Networks of venture capital firms in Silicon Valley

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Abstract: By comparing the network structure of venture capital (VC) firms in Silicon Valley (California) to that of VC firms in Route 128 (Massachusetts), the present study challenges any market-centred theory of regional development. I show that there are advantages in examining the structure of social networks of cooperation within the venture capital industry to understand the level of development of a region. I support two distinctive propositions regarding the regional advantage of Silicon Valley over other US high-technology regions such as Route 128. First, collaboration among VC firms in Silicon Valley is more pronounced and dense than in Route 128. Second, the number of investments and amount of money invested by VCs in Silicon Valley staying local are much higher than the number of investments and moneys invested locally by Route 128 VC firms. I argue that historical development as well as the particular structure of the social networks in Silicon Valley is precisely what has fostered relatively higher growth and development of the region compared to many other regions of the world.

Keywords: Social networks; venture capital firms (VCs); Silicon Valley; Route 128; regional development.

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1 Introduction

Despite the theoretical importance of social networks in regional development, the precise nature of social networks at work in Silicon Valley still remains quite obscure. In this paper, I seek to shed light on the social network phenomenon in Silicon Valley. Silicon Valley's dense network structure is universally famous for providing the support that facilitates and even accelerates the process of starting new technology-oriented

businesses. It has been argued that this structure of support has consequently fostered the tremendous economic growth of the valley in the last decades. But very little empirical work has been done to show the particular network structure characteristics that make Silicon Valley unique [1–3].

The purpose of this paper is to present the beginnings of a systematic comparative study of social networks of venture capitalists. Specifically, I examine the role of social networks of venture capital firms (VC henceforth) in the development of industrial regions like Silicon Valley (California) with both a comparative and a network perspective. By analysing a sample of investments from VC firms in Silicon Valley, I first show how the structure of venture capital in Silicon Valley has been indeed dominated from the very beginning by a group of firms highly interconnected with each other like nowhere else in the world. Second, by comparing the network structure of cooperation among VC firms in Silicon Valley to the network structure of cooperation in Route 128 (New England, Massachusetts), the present study challenges any market-centred theory of regional development and offers a network explanation to account for differences in the level of development of any regions. Both Silicon Valley and Route 128 appear to have comparable concentrations of skills, technology, companies and other social institutions. However, in Silicon Valley, the entrepreneurial efforts and venture capital activities happen to be more embedded in densely connected networks. The relatively higher growth and development of Silicon Valley has been attributed to historical development as well as the particular structure of the social networks in the valley in comparison with many other regions of the world [4–7].

I begin with a brief review of the venture capital industry, with particular emphasis on the historical development of venture investing and networks of venture investors in the Western Region of the USA prior to the institutionalisation of venture capital. The section also focuses on network methods that enable us to identify the most influential VC firms in Silicon Valley since 1995. To gain a better understanding of the dominance of Silicon Valley in the new economy, the second part of this paper compares the structure of venture financing in Silicon Valley with the structure of venture financing of another important US region, Route 128. I empirically illustrate some of the most important differences that exist in the way of doing venture investing between firms in Silicon Valley and Route 128. In particular, two propositions are tested regarding the regional advantage of Silicon Valley over other US high-technology regions such as Route 128:

1 collaboration networks among venture capital firms in Silicon Valley are more dense and dominated by more connected cliques than in Route 128

2 the number of investments and amount of money coming from VC firms in Silicon Valley that stays local are much higher than the number of investments and amount of money invested locally by Route 128 VC firms.

These two important differences in the network structure have definitely shaped, from the beginning, the allocation of resources, support, information and legitimacy necessary for the development and success of new local organisations and consequently, the long-term development of the region. In the conclusion, I discuss the results of my analyses and suggest directions for future research on social networks in industrial districts. I also make some policy recommendations that support the creation and expansion of regional networks among firms to promote economic and technological regional growth.

2 Venture capital in Silicon Valley

The venture capital industry has undoubtedly been the financial engine of the most recent entrepreneurial process. Harmon's Zero Gravity [8] relates the personal insights and general advice from leading venture capitalists on how to navigate through different stages of the venture capital process [8]. Harmon starts his recent book with a very popular belief now:

> "the venture capitalists are the new power brokers, banks, management providers, gurus and mothers who hold the hands of the newbie idea-ites, taking them past the training wheels stage into rocket racers. It is smart money, the people and their capital. It has to be smart – there is no time to make the wrong moves in a world where every great idea has a dozen imitators in sixty seconds." [8, pp.3-4]

Venture capitalists are management firms that invest capital in companies at very different stages of development. The capital is provided by individual and corporate investors who contribute to a 'fund'.

Venture capitalists participate together in rounds of financing of companies. Clearly, some venture capitalists have strong preferences for working with certain other venture capital firms. Those currently investing in a young company might often be recruiting and selecting other VC firms for participation in subsequent rounds of financing. These processes create cliques of VC firms which cooperate with each other in the funding of similar start-ups or investee companies in other development stages. Social networks are also important sources of power and influence [9]. In Silicon Valley, venture capitalists play more than merely conventional roles. They are highly influential when it comes to the shaping as well as the future evolution of their client organisations. Venture capitalists provide start-ups with not only financial resources but also management, recruiting, accounting and legal advice and other consulting services which are just as important to the success of the new venture as is the funding. Moreover, venture capitalists have access to an informal and formal network of professionals and experts who can evaluate the long-term viability of a newly created firm and provide in-depth knowledge of high technology industries from their portfolio of ventures. These networks constitute a form of social capital and are a good example of the Granovetter embeddedness concept [10]. The entrepreneurial effort as well as its financing by VC firms is clearly embedded in a formal and informal network of social connections that provide support, information, status and legitimacy to the investee company.

West Coast venture capitalists have helped make Silicon Valley the focus of world attention and the cradle of technology-based entrepreneurship. Experienced venture capitalists now manage billions of dollars. Half of the VC firms in the USA are now in Silicon Valley. From 1998 to 1999, venture capital investments in Silicon Valley firms increased from $3.2 billion to $6.1 billion (an increase of 90%). In the first quarter of 2000 alone, Silicon Valley attracted $6.1 billion in venture capital funding (in comparison with New England which captured $2.4 billion) with 394 investment deals [11]. This is over half of the venture capital invested in the top ten technology regions of the USA (including Atlanta, Austin, Boston, Dallas, Denver, Phoenix, Portland, Raleigh-Durham, Salt Lake City and Seattle). Investment in software/internet companies still attracted the largest share of total investment, at 33%. Communications attracted the second-largest investment share at 28% [12].

Many social scientists argue that in addition to being a critical source of capital for many start-ups, venture capitalists of Silicon Valley have been central in the development of the region's social and professional networks in comparison with the more passive role of venture capital in other regions [5–7]. Networks of venture capitalists in Silicon Valley relied on major inflows of technical entrepreneurs, venture capitalists, management talent and supporting services from other regions. It is this shared regional affiliation which provides an underlying social bond for the region's network of entrepreneurs and inventors [7, p.255]. By the late 1980s, this combination of technology and venture financing had already turned into a phenomenon known around the world as Silicon Valley, a centre where entrepreneurs, investors and venture capitalists meet to promote entrepreneurship and economic growth.

Venture capital on the West Coast has no exact age. However, it is well established that venture capital matured in the West Coast. Wilson's study in 1985 is probably the first systematic analysis of the phenomenon of venture capital in the USA [13]. In Wilson's words:

> "Born in New York, nurtured in Boston and almost smothered in Washington, venture capital did not really come of age until it moved to California and joined forces with the brash young technologists who were using bits of silicon to create an information revolution as profound as the industrial revolution a century later." [13, p.31]

With the formation of many modern venture capital firms such as *Draper, Gaither & Anderson* and *Western Business Assistance Corporation* in 1958, however, the basic foundations of todays venture structure started to be laid, even though several individuals antedated these early firms in activity.

Between 1958 and 1983, venture capital grew into a 'heavy gravity business' [8]. While in 1958 a small number of deals were allocated a few thousand dollars each, by 1983 billions of dollars were invested in each good idea. According to the *Asset Management Company* (AMC)'s 'West Coast Venture Capital – 25 years' Genealogy Chart' published in 1983, over 300 people in over 100 companies built West Coast venture capital in the 25 years since 1958 [14]. One hundred and twenty nine organisations were identified in the genealogy chart (including fund spin-offs) related to Western venture capital from 1958 until 1983. The rate of founding new VC firms remained relatively stable until 1967-1968, after which it rocketed. During the late 1960s, limited partnership became a very usual practice and even large financial institutions started to invest as limited partners [15,16].

The venture capital industry has experienced dramatic growth since 1968. By the early 1960s, several large financial institutions became involved in venture capital. *First National Bank of Boston* formed an SBIC affiliate for providing loans to technology-oriented businesses and around the same time, *Federal Street SBIC* was established by a consortium of Boston banks with the same aim [6, pp.19-20]. The evolution of the venture-capital industry followed a pattern similar to that of new high-technology business enterprises. Proliferation by spin-offs from preceding generations was prevalent in the venture capital industry as it was in high-technology enterprises. Some of the prominent cases of this mode of growth by spin-offs are documented by Florida and Kenney [6, pp.20-21]. After 1983, the number of venture capital firms in the Western region of the USA continued to grow, mainly as the result of spin-offs [17–22].

2.1 Social networks of venture capital firms in Silicon Valley

Data from PricewaterhouseCoopers' Money-Tree-Historical Data of VC funds and investee companies are used to examine the most recent networks of VC firms in Silicon Valley (from 1995 up to the first quarter of 1998) [23]. I use MAGE [24], a computer graphic program, to explore and evaluate the social structure of VC firms using dynamic three-dimensional colour images [24–26]. A graph can give us a representation of a social network as a model of a social system consisting of a set of actors (in this case, VC firms) and the existing ties among them.

The graph for the venture capital social network in Silicon Valley is given in Figure 1. In the graph, the points (called nodes) are used to represent each of the existing VC firms in Silicon Valley during the 1995-1998 period. The lines connecting the points are used to represent the ties between those organisations. In this case, the presence of a tie between any two VC firms indicates that they have at least one investee company in common; that is, that both VC firms cooperated in the financing of the same company or companies. In this sense, a tie is either present or absent between each pair of venture firms. In addition, the length of the tie between two VC firms is inversely proportional to the number of investee companies in common: the shorter the tie (i.e., the closer the two VC firms in the three-dimensional space), the higher the number of investee companies in common [27,28,2,29,30].

Figure 1 Network of venture capital firms in Silicon Valley

Source: PricewaterhouseCoopers 1995-1998

In Silicon Valley, during the 1995-1998 period, there were 111 firms and 312 lines between the pairs of firms; the sum of the values of such ties is 550 indicating the number of occasions in which at least two different VCs happen to cooperate and therefore to co-invest money in the same company [31]. The graph looks rather complicated or dense, since the level of connection among VC firms in Silicon Valley is high (the density of the network is .025). The five most prominent VC firms, *Accel Partners, Kleiner, Perkins, Caufield & Byers, Crosspoint Venture Partners, Sequoia Capital and Hambrecht & Quist Venture Capital* are located in the centre of the plot; whereas firms like *Alta Communications, Alpha Partners, Robertson, Stephens & Company* and *Softbank Technology Ventures Fund* are all on the side of the plot, but still weakly connected to the main network component. Then, there are firms which are not connected to this principal network of VC firms at all (about 30% of all VC firms in Silicon Valley).

In general, the nodal degree of a VC company is a measure of the 'activity' of the VC firm. The mean degree is a statistic that reports the average degree of all VC firms in the network. In Silicon Valley, there are some VC firms (30% of all VC firms) which are not related to any of the other existing organisations by the 'cooperation' relation here defined (that is by having at least one investee company in common). They are therefore isolates on the relation of cooperation to fund an investee company. The overall density of the graph (excluding isolate VC firms) is 0.0256. The mean nodal degree is 2.81, the median is 2.0 and the standard deviation is 3.35. Thus, VC firms in Silicon Valley have (on average) between two and three connections to other VC firms in the same region, with VC firms like *Crosspoint Venture Partners* in Los Altos and *Sequoia Capital* or *Kleiner Perkins Caufield & Byers* in Menlo Park having 12 or more connections in the 1995-1998 period.

It is important to identify which VC firms are especially powerful in the VC industry. To become a powerful organisation within a network, one can argue that such organisations must be relatively central to the network structure. Broadly speaking, centrality (in social network analysis) refers to how critical a firm is to the network's global structure. Centrality can be measured in several ways, each of which is associated with a different substantive interpretation. An organisation's degree of centrality is simply the number of other organisations to which the given organisation is tied. Degree is typically used as a measure of an actor's involvement in a network [32]. In this sense, an organisation tied to two other organisations is said to be twice as involved as an organisation with only one link. I calculated the standardised degree centrality [33]. In looking at the VC firms in Silicon Valley, *Crosspoint Venture Partners, Sequoia Capital, Hambrecht & Quist Venture Capital, Kleiner Perkins Caufield & Byers, Accel Partners, Burr Egan Deleage & Company, Institutional Venture Partners* and *Mayfield Fund* are among the Silicon VC firms which have the highest degrees (starting from 13.64 down to 9.09). Substantively, one could tell that much of the financial activity in Silicon Valley– is centred on these firms – most of them are located in the Los Altos-Menlo Park-Palo Alto neighbourhood – since their standardised degree centrality is between three and five times the average standardised nodal degree for the whole network. These firms have the largest degrees and thus many are connected to many other firms in this network.

In addition, *betweenness centrality* could be easily interpreted as a measure of a firm's power. An organisation gains power over any two organisations when it lies on the shortest path between the two in a given network of relations. For example, if organisation A is tied directly to organisation B and organisation B is tied directly to organisation C, but organisations A and C have no direct ties, then the shortest path

(the geodesic) between A and C is the two-step path through B. B therefore has power over A and B because it is in a position to broker the flow of information and resources between A and C [34]. I calculated the standardised betweenness (expressed as a percentage) for each VC firm in Silicon Valley [35]. *Sequoia Capital, Hambrecht & Quist Venture Capital, Mayfield Fund, Crosspoint Venture Partners, Technology Funding Venture Partner, Burr Egan Deleage & Company, Kleiner Perkins Caufield & Byers* and *Accel Partners* score the highest normalised betweenness index among all the Silicon VC firms. *Sequoia Capital* reaches the highest betweenness index in the network, 9.34.

A third view of firms' centrality can be based on closeness or distance. The *closeness centrality* measure focuses on how 'close' a firm is to all the firms in the network. The idea is that a firm is central if it can quickly interact with all others. This notion of closeness states that central firms in a network have 'minimum steps' when relating to all other firms; that is, the geodesics (or shortest paths) linking the central firms to the rest must be the shortest possible. In the example of organisations A, B and C above, where organisation A is tied directly to organisation B and organisation B is tied directly to organisation C, but organisations A and C have no direct ties, then B has the maximum closeness, since B can reach all other firms in a minimum number of steps. I calculated the standardised closeness centrality measure (expressed as a percentage) for each VC firm in Silicon Valley. Again *Crosspoint Venture Partners* in Los Altos and *Sequoia Capital* in Menlo Park reach the maximum closeness levels in the Valley. *Accel Partners, Institutional Venture Partners, Mayfield Fund, Hambrecht & Quist Venture Capital, Kleiner Perkins Caufield & Byers* and *InterWest Partners* also score among the most central firms according to the closeness index.

Table 1 displays the results of this overall centrality analysis for the 20 most influential VC firms in Silicon Valley. All 20 firms invested 4,827 millions of dollars in 936 different investee companies between 1995 and the first quarter of 1998; this represents 55% of all money invested by VCs in Silicon Valley (over 52% of all company recipients of Silicon Valley funds). They also invested over 14.4% of the total capital invested by all US VC firms in the 1995-1998 period. Examining the results of the centrality analysis reported in Table 1, these 20 VC firms have a mean nodal degree of eight firms; thus, these 20 VC firms have on average eight connections to other VC firms in the region. Their mean closeness score is 2.7 (much higher than the mean value for all VCs in Silicon Valley) and their mean betweenness score is almost four (four times the mean level of betweenness for all VC firms in Silicon Valley).

It is very difficult to understand the relative position of VC firms in Silicon Valley, especially of these 20 most influential ones, in the absolute. The purpose of the next section is to compare the structure of the network of VC firms in Silicon Valley to the one in Route 128, which is argued to be the second leading technology region in the USA. Only when examining the structure of the venture investing network as well as the investment patterns, important variations can be found between Silicon Valley and Route 128 VC firms which could consequently account for their differences in the level of economic and social development.

Table 1 Centrality measures for the 20 most influential venture capital firms in Silicon Valley (1995-1998)

Firm Name	*Location*	*Degree Centrality (%) (a)*	*Closeness Centrality (%) (a)*	*Betweeness Centrality (%) (a)*	*Number of investee companies (1995-1998)*	*Amount of money invested in millions of $ (1995-1998)*
Crosspoint Venture Partners	Los Altos	13.64	2.71	5.94	52	288.30
Sequoia Capital	Menlo Park	11.82	2.71	9.34	76	319.11
Hambrecht & Quist Venture	San Francisco	10.91	2.70	8.18	111	460.43
Kleiner Perkins Caufield & Byers	Menlo Park	10.91	2.70	4.97	63	517.11
Accel Partners	Palo Alto	9.09	2.71	4.85	51	270.33
Burr Egan Deleage & Company	San Francisco	9.09	2.69	5.28	55	317.65
Institutional Venture Partners	Menlo Park	9.09	2.71	3.31	43	241.09
Mayfield Fund	Menlo Park	9.09	2.71	6.24	59	286.08
InterWest Partners	Menlo Park	8.18	2.70	4.26	43	247.93
Menlo Ventures	Menlo Park	7.27	2.69	3.57	50	208.27
Sierra Ventures	Menlo Park	7.27	2.70	1.88	42	220.73
Weiss Peck & Greer Venture	San Francisco	7.27	2.69	1.04	37	272.09
Alta Partners/Burr Egan Deleage &	San Francisco	6.36	2.69	2.00	28	112.62
Mohr Davidow Ventures	Menlo Park	6.36	2.69	0.49	38	207.97
Robertson Stephens Venture	San Francisco	6.36	2.69	3.12	46	289.35
Trinity Ventures Ltd.	San Mateo	6.36	2.69	3.22	33	132.04
Benchmark Capital	Menlo Park	5.45	2.69	1.39	34	210.78
Draper Fisher Jurvetson	Redwood City	5.45	2.67	1.51	22	69.52
Technology Funding Venture	San Mateo	5.45	2.68	5.29	34	90.67
Altos Ventures	Menlo Park	4.55	2.68	2.68	19	65.22
Normalized Degree Centrality for the 20 most influential VC Firms in Silicon Valley:						
Mean		8.00	2.70	3.93	47	241.36
Standard Deviation		2.43	0.01	2.36	21	116.89
Minimum		4.55	2.67	0.49	19	65.22
Maximum		13.64	2.71	9.34	111	517.11
Normalized Degree Centrality for all VC Firms in Silicon Valley:						
Mean		2.56	2.11	0.96	16	78.73
Standard Deviation		3.04	0.82	1.79	21	108.75
Minimum		0.00	0.90	0.00	1	0.05
Maximum		13.64	2.71	9.34	111	517.11

Note: (a) The three centrality measures are normalised and expressed as a percentage (so the minimum possible value is 0 and the maximum is 100).

Source: PricewaterhouseCoopers 1995-1998 (first quarter).

3 A comparative analysis of venture capital firms in Silicon Valley and Route 128

Much research on the experiences of Route 128 and Silicon Valley has suggested that there are important regional sources of competitive advantage [5]. Neither accounts of industrial adaptation as a national or a sectoral process nor classical theories of regional development, or standard economic theories, which all treat Silicon Valley and Route 128 as comparable concentrations of skill and technology, can account for Silicon Valley's superior performance since the 1980s. These differences in performance cannot be explained by any market-centred theory of regional development or any other approaches that view firms as separate from the social structures and institutions of the local economy.

In this section, I challenge any of these traditional theories of regional development and present a network explanation to account for the high rate of new local successful organisations in Silicon Valley. I perform some network analyses to show empirically how entrepreneurial effort and venture capital activities are indeed much more embedded in a network of cooperation and social relations in Silicon Valley than in Route 128. This section also shows some of the major differences in the organisation of venture investment between Silicon Valley and Route 128 VC firms. I perform several tests to illustrate some of the clear differences in the number of investments, the amount of money invested and the regional location of investments between VC firms in Silicon Valley and VC firms in Route 128.

Following is the operationalisation of some of these non-economic factors (i.e., specific characteristics of the network structure in Silicon Valley compared to any other industrial region in the USA such as Route 128) which, I propose, account for the successful development of Silicon Valley. The first proposition to test empirically is that networks of inventors, entrepreneurs, engineers and venture capitalists are, in general, more dense in Silicon Valley than in Route 128. These networks are more dominated by cliques or clans of actors in Silicon Valley, whereas in Route 128, networks are less dense and more disconnected, containing a much lower number of cliques or cohesive groups. Applying this general proposition to the study of networks of VC firms, I hypothesise that VC firms in Silicon Valley will tend to cooperate more in financing investee companies and overall will appear to be more central than VC firms in Route 128 which are, by contrast, less connected among each other.

A second proposition is that in Silicon Valley, investments come and continue to come mainly from local funds. In the specific case of venture capital funds, the number of investee companies and the amount of capital invested in Silicon Valley are relatively higher in comparison with Route 128. In addition, those investments come more from local VC funds in Silicon Valley. In other words, the number of investments (and the amount of money) coming from VCs in Silicon Valley that stays in the Valley is relatively higher than the number (and amount of money) invested by Route 128 VCs in New England.

A descriptive analysis of the data available from PricewaterhouseCoopers from 1995 to the first quarter of 1998 includes 111 VC companies located in Silicon Valley and 91 VC firms located in Route 128 (Massachusetts). The number of investee companies for VC firms in Silicon Valley is 1,787; 1,163 for the VC firms in Route 128. The differences are even more striking when examining the amount of capital invested:

VC firms in Silicon Valley invested 8.7 billions of dollars as opposed to 5.9 billions in Route 128.

3.1 Network analysis of venture capital firms in Silicon Valley and Route 128

In order to examine the structure of cooperation and social relations among VC firms and identify influential groups of firms in both the venture capital industry in the Silicon Valley and Route 128 regions, several network methods can be employed. Each of these methods explores a different level of information regarding the structural relationship of these influential groups of companies.

Influential actors are those who are extensively involved in relationships with other actors. There are several centrality measures for each firm's level of involvement. At this point, since the purpose of this section is to compare two networks of VC firms, I use standardised centrality measures [36]. So far I have presented three centrality indexes concerning individual firms. The same centrality measures can be calculated at the network level. Any network-level measures allows a systematic comparison of different networks as a whole. The larger the network-level index is, the more likely it is that a single actor is quite central, with the remaining actors considerably less central [2, p.176]. The range of this index is between 0 and 100%. A 0 means every social actor's centrality degree is exactly the same; no one is more central than the other. On the other hand, it equals 100% if and only if one actor completely dominates the network [32, p.228]. Following UCINET terminology, I call these indexes *Network Centralisation* [37]. Three Network Centrality measures are employed to characterise the network of VC firms in Silicon Valley and in Route 128: *Degree, Closeness* and *Betweenness Network Centralization*.

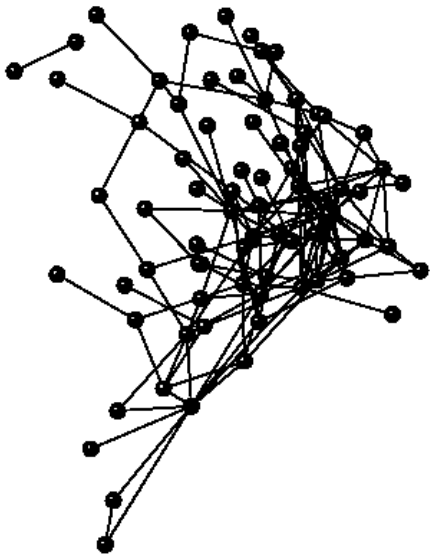
It is often a group of influential firms rather than a single firm that can dominate the whole association. Since centrality degree only informs us of the level of involvement at the firm level, I use another procedure to detect sub-groups of firms within a network. The simplest of the various sub-graph concepts is that of the *component*, which is formally defined as a 'maximal connected sub-graph'. A sub-graph, like a graph, is connected when all of its points are linked to one another through paths: all points in a connected sub-graph can 'reach' one another through one or more paths, but have no connections outside the sub-graphs [38].

Finally, social network analysis can also be used to discover the various 'cliques' and cohesive sub-groups into which a network can be divided. The *clique* definition is a very useful technique to formalise the notion of the social group using social network properties. It is a very strict way of specifying the formal properties that a cohesive group has in a network of social actors. A clique is a 'maximal complete sub-graph' of three or more actors. It consists of social actors, all of which are adjacent to each other and there are no other actors who are also adjacent to all the members of the clique [2, p.254]. In the example of VC firms, one can think of a clique as a group of VC firms all of which cooperate with each other in the founding of similar start-ups or investee companies in other development stages and there are no other firms in the group which also cooperate with all the members of the group of VC firms [39].

This concept of the clique is constraining for real social networks, as such tightly knit groups of actors are quite uncommon [28, p.118]. That is why an extension to the idea of clique, the concept of *n-clique*, is used in this paper. The concept of n-clique, where n is the maximum path length (i.e., number of ties) connecting all organisations of the clique,

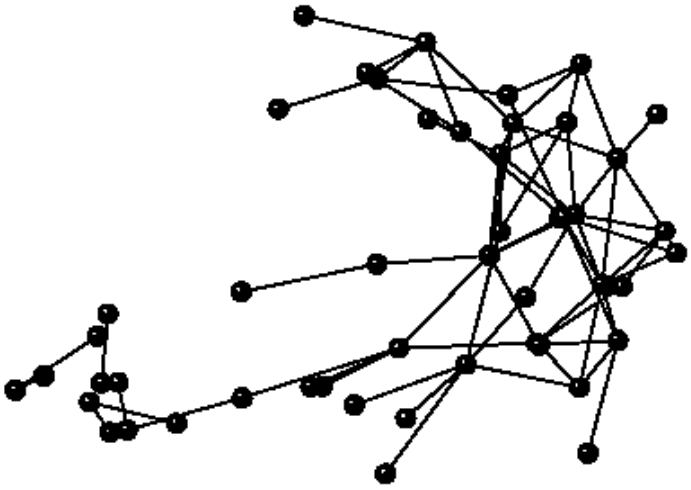
is closer to people's understanding of the word 'clique'. Thus, a 2-clique is one in which all organisations are linked either directly (at distance 1) or indirectly through a common intermediary organisation (distance 2).

Figure 2a Network of venture capital firms in Silicon Valley. Only connected VC firms shown (N=78)



Source: PricewaterhouseCoopers 1995-1998

Figure 2b Network of venture capital firms in Route 128. Only connected VC firms shown (N=49)



Source: PricewaterhouseCoopers 1995-1998

Table 2a Network analysis for venture capital firms in Silicon Valley and Route 128 (1985-1998)

	VC Firms in Silicon Valley (N=111)	*VC Firms in Route 128 (N=91)*
Number of ties to other venture capital firms:		
None	29.7%	46.2%
1 to 3	40.5	37.4
4 to 6	15.3	13.2
7 to 9	7.2	3.3
Ten or more	7.2	0.0
	100%	100%
Average number of ties:	2.81	1.53
Standard Deviation:	3.35	2.09
Maximum number of ties:	15	8
Normalised Degree Centrality:		
Mean	2.56	1.71
Standard Deviation	3.04	2.31
Minimum	0.00	0.00
Maximum	13.64	8.89
Network Centralisation	11.28%	7.34%
Closeness Centrality:		
Mean	2.11	1.47
Standard Deviation	0.82	0.41
Minimum	0.90	1.10
Maximum	2.71	1.94
Network Centralisation	1.23%	0.95%
Betweeness Centrality:		
Mean	0.96	0.54
Standard Deviation	1.79	1.16
Minimum	0.00	0.00
Maximum	9.34	6.68
Network Centralisation	8.46%	6.21%

Source: PricewaterhouseCoopers 1995-1998 (first quarter)

To create the graphic representation of networks of VC firms in both Silicon Valley and Route 128, MAGE is used again. Each node represents a VC firm; the presence of a tie between two firms indicates that both firms have at least one investee company in common. Figure 2a shows the graph for VC firms in Silicon Valley. For the purposes of getting a clearer picture of the network of financial cooperation, I deleted (also from the graph in Figure 2b) those VC firms which are isolates (i.e., that do not have any tie to any other VC firms in the same region). Hence, the graph of connected VC firms in Silicon Valley includes 78 firms (70% of all 111 firms surveyed in the Silicon Valley region). Only the connected VC firms in Route 128 (54% of all 91 firms) are graphically represented in Figure 2b. In Silicon Valley, during the 1995-1998 period, there are 78 connected VC firms and 312 lines between the pairs of firms. By contrast, the network of

connected VC firms for Route 128 during the same period has almost half the size of the Silicon Valley one: 49 firms and 140 lines between the pairs of firms. The density of the network in Route 128 is (including isolates) 0.017; the network in Route 128 is 50% less dense than the network in Silicon Valley.

The network of VC firms in Silicon Valley is clearly denser overall, which in substantive terms, suggests that VC firms in Silicon Valley cooperate with other local firms more often than in Route 128. The average number of ties is 2.8 for Silicon Valley VCs versus 1.5 for VCs in Route 128. Over 14% of VCs in Silicon Valley have more than seven ties (with a maximum of 15 ties) to other VCs in the region. The figure is much lower (3.3%) for VCs in Route 128 (with a maximum of eight ties). In addition, the network of firms in Silicon Valley scores higher in all network centralisation measures (when compared to Route 128). The Degree Network Centralisation is 11.28% for Silicon Valley (7.34 for Route 128); Closeness Centralisation is 1.23% (versus 0.95) and the Betweenness Centralisation is 8.46 (versus 6.21).

The network analysis of components and cliques in both networks of VC firms is summarised in Table 2b. Not surprisingly, the Table confirms that the social network in Silicon Valley is much more cohesive and connected than the one in Route 128. In Silicon Valley there are only two components with two or more VC firms. The main component consists of 76 VC firms. The other component consists of two firms which cooperate with each other but do not cooperate with other Silicon Valley VC firms (i.e., this is the case of *Charter Venture Capital* in Palo Alto and *Peregrine Venture* in Cupertino). By contrast, in Route 128, the major component contains 41 VC firms, with three additional components with only two and three members.

Table 2b A comparative analysis of cohesive groups of venture capital firms in Silicon Valley and Route 128 (1995-1998)

	Silicon Valley	*Route 128*
Components with 2 or more firms	2	4
Cliques (minimum size 3 VC firms)	45	12
2-Cliques (minimum size 10 VC firms)	70	1
K-Cores	2	4
Number of Venture Capital Firms:	111	91

Source: PricewaterhouseCoopers 1995-1998 (first quarter)

But the differences between the two regional social networks are even more striking and supportive of my hypothesis, when one examines the number of cliques, 2-cliques of size 10 and even k-cores. For example, there are 45 cliques of minimum size 3 (in comparison with only 12 in Route 128). The much higher numbers are consistently found for the Silicon Valley network of VC firms empirically supporting the hypothesis that social networks present in Route 128 are much less cohesive than the ones in Silicon Valley. In addition, cliques in Silicon Valley, do in fact, overlap more than in Route 128. That is, the same VC firms or set of VC firms belong to one or more cliques of firms.

Table 3 Descriptive statistics for the number of companies funded and the amount of money invested for venture capital firms in Silicon Valley and Route 128 (1995-1998)

	VC Firms in Silicon Valley N=111)			*VC Firms in Route 128 (N=91)*				*All VC firms (N=202)*		
	Mean	*Std. Dev.*	*Max.*	*Mean*	*Std. Dev.*	*Max.*	*Mean Difference*	*Mean*	*Std. Dev.*	*Max.*
Number of companies funded:										
In California	11.14	15.22	90	2.29	5.04	33	8.86***	7.15	12.56	90
In Massachusetts	0.91	2.23	16	5.35	7.91	42	-4.44***	2.91	5.97	42
Overall	15.98	20.90	111	12.60	15.30	62	3.38	14.46	18.62	111
Amount of money invested (in millions of $):										
In companies in California	52.46	78.26	427	13.73	50.21	460	38.72***	35.01	69.67	460
In companies in Massachusetts	4.37	10.56	64	16.87	28.98	156	-12.50***	10.00	21.81	156
Overall	78.73	108.75	517	64.26	116.20	802	14.48	72.21	112.12	802
Percent of funded companies located in the same state where the funding VC firm is located.	69.01%	30.80	100	40.74%	35.63	100	28.27***	56.28%	35.87	100
Percent of the amount of money invested in companies located in the same state where the VC firm is located.	68.39%	32.74	100	39.21%	37.23	100	29.18***	55.24%	37.67	100

*** p<.001; ** p<.01; * p<.05 (two-tailed t-tests).

Source: PricewaterhouseCoopers 1995-1998 (first quarter).

3.2 A comparative analysis of venture capital funding in Silicon Valley and Route 128

One of the most important differences between VC firms in Silicon Valley and Route 128 is the number of funded companies. Whereas the number of investee companies for VC firms in Silicon Valley is 1,787, the number for VC firms in Route 128 is 1,163. Table 3 shows some descriptive statistics for the number of investments or investee companies and the amount of capital invested by VC firms in Silicon Valley and VC firms in Route 128.

Many interesting investment patterns can be highlighted from Table 3. VC firms in Silicon Valley invest in a higher number of companies located in California, whereas VC firms in Route 128 invest comparatively in a higher number of companies located in Massachusetts where Route 128 is located. These differences are statistically significant at the 0.001 level. The same pattern emerges when the amount of money invested in millions of dollars is examined. The difference of almost 40 millions of dollars in the amount of money invested by VCs in Silicon Valley and VCs in Route 128 in California is enormous. VCs in Route 128 invest in Massachusetts over 12 millions more than Silicon Valley VCs. In relative terms, VC firms in Silicon Valley fund a higher percentage of local companies and invest 'locally' a higher percentage of money (almost 70% of their funded companies and amount of money goes to local firms; versus 40% in the case of VC firms in Route 128). These differences are statistically significant at the 0.001 level.

Table 4 shows the count of funded companies by location of the VC firm (either Silicon Valley or Route 128), location of the investee company (i.e., whether the investee company is located in the same state where the VC firm is or not), stage of the investee company and industry of the investee company. Several chi-square tests of independence between location of VC firm and stage of the investee company, location of VC firm and industry of the investee company and location of VC firm and location of investee company suggest that there are important (and significant) differences in the patterns of investment of VC firms in Silicon Valley and Route 128.

Over 50% of the portfolio of VC firms in Silicon Valley consists of investee companies in their first, second and third stages of development; it is less than 40% of the Route 128 VC firms' portfolios. VC firms in Route 128 tend to invest much more in buy-outs and follow-on investee companies (23.5% of investments versus 11% in the case of Silicon Valley VC firms). These differences in the number of investments by stage between VC firms in Silicon Valley and Route 128 are statistically significant at the 0.001 level (chi-square test = 148; df = 11).

Both VC firms in Silicon Valley and in New England invest highly in the Software & Information and the Communications industries (60% of all investee companies in Silicon Valley and almost 48% of all investee companies in Route 128). Clearly, Silicon Valley VC firms have more investments in the Software & Information, Computers & Peripherals and Semi-Conductors/Equipment industries (half of the total number of investments; only about a third of total investments in Route 128). VC firms in Route 128 invest, on the contrary, far more in the healthcare and industrial sectors. All these differences seem to be significant at the 0.001 level (chi-square test = 169; df = 14).

Table 4 Number of investee companies for venture capital firms in Silicon Valley and Route 128, by stage, industry and location of investee company (1995-1998)

	Investments by VC firms in Silicon Valley		*Investments by VC firms in Route 128*		
	Count	*% (a)*	*Count*	*% (a)*	*Chi-Square Tests (df)*
Stage of Investee Company:					
Initial/Seed	145	8.1	96	8.3	
First	362	20.3	201	17.3	
Second	387	21.7	172	14.8	
Third	194	10.9	85	7.3	
Fourth and Beyond	91	5.1	29	2.5	
Bridge/Mezzanine	193	10.8	164	14.1	
Follow-on	185	10.4	204	17.5	
Buyout	14	0.8	70	6.0	
IPO	7	0.4	4	0.3	
Secondary Purchase	9	0.5	12	1.0	
Other	32	1.8	27	2.3	
Not Categorised	168	9.4	99	8.5	148 (11) ***
Industry of Investee Company:					
Biotechnology	91	5.1	70	6.0	
Business Services	51	2.9	46	4.0	
Communications	305	17.1	183	15.7	
Computers & Peripherals	101	5.7	37	3.2	
Consumer	63	3.5	63	5.4	
Distribution/Retailing	37	2.1	60	5.2	
Electronics & Instrumentation	58	3.2	48	4.1	
Environmental	8	0.4	10	0.9	
Healthcare	119	6.7	93	8.0	
Industrial	19	1.1	94	8.1	
Medical Instruments & Devices	95	5.3	51	4.4	
Pharmaceuticals	31	1.7	26	2.2	
Semiconductors/Equipment	25	1.4	4	0.3	
Software & Information	773	43.3	375	32.2	
Not Categorised	11	0.6	3	0.3	169 (14) ***
State Location of Investee Company:					
Different from VC firm	531	30.1	669	57.5	
Same as VC firm	1250	69.9	494	42.5	220 (1) ***
Number of Investments:	1787	100.0	1163	100.0	
Number of Venture Capital Firms:	111		91		

*** p<.001; ** p<.01; * p<.05.
Note: (a) Column percentages.

Source: PricewaterhouseCoopers 1995-1998 (first quarter)

Table 5 Mean amount of money (in $ millions) invested by venture capital firms in Silicon Valley and Route 128, by stage, industry and location of investee company (1995-1998)

	Amount invested by VC firms in Silicon Valley			*Amount invested by VC firms in Route 128*			
	Mean	*Std. Dev.*	*% (a)*	*Mean*	*Std. Dev.*	*% (a)*	*Mean Difference*
Stage of Investee Company:							
Initial/Seed	2.0	2.4	8.1	3.1	13.0	8.3	-1.1
First	4.1	4.5	20.3	3.5	4.2	17.3	0.6
Second	5.4	5.8	21.7	4.9	6.6	14.8	0.4
Third	6.6	5.3	10.9	6.5	8.9	7.3	0.1
Fourth and Beyond	7.7	7.1	5.1	8.6	11.0	2.5	-0.9
Bridge/Mezzanine	2.6	5.3	10.8	2.2	4.6	14.1	0.4
Follow-on	5.6	6.1	10.4	3.6	6.5	17.5	2.0***
Buyout	22.5	17.0	0.8	18.2	24.6	6.0	4.3
IPO	10.0	10.8	0.4	11.1	19.3	0.3	-1.1
Secondary Purchase	4.8	5.5	0.5	5.5	7.2	1.0	-0.8
Other	6.0	8.6	1.8	5.5	8.6	2.3	0.5
Not Categorised	4.5	6.0	9.4	6.1	9.2	8.5	-1.6
Industry of Investee Company:							
Biotechnology	4.8	5.1	5.1	4.9	7.4	6.0	-0.1
Business Services	4.1	5.3	2.9	11.1	19.6	4.0	-6.9*
Communications	6.4	6.9	17.1	7.9	15.5	15.7	-1.5
Computers & Peripherals	6.3	8.2	5.7	6.4	16.5	3.2	-0.1
Consumer	6.8	12.0	3.5	6.0	8.7	5.4	0.8
Distribution/Retailing	5.0	7.5	2.1	6.0	11.4	5.2	-1.0
Electronics & Instrumentation	4.0	5.3	3.2	3.4	5.7	4.1	0.6
Environmental	1.6	2.1	0.4	2.3	4.0	0.9	-0.6
Healthcare	5.4	5.5	6.7	4.5	8.1	8.0	0.9
Industrial	3.7	4.4	1.1	5.4	9.6	8.1	-1.6
Medical Instruments & Devices	4.3	4.9	5.3	2.3	3.0	4.4	2.1**
Pharmaceuticals	4.2	4.5	1.7	3.4	7.9	2.2	0.9
Semiconductors/Equipment	7.2	6.4	1.4	9.3	4.4	0.3	-2.1
Software & Information	4.1	4.7	43.3	3.4	4.6	32.2	0.7**
Not Categorised	4.4	4.2	0.6	4.4	6.6	0.3	0.1
State Location of Investee Company:							
Different from VC firm	5.4	7.0	30.1	6.5	12.4	57.5	-1.1
Same as VC firm	4.7	5.5	69.9	3.1	4.9	42.5	1.5***
Number of Investments:		1787			1163		
Amount of Money (in millions):		8765			5892		
Number of Venture Capital Firms:		111			91		

*** p<.001; ** p<.01; * p<.05 (two-tailed t-tests).

Note: (a) Number of investments as a percentage of the total number of investments or investee companies.

Source: Pricewaterhouse Coopers 1995-1998 (first quarter)

An interesting finding is the pronounced differences in the location of the investee companies. It was already noted that VC firms in Silicon Valley tend to invest more 'locally' than VC firms in Route 128. From 1995 to the first quarter of 1998, 70% of all investee companies for VC firms in Silicon Valley are located in California and only 30% are located somewhere else in the USA. In the case of VC firms in Route 128, only about 42% of their investment stays in Massachusetts. These differences are also statistically significant (chi-square test = 220; df = 1). This supports the hypothesis that VC firms in Silicon Valley fund more companies in the Silicon Valley area, in comparison with VC firms in Route 128 which invest in companies all around the country.

Another important difference between VC firms in Silicon Valley and in Route 128 is the amount of money invested in companies. From 1995 to the first quarter of 1998, the amount of capital invested by VC firms in Silicon Valley is 8.7 billions of dollars in comparison with 5.9 billions in Route 128. Table 5 shows the mean amount of capital invested for VC firms in Silicon Valley and VC firms in Route 128, again, by stage of investee company, industry of investment and state location where funding goes.

Table 5 (last column) also displays the mean difference in the amount of money invested between Silicon Valley and Route 128 VC firms by location of the investee company, stage of the investee company and industry of the investee company. There are not many significant differences according to the several t-tests performed. It is worth noting that the amount invested in software and information by VC funds in Silicon Valley is higher (statistically significant at the 0.001 level). Also, on average, VC firms in Silicon Valley spend $1.5 millions more on investee companies located in their same state (in comparison with Route 128 VC firms). The difference is again statistically significant at the 0.001 level.

4 Conclusion

In the present study, I have shown some of the most important differences in the network structure of venture capital firms in Silicon Valley, compared to the one in Route 128. First, collaboration among venture capital firms in Silicon Valley is more pronounced and dense than in Route 128. The network analyses clearly show that the network of VC firms in Silicon Valley is denser overall, which in substantive terms, illustrates the culture of cooperation among local firms. The average number of ties in Silicon Valley is two times the average number in Route 128. In addition, the network of firms in Silicon Valley scores higher in all centralisation measures. The network analyses of components and cliques in both regional networks of VCs confirm that the social network in Silicon Valley is much more cohesive and connected. Not only is the structure of VCs denser, but also firm participation in such networks is higher. In Silicon Valley, 70% of all VCs cooperate with other VCs in the funding of companies; the percentage is much lower, 50%, in the case of VCs located in Route 128.

Second, the number of investments and the amount of money coming from VC firms in Silicon Valley that stay in Silicon Valley are higher than the number of investments and amount of money invested by Route 128 VC firms in New England. I have supported the view that Silicon Valley VC firms tend to invest more 'locally' than VC firms in other prominent regions in the USA like Route 128. In the case of VC firms in Silicon Valley, almost 70% of their funded companies and 70% of the amount invested go to

local investee firms. It is only 40% in the case of VC firms in Route 128. Differences in the patterns of investments between VCs in Silicon Valley and VCs in Route 128 are quite significant. Over 50% of the portfolio of VC firms in Silicon Valley consists of investee companies in their first, second and third stages of development. VC firms in Route 128 tend to invest much more in buy-outs and follow-on companies. Both firms in Silicon Valley and Route 128 invested substantially in the software and information and communication industries during the three-year period of analysis.

The present structure of the social networks in Silicon Valley and its historical development can explain the higher growth and development of the region in comparison with other regions in the world. This network structure explanation challenges any market-centred theory of regional development. Both Silicon Valley and Route 128 have comparable concentrations of skills and technology and even similar numbers of companies and institutions. However, important network differences emerge when examining the venture capital sector only – the most critical source of capital for many start-up companies since the 1950s. Venture capital in Silicon Valley seems to be more central in the development of the region's social and professional networking in comparison with the more passive role of VC firms in other regions. At the same time, networks of venture capitalists rely on major inflows of technical entrepreneurs, venture capitalists, management talent and supporting services.

A network approach to the study of regions that explores the network structure among important actors of a region can give us a satisfactory account for Silicon Valley's superior performance. My network analysis of venture capital firms and the differences across two regions within the USA is only the beginning of a regional network approach to the understanding of regional development. Entrepreneurial efforts and venture capital activities are indeed more successful when embedded in a densely connected network such as in Silicon Valley. This is mainly because such embeddedness in social networks shapes and facilitates the allocation of resources, support and information necessary for the development of new local organisations and the development and success of the region in the long run.

In general, social networks matter because trust, information, action, cooperation, all operate through social relations. Developing better models that account for these crucial network factors affecting regional development first requires that we understand how they are shaped by networks and reshaped in turn. Regional development, in this sense, may rely more on the structure of networks of social actors since social actors ultimately influence the pattern of economic and organisational practices as well as the institutional infrastructure of a region. In this sense, a network theoretical perspective of regional development should operate under at least five basic premises:

1 organisations are connected to one another and they are therefore members of regional social networks
2 an organisation's environment consists of a network of other organisations and institutions (such as universities, VC firms, law firms, trade associations)
3 the actions (attitudes and behaviours) and their outcomes (performance, survival and legitimacy) of organisations can be best explained in terms of their position in networks of relationships
4 certain networks promote certain actions, but in turn constrain other actions
5 networks of organisations change over time.

Those five premises are important steps to follow when comparing regions and/or industrial districts. A comparative analysis of regional development should therefore pay attention to at least a few of these network premises. It is about time that we learnt more about what kinds of regional networks help to promote superior economic and social development.

The analyses in my paper have also important implications for practice and policy. Any attempt to replicate Silicon Valley is unlikely to succeed (or succeed at the level that Silicon Valley has) unless dense social networks among actors that promote trust and cooperation are simultaneously developed and supported over time. Although establishing venture capital industries and technology parks in an effort to replicate Silicon Valley's infrastructure has been the goal of many governments in the world in recent years, these governments have not necessarily worked to create and maintain beneficial networks across firms not only within the venture capital industry but also across different institutional settings. The case of Taiwan is a successful story of regional development. During the 1970s and 1980s, Taiwanese government agencies and policy makers in their efforts to improve the region's position in the international economy, created a technology park (i.e., the Hsinchu Science-based Industrial Park) and a venture capital industry. Moreover, they recruited Taiwanese and Chinese engineers and entrepreneurs working in the USA to return to Taiwan and they promoted the development of connections to the US market [40,41]. The Taiwanese case suggests that regions aiming to develop in the information technology era need to pay attention not only to the creation of an infrastructure of institutions that funds and supports new firms but also to the facilitation and promotion of financial, technical and technology connections among Taiwanese firms and also between Taiwanese firms and institutions in other regional communities like Silicon Valley.

In my paper, I have attempted to study the venture capital sector and how differences in the network cooperation among VC firms in two regions can explain differences in regional development. Future analyses should extend the network analyses to other economic sectors and institutions. A network approach can help social scientists and policy makers to understand the nature of the relationship between social networks of actors and regional development. Such types of network analyses are indispensable steps for the understanding of industrial and regional economies.

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References and Notes

1 For comprehensive reviews of the wide-ranging literatures on the role of social networks in economic life and network analysis.

2 See Wasserman, S. and Faust, K. (1994) *Social Network Analysis: Methods and Applications,* Cambridge University Press, New York.

3 Powell, W.W. and Smith-Doerr, L. (1994) 'Networks of economic life', *The Handbook of Economic Sociology,* N.J. Smelser and R. Swedberg (Eds.) Princeton University Press, New Jersey, pp.368–402.

4 Saxenian, A. (1990) 'Regional networks and the resurgence of Silicon Valley', *California Management Review,* Vol. 33, pp.89–112.

5 Saxenian, A. (1994) *Regional Advantage: Culture and Competitions in Silicon Valley and Route 128*, Harvard University Press, Massachusetts.

6 Florida, R.L. and Kenney, M. (1987) 'Venture capital and high technology entrepreneurship', *Journal of Business Venturing,* Vol. 3, pp.301–319.

7 Nohria, N. (1992) 'Information and search in the creation of new business ventures: The case of the 128 Venture Group', *Networks and Organizations: Structure, Form and Action*, N. Nohria and R.G. Eccles (Eds.) Harvard Business School Press, Massachusetts, pp.240–261.

8 Harmon, S. (1999) *Zero Gravity: Riding Venture Capital from High-Tech Start-Up to Breakout IPO*, Bloomberg Press, New Jersey.

9 Mintz, B. and Schwartz, M. (1985) *The Power Structure of American Business,* University of Chicago Press, Illinois.

10 Granovetter, M. (1985) 'Economic action and social structure: The problem of embeddedness', *American Journal of Sociology,* Vol. 91, pp.481–510. See also, Granovetter, M. (1974) *Getting a Job: A Study of Contacts and Careers*, Harvard University Press, Massachusetts; Granovetter, M. (1995) 'Coase revisited: business groups in the modern economy', *Industrial and Corporate Change,* Vol. 4, pp.93–131.

11 More detailed results, including an expanded electronic version of this report, can be found in the Money Tree web site at www.pwcmoneytree.com.

12 Joint Venture (2000) *2000 Index of Silicon Valley: Measuring Progress Toward Silicon Valley 2010*; Joint Venture (1999) *Silicon Valley 2010: A Regional Framework for Growing Together*. For more information, visit: http://www.jointventure.org/resources.html.

13 Wilson, J.W. (1985) *The New Venturers: Inside the High-Stakes World of Venture Capital,* Addison-Wesley Publishing Company, California.

14 Asset Management Company's 'West Coast Venture Capital - 25 years' Genealogy Chart 1983. There are some omissions from the chart such as Tom Flowers, Bud Moose and Ray Lyon, who started early SBICs and were leaders of the old *Western Association of Small Business Investment Companies* (WASBIC). These people were not included since they were primarily real estate brokers. WASBIC was the predecessor of today's *Western Association of Venture Capital* (WAVC). The information is current from 1958 up to December 1983, to the best of *Asset Management Company*'s knowledge.

15 For a complete analysis of the historical development of networks of VC firms in Silicon Valley see [16].

16 Castilla, E.J., Hokyu, H., Granovetter, E. and Granovetter, M. (2000) 'Social networks in Silicon Valley', *The Silicon Valley Edge: A Habitat for Innovation and Entrepreneurship,* C-M. Lee, W.F. Miller, M.G. Hancock and H.S. Rower (Eds.) Stanford University Press, California, pp.218–247.

17 A general note that includes references to venture capital literature: see [18–22].

18 Bartlett, J.W. (1998) *Venture Capital: Law. Business Strategies and Investment Planning,* John Wiley & Sons, New York.

19 Bygrave, W.D. and Timmons, J.A. (1992) *Venture Capital at the Crossroads*, Harvard Business School Press, Massachusetts.

20 Eccles, R. and Crane, D. (1998) *Doing Deals: Investment Banks at Work,* Harvard Business School Press, Massachusetts.

21 Halloran, M.J., Benton, L.F., Lovejoy, J.R., Kearney, K.L. and Gunderson, R.V. (1991) *Venture Capital and Public Offering Negotiation,* Prentice-Hall Law & Business, New Jersey.

22 Timmons, J.A. and Sapienza, H.J. (1991) 'Venture capital: More than money?', S.M. Pratt and J. Morris. (Eds.) *Pratt's Guide to Venture Capital Sources,* Venture Economics, Inc., Massachusetts, 15th Edition, pp.35–41.

23 One of the data sets analysed in this paper was collected from the ACI Genealogy chart as part of the project 'Social Networks in Silicon Valley' funded by the Bechtel Initiative, Stanford University, with Mark Granovetter, Emilio J. Castilla and Hokyu Hwang. I especially want to thank Michel Ferrary (ESSEC, France) for his help in accessing the database of venture capital funds and start-up companies organised by PricewaterhouseCoopers. The PricewaterhouseCoopers Money Tree Survey is a quarterly study of equity investments made by the venture capital community in the USA. Survey questionnaires are mailed. For more information about the survey, go to: www.pwcmoneytree.com

24 Richardson, D.C. and Richardson, J. S. (1992) 'The Kinmage: A tool for scientific communication', *Protein Science,* Vol. 1, pp.3–9.

25 MAGE was developed as a device to be used in molecular modelling. It produces three-dimensional scientific illustrations that are presented as interactive computer displays. For learning and downloading the latest version of the MAGE program, visit: http://www.faseb.org/protein/kinemages/kinpage.html. See [26].

26 Freeman, L.C., Webster, C.M. and Kirke, D.M. (1998) 'Exploring social structure using dynamic three-dimensional color images', *Social Networks,* Vol. 20, pp.108–118.

27 The diagram is therefore the visualisation of a valued graph or network: given that in the case of a link between two VC firms, I also know the number of instances in which both VCs co-invested in the same company. The diagram displays the VC firms in a three-dimensional *x* by *y* by *z* space. Location of the points is produced by the multidimensional scaling technique (MDS). So two VC firms with four companies in common, for example, will be closer to one another than two companies which have just three companies in common; how much closer they are in the three-dimensional space is determined by the MDS procedure. The MDS technique is designed to represent proximities among a set of entities in a low-dimensional space so entities that are more proximate to each other in the input data are closer in the space and entities that are less proximate to each other are further apart in the space. The usual input to a multidimensional scaling is a one-mode symmetric matrix consisting of measures of proximity between the pairs of entities. In this case, the input matrix was the adjacency matrix of VC firms in which the cells measure the number of investee companies in common during the 1995–1998 period. The output of multidimensional scaling is a set of estimated distances among pairs of firms, which can be expressed as coordinates in a three dimensional space. Results are also displayed as a diagram in which the coordinates are used to locate the entities in the resulting three-dimensional space. Using multidimensional scaling to study a network shows which subsets of firms are relatively close to each other in a graph theoretic sense and which set of firms are isolates. Because the adjacent matrix of firms by firms to analyse was valued (i.e., non-binary matrix where each of the cells shows the number of investee companies in common for a given pair of VC firms), I use a non-metric method of multidimensional scaling (starting with a metric solution). I use UCINET to run MDS and then MAGE to represent the plot in a three-dimensional space. Multidimensional scaling is a very general data analysis technique. There are numerous texts and articles describing multidimensional scaling. For more information, see [28–30].

28 Scott, J. (1991) *Social Network Analysis,* Sage Publications, California.

29 Krustal, J.B. and Wish, M. (1978) *Multidimensional Scaling,* Sage, California.

30 Coxon, A.P.M. (1982) *The User's Guide to Multidimensional Scaling,* Heinemann, New Hampshire.

31 This does not mean that both VC firms necessarily invested their capital the same quarter or year, or at the same stage of development of the investee company. Rather they could both have participated in the financing of the investee company at any stage in the 1995–1998 period of time here analysed.

32 Freeman, L.C. (1979) 'Centrality in social networks: conceptual clarification', *Social Networks,* Vol. 1, pp.215–239.

33 The standardisation of such crude degree measure is achieved through dividing degree centrality by the number of firms in the network minus one. Thus, the standardised centrality degree thus is the proportion of other VC firms who are connected to a given VC firm.

34 In general, the firm betweenness index for the i^{th} firm is simply the sum of the estimated probabilities over all pairs of firms in the network not including the i^{th} firm. So, this index, which counts how 'between' each of the firms is, is a sum of probabilities. It has the minimum of zero, attained when the firm falls on no geodesics. Its maximum happens when the firm falls on all geodesics [2, Ch. 5]. In the example of the A, B and C case, the standardised betweenness centrality is 1 for B (or 100%, if betweenness is measured as a percentage) and 0 for A and C.

35 In a network of N organisations, an organisation obtains the highest possible betweenness score when all N–1 other organisations are tied only to that organisation. In this case the focal organisation would lie on all the geodesics in the network and would be called a 'star'. The relative betweenness of a point is a ratio that measures the extent to which a point in a network approaches the betweenness score of a star [32]. An organisation's relative betweenness can vary from a minimum of 0, when it lies on no geodesics, to a maximum of 1, when the organisation is a star. See [32].

36 The non-standardised centrality measures are dependent on the group size and hence are difficult to compare across different networks. In general, the standardised centrality indexes are independent of the group size and can be compared across networks of different sizes [2]. The minimum value of any centrality index is 0 but the maximum value is 100 (when the standardised centrality measures are expressed as percentages).

37 UCINET 5 for Windows, a computer software, was used to perform all network analyses of this paper. Borgatti, S., Everett, M. and Freeman, L. (1999) *UCINET 5.0 Version 1.00*, Analytic Technologies, Massachusetts.

38 Within a component, all points are connected through paths, but no paths run to points outside the component [28, p.104]. If there is only one component, the graph is connected. If there is more than one component, the network is disconnected [28].

39 Clique is a very strict definition of a cohesive group [2, p.256]. The absence of a single tie or 'cooperation' in the funding of a similar company will prevent a subgroup of firms from being a clique. This definition is, still, very useful for the purposes of this paper since one of the points I want to make is that in a sparse network of VC firms such as Route 128 there are very few cliques. By contrast, in Silicon Valley, I find a larger number of cliques, which are quite large and which overlap one another.

40 Kraemer, K., Dedrick, J., Hwang, C-Y., Tu, T-C. and Yap, C-S. (1996) 'Entrepreneurship, flexibility and policy coordination: Taiwan's computer industry', *The Information Society,* Vol. 12, pp.215–249.

41 Mathews, J.A. 'A Silicon Valley of the East: Creating Taiwan's semiconductor industry', *California Management Review,* Vol. 39, No. 4.