s^1_{-i}, s^2_i, s^2_{-i}) = \alpha_i P^x(s^1_i, s^1_{-i}, s^2_i, s^2_{-i})V^t(s^1_i, s^1_{-i}, s^2_i, s^2_{-i}) + \sum_{j \neq i} B_{ij}^F(s^1_i, s^1_j, s^2_i, s^2_j) - C^1_i(s^1_i, s^1_j, s^2_i, s^2_j) - C^2_i(s^1_i, s^1_j, s^2_i, s^2_j)
\]

\[+ [P^x(s^1_i, s^1_{-i}, s^2_i, s^2_{-i})V^t(s^1_i, s^1_{-i}, s^2_i, s^2_{-i}) - C^0_i(s^1_i, s^1_{-i}, s^2_i, s^2_{-i})] \] (1)

where \( \alpha_i \in [0, 1] \) is i's share of the expected payoff of current project to i, which is \( P^xV^t \) with \( x \in \{L, H\} \), and \( t \in \{L, H\} \), while \( x' \) and \( t' \) might be different from \( x \) and \( t \), respectively. \( B_{ij}^F \) is the present value of the future deal flows from a syndicate initiated by i and accepted by j. \( C^1_i \) is i's initiating cost, and \( C^2_i \) is i's accepting/managing costs from forming a syndicate with other VC firm. By the way, \( C^0_i \) is the operating cost of one's own project by itself.

4 A Local Network Formation Game

Here we consider a sequential network formation game for a local network. The goal of this section is to find a network architecture for a local venture capital co-investment network. We begin with an arbitrary local group of venture capital firms; this set is denoted by \( N^l \) and the local network formed by these venture capital firms is denoted by \( G^l \). This network formation game can be also classified as a multi-stage game with observed actions. Accordingly, at stage 1 all the venture capital firms will determine whether or not to offer syndication partnership to one another. As discussed before, we allow multiple offers by a local venture capital firm , which means that one VC in a local group, \( N^l \), may extend an invitation offer to ‘\( n_i - 1 \)’ other VC firms in that group. Note that this first-stage invitation cost is a function of the distance between the two members of a syndicate. Yet as we assumed above, each VC firm has a sufficient number of neighbors around it. Therefore, even though all the VC firms initiate a syndicate offer only to those VC firms in one's
neighborhood, all VC firms in a local group will have received at least one offer at the end of stage 1. At stage 2, the VC firms will determine whether or not to accept an invitation offer as well as with whom to form a syndicate, based on the network payoffs from the syndication formation. Then, at the end of the second period, the network architecture of the local group will be determined. As usual we will solve the game as applying the backward induction, which means the game will be analyzed from the second stage where all the VC firms have received at least one offer to form a syndicate. Given this setting, one’s unilateral decision to form a syndicate will form the network at stage 2. In essence this subgame becomes a noncooperative, directed network formation game in the sense that a VC’s unilateral action (accepting the invitation from other VC firm) will form a new syndicate connection and the network architecture of the local network will be determined accordingly.

Now we turn to the analysis of the subgame at stage 2. At stage 2, given that at least one invitation offer is available to it, a VC firm with a \(V^L\)-project, \(j\), may choose one of two alternative actions. One is to seek to form a syndicate with \(i\) (the VC firm with the \(V^H\)-project). On the other hand, it may accept the invitation offer from other \(V^L\)-project VC firm, \(k\). From the former strategy, its net payoff is

\[
\pi_j(g_{ij} = 1) = \alpha_j P^H(s_i^1 = O, s_{ji}^2 = D, s_{ji}^3 = A)V^H(g_{ij} = 1) \\
+ B_j^F(g_{ij} = 1) - C_j^2(g_{ij} = 1). \tag{2}
\]

And \(j\)’s net payoff from accepting the invitation from \(k\) with a \(V^L\)-project is

\[
\pi_j(g_{kj} = 1) = \alpha_j P^H(s_{kj}^1 = O, s_{kj}^2 = D, s_{kj}^3 = A)V^L(g_{kj} = 1) \\
+ B_j^F(g_{kj} = 1) - C_j^2(g_{kj} = 1). \tag{3}
\]

Since \(C_j^2\) is the same in both cases, \(B_j^F(g_{ij} = 1) > B_j^F(g_{kj} = 1)\) and \(\alpha_i P^H \Delta V > 0\), \(j\) prefers to form a syndicate with \(i\) as accepting \(i\)’s syndicate offer made at stage 1. Clearly, it has no incentive not to seek a syndicate with other VC firm (even with \(k\), since its net payoff from solely managing its original project is just \(\pi_j^0 = \alpha_j P^L V^L - C_j^0 = 0\) by assumption for simplicity.

Now we consider the VC firm, \(i\), with a \(V^H\)-project. This VC firm may choose its action at stage 2 from two options. That is, \(A_i^2 = \{\text{Accept other VC firm’s offer, Decline the offer}\}\). When this VC firm consider declining the other VC firms’ offers, there are two possible outcomes of this action choice. One is that no syndicate network is formed. The other is that a syndicate initiated by another VC (with a \(V^L\)-project) is formed. And we also have many cases corresponding the intermediary cases in which \(i\) accepts more than one offers from other VC firms.

First, we consider one extreme case in which \(i\) have offered the syndicate invitation to all the other VC firms. As we discussed above, all the VC firms with a \(V^L\)-project are willing to form a syndicate with this VC firm due to the higher present value of future deal flows.

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59 This strategy costs least to the initiating VC firms as discussed above.

60 As assumed before, a VC at stage 2 can accept only one offer. However, a VC firm at stage 2 actually has a third option - managing its own project by itself while declining all the invitation offers. See below for a detailed discussion.
From this, we have the following condition for $\alpha_i$ and we assume the following condition for the strict subgame-perfect Nash equilibrium:

Accordingly, we need to compare $i$’s network payoff from $g_{ij} = g(s_i^1 = O, s_j^1 = N, s_{ij}^2 = D, s_{jk}^2 = A) = 1$ and that from $g_{ji} = g(s_i^1 = O, s_j^1 = O, s_{ij}^2 = A, s_{ik}^2 = D) s_{j}^2 = D) = 1$, and $g_{ik} = 1$. Note that $k \neq j, i$.

$$
\pi_i(g_{ij} = 1) = \alpha_i P^H(s_i^1 = O, s_j^1 = N, s_{ij}^2 = D, s_{ik}^2 = A)V^H(g_{ij} = 1) + \sum_{j \neq i} \{B_i^F(g_{ij} = 1) - C_i^1(g_{ij} = 1)\}. \quad (4)
$$

$$
\pi_i(g_{ji} = 1; g_{ik} = 1) = \alpha_i P^H(s_i^1 = N, s_j^1 = O, s_{ij}^2 = A, s_{jak}^2 = D)V^H(g_{ji} = 1; g_{ik} = 1) + \alpha_i P^H V^L + B_i^F(g_{ji} = 1) - C_i^2(g_{ji} = 1) + \sum_{k \neq j, i} \{B_i^F(g_{ik} = 1) - C_i^1(g_{ik} = 1)\}. \quad (5)
$$

The difference between these two network payoffs is $-\alpha_i P^H V^L - C_i^1(g_{ij}) + C_i^2(g_{ji})$. And we assume the following condition for the strict subgame-perfect Nash equilibrium:

$$
[\pi_i(g_{ij} = 1) - \pi_i(g_{ji} = 1; g_{ik} = 1)] = -\alpha_i P^H V^L - C_i^1(g_{ij} = 1) + C_i^2(g_{ji} = 1) > 0. \quad (6)
$$

From this, we have the following condition for $\alpha_i$:

$$
\alpha_i < \frac{[C_i^2(g_{ji} = 1) - C_i^1(g_{ij} = 1)]}{P^H V^L}
$$

This condition implies that when $i$ accepts $j$’s offer to join a syndicate, $i$’s share of the current value must be smaller than the ratio of cost difference to the whole value of $j$’s project. The numerator is positive since for $i$ with the $V^H$-project, the initiating cost should be smaller enough to make $i$ syndicate offers to all the other VC firms in its neighborhood and the acceptance cost for a lead VC firm can be relatively high even though $i$’s acceptance cost might be smaller than $j$ or $k$’s acceptance costs.

Now we consider another extreme case in which the VC with a $V^H$-project does not initiate any offer while only $j$ initiates a syndicate offer to $i$ at stage 1 and then only $i$

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61It is plausible that the individual share of $j$ from its own project ($\alpha_j$) may be large enough that the $j$’s share in $i$’s $V^H$-project is almost the same as this payoff from $g_{ji}$. Yet we assume that this increase in its payoff from the increased individual share in the $V^H$-project is negligible; moreover, the initiating cost for all VC firms with the $V^L$-project is sufficiently high to deter this kind of individual deviations.

62If a VC firm accepts the other VC firm’s syndicate offer, it may keep its own project given at stage 0 by the Nature. And the net payoff from managing this original start-up project is positive only for the VC firm (here, $i$) with the $V^H$-project; for other VC firms, the net payoff is zero and they would not manage their original projects by themselves.

63This higher acceptance cost also help explain the one-acceptance offer assumption at stage 2 for all the VC firms in this local group.
accepts $j$’s invitation offer while all the other VC firms choose not to accept any offers at stage 2. Then the strategy profile of all VC firms will be $(s_i^1 = N, s_{ji}^1 = O, s_{ij}^2 = A, s_{ik}^2 = D, s_j^2 = D)^{64}$. And we have the $i$’s network payoff as follows:

$$
\pi_i(g_{ji} = 1; g_{ik} = 0) = \alpha_i P^H(s_{ij}^1 = N, s_{ji}^1 = O, s_{ij}^2 = A, s_{ji}^2 = D)V^L(g_{ji} = 1; g_{ik} = 0)
+ B^F_i(g_{ji} = 1) - C^2_i(g_{ji} = 1) + [P^L VH - C_i^0].
$$

(7)

The difference between this network payoff and that from the equilibrium strategy profile, $(s_i^1 = O, s_j^1 = N, s_i^2 = D, s_j^2 = A)$ is as follows:

$$
[\pi_i(g_{ij} = 1) - \pi_i(g_{ji} = 1; g_{ik} = 0)] = \sum_{k \neq j, i} \{B^F_i(g_{ik} = 1) - C^1_i(g_{ik} = 1)\} - C^2_i(g_{ji} = 1) + \alpha_i P^H VH - C_i^0 > 0
$$

(8)

The first part is positive since the cumulative net payoff from forming a syndicate with $k$’s less the acceptance costs for $i$ to form a syndicate with $j$ must be positive. And for the second part, we assume that $i$’s gain in network payoff from extending an invitation offer to another VC firm is larger than the ex-ante net payoff from managing its own project by itself. This assumption finds its support from the empirical result that the value enhancement effect of forming a syndicate is significant$^{65}$.

In addition, we may consider a case in which the VC with a $V^H$-project may have not initiated any offer and does not accept any other VC firm’s invitation offer, then it would manage its original project by itself. This generates the net payoff$^{66}$ of $P^L VH - C_i^0$. This net payoff is the smallest among the three possible net payoffs for the VC firm, $i$. Therefore, at stage 2, the VC firm with the $V^H$-project does not accept any other offer since he would not give up its $V^H$-project in any case as shown above. On the other hand, other VC firms with the $V^L$-project would be willing to give up their own projects as long as they can form a syndicate with the VC firm with a $V^H$-project.

At stage 1, anticipating what would happen at stage 2, the VC firm with a $V^H$-project will extend the invitation offers to its own neighbors$^{67}$. And the other VC firms would not offer a syndicate to their neighboring VC firms since initiating syndicates cost them whether a syndicate is formed or not at stage 2. Rather, these VC firms with $V^L$-projects are willing to wait (and accept $i$’s offer to form a syndicate at stage 2). This conclusion is evident when we compare the expected payoffs for both $i$ and other VC firms (like $j$ and $k$). For $j$,

$$
\pi_j(g_{ij}) = \alpha_j P^H VH + B_j^F(g_{ij}) - C_j^2 > \pi_j(g_{ji}) = \alpha_j P^H V^L + B_j^F(g_{ij}) - C_j^1.
$$

(9)

In order to make this payoff difference to be positive, we need the following condition:

$$
[\pi_j(g_{ij}) - \pi_j(g_{ji})] = \alpha_j P^H VH + [C_j^1(g_{ij}) - C_j^2(g_{ij})] > 0.
$$

$^{64}$where $k \neq j, i$.

$^{65}$Also Hochberg, Ljungqvist, and Lu(2007a) indirectly supports this assumption.

$^{66}$It will be denoted by $\pi_i^0$.

$^{67}$The equilibrium local network formed at the end of this game is actually comprised of all the VC firms around the VC firm with the $V^H$-project and the VC firm with the $V^H$-project itself.
This condition is easily satisfied since the second group of terms in the bracket is always positive. That is, as discussed before, this inequality is from the cost heterogeneity assumption of the initiation and acceptance actions among the VC firms in a local group. Again, for \( j \), a VC firm with the \( V^L \)-project, the acceptance cost is always positive. That is, as discussed before, this inequality is from the cost heterogeneity assumption of the initiation and acceptance actions among the VC firms in a local group. Again, for \( j \), a VC firm with the \( V^L \)-project, the acceptance cost is smaller than the initiation cost. And for \( i \), the VC firm with the \( V^H \)-project, the inverse relationship between the initiation cost and the acceptance cost holds. Therefore, we say that the cost heterogeneity assumptions are critical in achieving the strict subgame-perfect Nash equilibrium\(^{68} \).

Therefore, all the VC firms except \( i \) will be directly connected to \( i \) by syndicate connections initiated by \( i \) while they are indirectly connected to each other through \( i \). This network architecture is a center-sponsored star; i.e., \( g_{ij} = 1 \), and \( g_{ji} = g_{ik} = 0 \) for \( \forall i \) with a \( V^H \)-project and \( \forall j, k \) with a \( V^L \)-project. We summarize this discussion as a proposition below:

**Proposition 1** With the network payoff function, and the value and cost heterogeneity reflecting the network characteristics of local networks, the local venture capital syndicate network will be a center-sponsored star; one stellar performer is located at the center of the network and is connected to all the other local venture capital firms as inviting all the other VC firms to form syndicates. And this center-sponsored star is the strict subgame perfect Nash equilibrium and all the other VC firms become peripheral VC firms while being connected through the central venture capital firm; i.e., all the network connections among other peri-VC firms are indirect.

**Proof.** We only need to consider one-time deviation for \( i \) and then for \( j \). First, if \( i \) would deviate at stage 1 by not offering syndicate invitation to at least one of its neighboring VC firms, then the highest possible network payoff for \( i \) will be obtained from the following strategy: \( (s^1_{ij} = N, s^1_{ik} = O, s^1_j = N, s^2_i = D, s^2_j = A) \). And we have the net payoff as follows:

\[
\pi_i[g_{ij} = g_{ij} = 0; g_{ik} = 1, \forall k \in N^i \setminus \{i, j\}] = \alpha_i P^H V^H + \sum_{k \neq j, i} B^F_i (g_{ik} = 1) - C^1_i (g_{ik} = 1). \tag{10}
\]

But this network payoff is smaller than \( \pi_i (g_{ij} = 1, \forall j \in N_i^{bd}) \). The difference between these two payoffs are \( B^F_i (g_{ik} = 1) - C^1_i (g_{ik} = 1) > 0 \) where \( k \neq j, i \). The difference is positive due to the sufficiently large size of the present value of future deal flows when syndicated with \( i \). Thus, \( i \) does not have any incentive to deviate at stage 1.

At stage 2, even if \( i \) decides to deviate by accepting other VC firm’s offer, its attempt to form a syndicate connection of \( g_{ji} \) will be futile since \( \forall j \in N_i^{bd} \) does not have any incentive to deviate from its equilibrium strategy (not offering at stage 1). Therefore, the net payoff from this deviation to \( i \) will be smaller than the equilibrium net payoff by the initiation cost, \( C^1_i \). All in all, \( i \) does not have any incentive to deviate at either stage.

For \( j \) and \( k \), the first-stage deviation means initiating a syndicate offer to other neighboring VC firms, which generates the maximum possible payoff:

\[
\pi_j(g_{ji}) = \alpha_j P^H V^L + B^F_j (g_{ji}) - C^2_j. \tag{11}
\]

\(^{68}\)This importance of cost heterogeneity reminds us the result of Galeotti et al. (2006) They also find the cost heterogeneity is more important in determining the network connectedness and the network architecture.
Yet this payoff is smaller than the network payoff:

$$\pi_j(g_{ij}) = \alpha_j P^H V^H + B_j^F(g_{ij}) - C_j^2$$

which is earned from accepting i’s invitation while not offering invitation at stage 1. Thus, j would not have any incentive to deviate at stage 1. The second-stage deviation for j is to accept k’s invitation offer, which gives definitely smaller network payoff of $$\pi_j(g_{kj}) = \alpha_j P^H V^L + B_j^F(g_{kj}) - C_j^2$$ than $$\pi_j(g_{ij})$$. All in all, all the venture capital firms in a local network would not deviate from their strict subgame-perfect Nash strategies:

For a VC firm with a $$V^H$$-project,
{Offering to all its neighboring VC firms, Declining all the syndicate invitations}

For a VC firm with a $$V^L$$-project,
{Not offering any syndicate invitation, Accepting only the syndicate offer from the VC firm with a $$V^H$$-project}  

This result is similar to that of Galeotti, et al. (2006) in that our model also has a center-sponsored star as the equilibrium network architecture. However, our model is a sequential network formation game and its equilibrium is a subgame-perfect Nash equilibrium.

5 Concluding Remarks

In this paper we show that the local venture capital syndicate network is a star structure. That is, one stellar performer (VC firm) is located at the center of the local network, and all the other VC firms are peripheral and directly connected only to the central VC firm. These peripheral VC firms are indirectly connected only through the central VC firm. This outcome is consistent with the empirical findings of Zheng(2004); Zheng shows that most of network connections among VC firms are indirect, and the prominent VC firm holds the 'structural hole' position, which emphasizes the brokerage function of a central player in a network. Even though our model is a simple sequential game, it is interesting because only with the heterogeneity among VC firms that are reflected in network benefits and costs can we show the emergence of a star structure in local VC networks. Yet we acknowledge the tradeoff we made in order to simplify the network formation game.

First of all, we introduced the Nature at stage 0 in order to simplify the start-up project selection process. In reality this process can be very costly, especially for inexperienced VC firms. For a more realistic model, we need to model the strategic behavior during this project search process. It is plausible that the search cost may be introduced and the probability of locating a high-value project may be assumed to be a function of a VC firm’s effort level and one’s network position. In addition, the value of a project can be assumed to be stochastic so that we may modify the network payoff function as an expected payoff function including a search-cost function.

Secondly, we deliberately choose a noncooperative game model in order to seek a network architecture problem in VC industry. This goal brought in the issue of how to model a bilateral-agreement network formation without relying on a cooperative game model. We evade this issue as introducing the multi-stage game with the assumption on the strategic situation of second stage game. That is, using the backward induction for our sequential
game model, we assume that each and every VC firm in a local group has received at least one invitation offer at the beginning of stage 2. This assumption turns our second stage game into a noncooperative, directed network formation game under unilateral network formation rule.

Thirdly, Another important assumption behind our model is about the causal relationship between how to take the central position in a network and to have power and status in a network and how to become financially successful in investing. One may think that the central position in a network gives that player power and status in the network and thus more chance to be a successful investor in this risky business. And the other may think of the causality in reverse; a VC firm that had managed start-up projects in the past was able to build a reputation and its local network as forming a syndicate in one or two start-up projects. Our choice in this paper is the latter one. And we begin seeking our network architecture of a local VC network from the scratch with the heterogeneity of start-up projects’ values.

As discussed above, our model lacks many realistic aspects of venture capital industry. Especially, we do not consider yet the problem of network architecture of the whole venture capital industry. This task can be tackled with a simple modification of our network payoff function or with totally different approach. According to empirical studies, the whole venture capital industry has a network architecture similar to an interlinked star. This architecture can be also modeled through the value and cost heterogeneity of our model. Moreover, in order to fully understand the evolution of the venture capital syndicate network, we should have a dynamic model that incorporates the external factors to affect the evolution process of the venture capital syndicate network.

Even though many corporate finance papers already dealt with the syndication process of the venture capital industry, a more realistic model should incorporate this ‘network’ feature into the syndicate partner selection process and the bargaining between the entrepreneur and the venture capitalists. The bargaining process of the syndicate partners with the entrepreneur may be also affected by the network position of the lead VC firm and/or non-lead VC firms. Hochberg, Ljungqvist and Lu (2007b) also point out that a well-networked VC firm has more bargaining power in negotiating the venture capital funding against an entrepreneur. Fluck, Garrison and Myers (2004) show that syndication of a start-up project may help mitigate the hold-up problem as assuring the entrepreneur more favorable terms in later rounds of financing. And this effect of the syndicate encourage the entrepreneur to exert more effort and ultimately lead to a higher value of the start-up project.

Also, we expect more realistic game-theoretic network formation model incorporating the Jackson-Wolinsky or Jackson-van den Nouweland network formation rules to be developed. Recently Chowdhury (2007)’s model deals with a completely-sequential network formation model in which every player takes turns to be a link initiator without introducing any heterogeneity among agents. Yet we need a fully developed model in which network connections are heterogeneous, directed arcs and the arc is formed by bilateral consents. Our model may also be used for a laboratory experiment to seek a star structure as incorpor-

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69 As discussed above, Sorenson and Stuart (2005) suggested two external factors to change the VC network: attractive, unusual investment opportunity and the experimentation by a stellar VC firm to reach another local venture capital network with some low-risk investment opportunity.

70 Casamatta and Haritchabalet (2003) study the syndicate partner selection process and provide the rationale for syndication. Their model also considers the competition among VC firms in deciding whether or not to form a syndicate with another VC firm.
porating the conditions on the benefits and costs from syndicate formation in our setup. Goeree, Riedl and Ule (2006) extend the Bala-Goyal model of network formation with cost heterogeneity among players to design an experiment and show that in all treatments, the efficient equilibrium network has a “star” structure.

References


