Venture Capital Formation, Investment, and Regional Industrialization

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Abstract. Venture capital is an important element of regional capital formation, technological innovation and regional industrialization. While neoclassical economic theory assumes perfectly free capital markets, geographers have long noted the spatial dimensions of finance and investment. This paper introduces metropolitan-level data on venture capital and develops statistical models for both the location of venture capital (supply) and the spatial distribution of investment (demand). The findings suggest that venture capital is characterized by: (1) high degrees of capital mobility operating through a well-defined spatial structure, (2) investment flows to the areas of greatest opportunity and return on investment, and (3) the development of specialized sources of venture capital supply around both established financial centers and centers of high-technology industry. Geographic proximity is required to reduce uncertainty, compensate for ambiguous information, and minimize investment risk. Investment pooling, or coinvestment, facilitates capital flows, and also loosens the spatial constraint on venture capital. Capital mobility occurs, not through the operation of a free market, but through the network structure of the venture capital industry, which is strongly rooted in geography.

Key Words: Venture capital, investment, capital formation, regional industrialization, high-technology.

VENTURE capital (VC) is an important element in the processes of capital formation, technological innovation, and regional industrialization. Economic theory assumes perfectly free and mobile capital markets (see Stiglitz 1982) and from this perspective, VC would be expected to flow freely across space. But studies (Bean, et al. 1973; Florida and Kenney 1988b) indicate that VC is a unique form of finance, combining elements of financial and industrial activity. Venture investing is characterized by uncertainty, risk, and ambiguous information. Geographic proximity to investments provides a way for venture capitalists to cope with uncertainty and reduce risk. Venture capitalists are involved in oversight and management of their investments. Surveys report that venture capitalists prefer to be close to their investments to screen, monitor, and assist in their management (U.S. Congress, Joint Economic Committee 1984). Government intervention in the VC market has been premised upon the concept of market imperfections, or "regional capital gaps," which allegedly hinder the ability of areas to develop high-technology industries. Our research explores the spatial distribution of VC in light of a more general conceptual debate occurring at the intersection of economics and geography.

Institutional economists and geographers have long argued that investment flows are subject to market imperfections and spatial rigidities. Myrdal (1957) suggested that investment is a cumulative process shaped by the existing distribution of productive activity and previous investments, and subject to incremental change. Clark, et al. (1986; also Gertler 1983, 1984, 1987) conceptualized the investment process as one of "dynamic adjustment" where previous investment patterns influence and shape new investments. Schumpeter (1934) argued that "exceptional entrepreneurs" funded by new groups of financiers were at times required in order to overcome the risks associated with technological innovation.[1] Ge-

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ographers and regional scientists have long noted the tendency of financial institutions to agglomerate. Hoover and Vernon (1962) suggested that the clustering of financial institutions was a product of the specialized, information-intensive, and transactional nature of finance capital. Thompson (1968) noted that established financial centers serve as incubators for new financial services.

There are compelling theoretical reasons to expect the demand for VC to be geographically concentrated. Ever since Marshall (1900), regional economists and geographers have noted the presence of agglomeration or localization economies, a form of external scale economy, in the location and organization of industrial activity. Krugman (1991a, b) made a strong case for the regional specialization of industrial activity based on increasing returns and simple pecuniary externalities (see also David and Rosenbloom 1990). Arthur (1986, 1988, 1990) argued that locational clusters are likely outcomes, given increasing returns, historical "path-dependence," and locational "lock-in." Thus, both from the viewpoint of classical industrial geography and from the recent "increasing returns" perspective in economics, one would expect to see a spatial concentration of the industries that comprise the main source of demand for VC.

A handful of empirical studies examine the geography of VC (Green 1989; Green and McNaughton 1988; Leinbach and Amrhein 1987; Florida and Kenney 1988a, c). The consensus view in the literature is that VC is geographically concentrated and that VC investments are unevenly distributed (see Thompson 1989 for a review). But most studies of the geography of VC rely on highly aggregated data and thus provide only a partial picture of the spatial distribution of VC. We are unaware of any academic research that has attempted to develop and test theoretically-informed statistical models of the geography of venture capital. Our research explores the spatial distribution of venture capital and the factors that influence that geography. We distinguish between two basic dimensions: the location of VC funds (supply) and the geography of VC investment (demand). We introduce new data on the spatial distribution of supply and investment at the metropolitan statistical area (MSA) level. The MSA level provides a relatively small and homogeneous geographic unit, which limits its potential problems related to "ecological fallacy." We develop and test statistical models of the geography of VC supply and investment.

Venture Capital in Economic and Geographic Theory

There is a growing body of literature on VC from the perspective of both economic and geographic theory. This literature emphasizes the connection between VC and high-technology industry (Kozmetsky et al. 1985; Soussou 1985; Florida and Kenney 1988a, b; Bygrave and Timmons 1992). VC is defined as a unique form of capital that involves the exchange of capital for an ownership stake in the firm (Wilson 1985; Kozmetsky et al. 1985; Sahlman 1991). This equity arrangement allows the venture capitalist to generate extraordinary profits (Timmons and Bygrave 1986). A study of the performance of 10 leading VC funds found that of 525 separate investments made during 1972–83, only 56 investments (or 10.7 percent) generated more than half ($450 million) of the total value held in portfolio ($823 million), while roughly half (266) either broke even or lost money (Horsley, Keough and Associates 1986).

Bean, et al. (1975) and Tyebjee and Bruno (1984) conceptualized VC investment as a stage process that includes screening, investment, monitoring, management assistance, and liquidation or exit. Investment pooling or "coinvestment" links VC firms together in local, regional, and national networks. A survey of venture capitalists found that approximately 90 percent of all investments involve coinvestment partners (U.S. Congress, Joint Economic Committee 1985). Timmons and Bygrave (1986) noted that coinvestment allows venture capitalists to pool expertise, diversify their portfolios, and share information and risk. They distinguished between "lead investors," who identify and monitor investment opportunities and organize investment syndicates, and "follow-on investors," who provide additional external sources of capital.

The characteristic that distinguishes VC from other types of risk capital is that it is highly organized and institutionalized (Bygrave and Timmons 1992; Reiner 1989; Florida and Kenney 1988b; Wilson 1985; Kozmetsky et al.

1985). Janeway (1986) explored VC in relation to the theories of Marx, Schumpeter, Keynes, and Braudel and concluded that it is a new, institutionalized form of finance capital which has grown up to bear the high risks associated with the new high-technology industries and to help organize the innovative process, and that venture capitalists are "a hybrid species of capitalist and entrepreneur" (Janeway 1986, 440). A recent study by Porter (1992) noted the ability of the VC industry to finance and nurture emerging industries as an important feature of the U.S. system of capital allocation, which tends to underinvest in productive activity and is characterized by short-term investment horizons.

The geographic literature suggests that VC is highly concentrated (Rubel 1975; Charles River Associates 1976; Venture Economics 1983; U.S. Office of Technology Assessment 1984; Leinbach and Amrhein 1987; Green 1987; Green and McNaughton 1988). There is a general assumption in the literature that the concentration of VC funds or the supply of VC is coincident with the location of high-technology industry. This association is in turn reflected in state and local economic development policies, which are premised on the rationale that the creation or enhancement of local VC supply will stimulate local high technology. But recent evidence (Florida and Kenney 1988a, c; Florida and Smith 1990) indicates that there are multiple determinants of VC location, which is in traditional financial centers (e.g., New York and Chicago) and established high-technology industrial complexes (e.g., Silicon Valley, California, and Route 128 around Boston).

The literature further suggests that VC investment is geographically concentrated and uneven. Leinbach and Amrhein (1987) used regional data to analyze regional variations in investment, concluding that the Pacific Southwest, New England, and the Gulf Coast/Southwest regions attract the largest volumes. While this work provided a good first cut on the issue, interesting substate and local differences in the VC industry are ignored. McNaughton and Green (1986) used Small Business Investment Corporation (SBIC) investment data as a proxy for VC investment, concluding that venture capitalists invest mainly in local industries. But SBICs are a less important type of VC institution whose investment patterns may differ from those of other institutions. Green (1989) and Green and McNaughton (1988) used the geographic investment preferences reported by venture capitalists to derive a set of preference indicators, concluding that venture capitalists have no geographic preference within the entire U.S. But the preferences reported are not necessarily followed in practice. Florida and Kenney (1988a) found that VC investments flowed mainly to established high-technology centers such as Silicon Valley and Route 128. They further found that while these capitalists in the high-technology centers invested locally, those in financial centers such as New York and Chicago tended to export their capital to established high-technology regions.

We explore the main factors responsible for the spatial distribution of VC supply and investment in light of the main themes and questions identified in the literature. The analysis begins by examining state and metropolitan-level data on the organization and geography of the industry. We then use statistical models to test a series of hypotheses about the geography of VC supply and investment.

Organization and Spatial Structure of Venture Capital

The VC industry has experienced significant growth over the past three decades. The pool of VC increased from roughly $2.5 billion in the late 1960s to more than $33 billion dollars by 1990. But the amount of new capital flowing into VC has declined in recent years. Venture capitalists invested $4 billion dollars in 1338 companies in 1988; of this total, 401 companies or roughly $1 billion dollars were first-time financing. High-technology industries received the bulk of VC investment. In 1988 venture capitalists placed 23 percent of their investments in computer hardware and software, 14 percent in telecommunications, 12 percent in medical technology, 9 percent in electronics and 6 percent in biotechnology (Table 1).

Venture capitalists provide a significant share of the total pool of risk capital for new business formations. Gupta (1990) reported that venture capitalists provided roughly 15 percent of all capital to "emerging growth businesses" in 1988; 35 percent came from individual investors, 25 percent from corporations, 15 percent from federal small business innovation research

Table 1. Share of Venture Capital Investment by Industry Sector

Industry	Percent of investment
Consumer products	17
Telecommunications	14
Computer hardware	13
Medical technologies	12
Computer software	10
Electronics	9
Biotechnology	6
Industrial products	6
Energy	2
Other	11

Source: Venture Economics (1988).

grants, and 10 percent from state and local economic development agencies. These capitalists are short-to-medium-term investors holding their stake in the company for 5–7 years, at which point the company is brought to market, merged, or sold off to another company. VC partnerships have a limited life course of 7–10 years, at which time the capital gains and equity shares accrued by the fund are distributed to the investors in the fund.

There are a variety of institutional types of VC. Private limited partnerships comprise by far the largest share of the industry, and have witnessed significant growth during the 1970s and 1980s. These partnerships are independent private funds comprised of professional venture capitalists who function as "general partners" and outside investors who function as "limited partners" and whose liability is limited to their investment in the fund. In 1988 limited partnerships managed on average between $30 million in capital; however, a number of large megafunds managed more than $500 million. The next largest group of VC funds were the subsidiaries of large financial institutions. In 1988 there were 85 (13 percent) of these, holding roughly $2.9 billion (9 percent) in capital, or an average of $15 million in capital. VC subsidiaries of industrial corporations were next with 84 funds (13 percent) and $2 billion (7 percent) in capital for an average size of $16.5 million (Venture Economics 1989, 5–11). There were 91 SBICs actively involved in VC; they accounted for only a very small amount, roughly $460 million, or 1.4 percent of the total pool, averaging just $2.5 million each in capital.

Outside the formal, institutional industry is a large group of independent informal investors, mainly wealthy individuals, referred to as "angels." Gaston (1989) estimated that there are approximately 720,000 informal investors nationwide who control more than $36 billion in capital and invest in approximately 87,000 entrepreneurial businesses per year. Their investment behavior is more localized and less technology-oriented than that of professional VC funds.

Location of Venture Capital

The location of VC offices in leading states over time is presented in Table 2. From 1973–87 there was a shift from established financial centers such as New York and Chicago to the new centers of high-technology industry, including Silicon Valley and Route 128. The number of VC offices in California increased from 98 to 247, while the number in New York experienced a modest decline from 164 to 158. California's share of the national total of offices increased by 9 percent, while New York's share witnessed an 11-percent decline. Illinois experienced a 2-percent decline in the national share of VC offices.

The location of VC fund offices at the MSA level is presented in Figure 1, supplemented by Table 3, which ranks the leading MSAs on the basis of VC office location. At the MSA level, there is clear unevenness, with the top 5 MSAs controlling roughly 46.5 percent of total offices. But 27 MSAs in 17 states possess 7 or more funds (one percent of the national total). These include rustbelt and sunbelt locations as well as established high-technology centers and traditional financial centers.

The change in the dollar volume of VC supply between 1977–89 is illustrated in Table 4. Note the tremendous rise in the amount and share of resources controlled by the leading high-technology areas, most notably California. In 1977 California controlled $524 million or 21 percent of the total pool; by 1989 it controlled more than $10 billion in VC, or 31 percent of the pool. Massachusetts registered a slight increase in share from 13–15 percent. New York, which was the leading center in 1977 with $718 million or 28 percent of the pool, saw its share of the pool decrease to 22 percent. Illinois's share of the total VC was cut in half, falling from 10 to 5 percent of the total pool.

Taken together, these data identify a shift in the location of supply from traditional financial centers towards the new high-technology in-

Table 2. Venture Capital Offices for the Top Twenty States, 1973–87

1987 Rank	State	1973	1987	Total change	Percentage change
1	California	98 (16.0)	247 (25.0)	149	+152.0
2	New York	164 (27.0)	158 (16.0)	–6	–3.7
3	Massachusetts	57 (9.0)	86 (9.0)	29	+50.9
4	Texas	28 (5.0)	66 (7.0)	38	+135.7
5	Connecticut	29 (5.0)	39 (4.0)	10	+34.5
5	Pennsylvania	24 (4.0)	39 (4.0)	15	+62.5
7	Illinois	34 (6.0)	38 (4.0)	4	+29.4
8	New Jersey	20 (3.0)	26 (3.0)	6	+30.0
9	Colorado	7 (1.0)	22 (2.0)	15	+214.3
10	Ohio	18 (6.0)	20 (4.0)	2	+11.1
11	Minnesota	10 (1.6)	17 (1.7)	7	+70.0
11	Washington, DC	11 (1.8)	17 (1.7)	6	+54.5
13	Maryland	5 (0.8)	16 (1.6)	11	+220.0
14	Washington	3 (0.5)	15 (1.5)	12	+400.0
14	Wisconsin	13 (2.1)	15 (1.5)	2	+15.3
16	Florida	13 (2.1)	13 (1.3)	0	+0.0
16	Georgia	9 (1.4)	13 (1.3)	4	+44.4
18	Michigan	3 (0.5)	12 (1.2)	9	+300.0
18	Oregon	3 (.5)	12 (1.2)	9	+300.0
20	North Carolina	4 (.6)	11 (1.1)	7	+175.0
	National totals	617	974	357	+57.9

Sources: Rubel (1974); Venture Economics (1989).

dustrial complexes. By the 1970s and 1980s, these high-technology complexes developed indigenous sources of VC. Whereas VC originally came from outside these complexes, it later became a central element of them. Regional industrial development and regional capital formation grew up in tandem over time, creating a system of indigenous financial intermediaries articulated to technology complexes.

Venture Capital Investment

Investment flows among the leading MSAs are identified in Table 5. San Francisco, New York, Boston, San José, Chicago, and Los Angeles represent the top six MSAs in terms of investments made—no other MSA made more than 200 investments. Figure 2 shows VC investments at the MSA level. These data suggest a dual pattern of investment. On the one hand, VC is highly mobile and on the other, it is very concentrated. Venture capitalists in four leading MSAs, New York, San Francisco, Los Angeles, and Chicago, exported between 85–95 percent of their investments. The flow of capital was toward high-technology complexes such as San Jose and Boston, which attracted 2462 and 884 investments respectively. The newer high-technology centers of Dallas, San Diego,

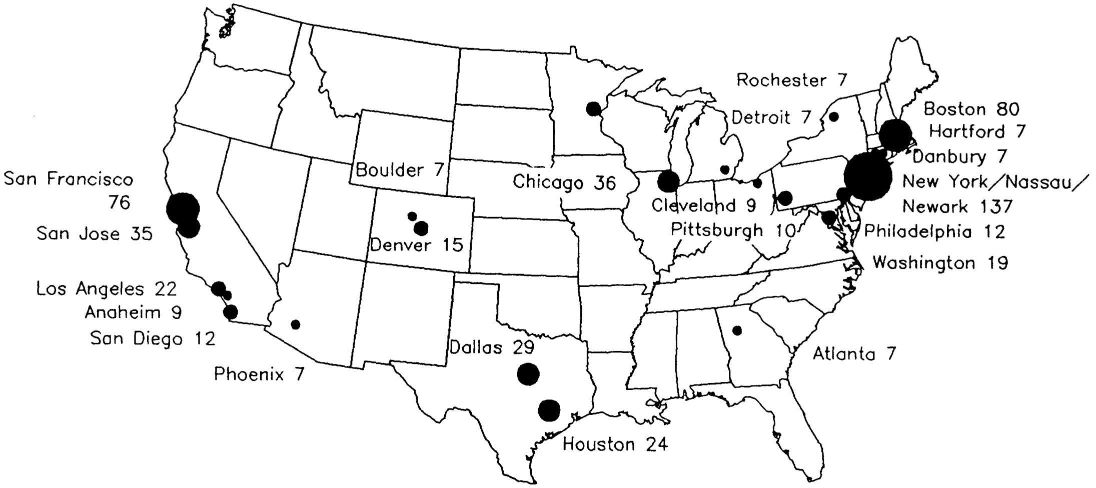

Figure 1. Geographic distribution of venture capital offices by MSA, 1987. Source: Pratt and Morris (1988).

Table 3. Location of Venture Capital Fund Offices by MSA, 1986

MSA	Number of offices	Share of total %	Venture capital conc. index[a]
1 New York, NY	125	15.9	47.99
2 Boston, MA	81	10.3	31.10
3 San Francisco, CA	81	10.3	31.10
4 Chicago, IL	38	4.8	14.59
5 San Jose, CA	37	4.7	14.21
6 Dallas, TX	29	3.7	11.13
7 Houston, TX	24	3.1	9.21
8 Los Angeles, CA	22	2.8	8.45
9 Washington, DC	22	2.8	8.45
10 Minneapolis, MN	15	1.9	5.76
11 Denver, CO	13	1.7	4.99
12 Philadelphia, PA	13	1.7	4.99
13 Seattle, WA	12	1.5	4.61
14 San Diego, CA	12	1.5	4.61
15 Pittsburgh, PA	12	1.5	4.61
16 Cleveland, OH	11	1.4	4.22
17 Anaheim, CA	10	1.3	3.84
18 Nassau, NY	9	1.1	3.46
19 Newark, NJ	8	1.0	3.07
20 Danbury, CT	8	1.0	3.07
21 Atlanta, GA	7	0.9	2.69
22 Detroit, MI	7	0.9	2.69
23 Boulder, CO	7	0.9	2.69
24 Providence, RI	7	0.9	2.69
25 Rochester, NY	7	0.9	2.69
26 Hartford, CT	7	0.9	2.69
27 Phoenix, AZ	7	0.9	2.69
National total	784	100.0	1.00 (avg.)

[a]Venture Capital Concentration Index is calculated as follows: $\frac{\text{Number of Venture Capital Offices in MSA}}{\text{Average Number of VC Offices per MSA}}$

Source: Pratt and Morris (1988).

Table 4. Venture Capital Supply by Leading Centers, 1977–89[a] (Millions of Dollars)

	1977	1982	1987	1989	Change
California	$524	$1,509	$8,710	$10,180	$9,656
	(21)	(22)	(30)	(31)	
New York	718	1,835	6,390	7,480	6,762
	(28)	(27)	(22)	(22)	
Massachusetts	334	892	4,260	5,080	4,746
	(13)	(13)	(15)	(15)	
Illinois	255	808	1,570	1,690	1,435
	(10)	(12)	(5)	(5)	
Texas	83	259	1,230	1,160	1,077
	(3)	(4)	(4)	(3)	
Connecticut	89	276	1,220	1,650	1,561
	(4)	(4)	(4)	(5)	
Total	$2,521	$6,711	$29,020	$33,400	$30,879

[a]Centers with more than $1 billion in 1989.
Source: Compiled from Venture Economics 1977–89.

Boulder, and Los Angeles-Anaheim received lower levels of investment. Together the San Jose and Boston MSAs attracted almost two-thirds (63 percent) of the investments made by San Francisco venture capitalists and roughly one half (47 percent) of the investments made by New York venture capitalists. On the other hand, a small number of MSAs were characterized by a high level of local VC investment. San Jose venture capitalists, for example, made 45 percent of their investments locally. These figures suggest an overall pattern of highly mobile capital flows, overlain on a landscape which is defined by pockets of extreme spatial concentration.

Venture Capital Coinvestment

Coinvestment patterns for the three most active states, California, New York, and Massachusetts, are depicted in Table 5, and detailed maps of coinvestment flows at the MSA level

Table 5. Investment Patterns for Leading MSAs[a]

Destination of investment	San Francisco	New York	Boston	San Jose	Chicago	Los Angeles	Total investment received
San Jose, CA	845	340	191	255	41	54	2462
Boston, MA	95	165	295	18	33	5	884
San Francisco, CA	144	66	37	43	11	6	441
Dallas, TX	45	43	29	13	6	7	313
Oakland, CA	107	24	15	36	2	9	304
San Diego, CA	64	38	26	24	5	15	335
Portland, OR	68	38	20	18	7	8	253
Anaheim, CA	48	30	24	12	5	31	265
Minneapolis, MN	1	12	9	3	6	9	210
Boulder, CO	57	16	15	11	19	2	244
Los Angeles, CA	26	31	14	6	9	29	196
Houston, TX	27	20	5	4	14	1	158
Seattle, WA	50	21	8	1	7	2	186
New York, NY	8	49	8	10	5	2	149
Chicago, IL	2	8	4	3	46	0	99
Other	312	373	346	115	104	63	
Total for MSA	1899	1274	1046	572	320	243	
Percentage inside MSA	7.6	3.8	28.2	44.6	14.4	11.9	
Percentage San Jose or Boston	62.7	46.7	51.4	61.5	27.2	30.5	

[a]This measures the total number of investment decisions for the period 1983–87. There were 9326 total investment decisions for this period.
Source: Authors' database as compiled from "News of Venture Capital Companies," *Venture Capital Journal* 1984–87.

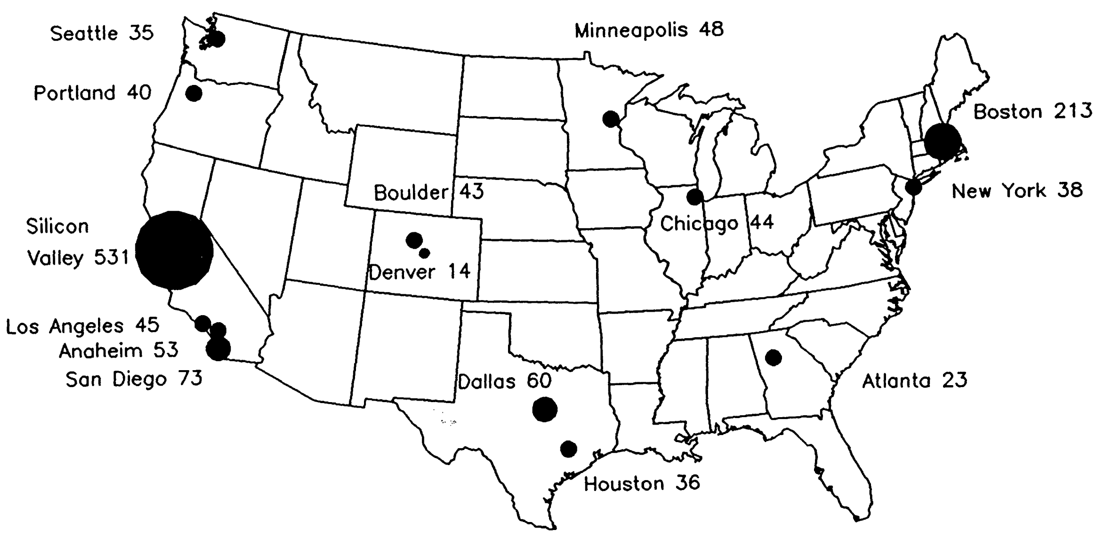

Figure 2. Geographic distribution of venture capital investments by MSA, 1982–87.
Source: Authors' database as compiled from "News of Venture Capital Companies," *Venture Capital Journal,* (Monthly, January 1984–December 1987).

Table 6. Venture Capital Coinvestments by Leading States

State	CA	NY	MA	CT	IL	TX	MN	CO
California	12884	3434	1941	1232	404	540	286	251
New York	3434	3134	1004	649	261	274	107	106
Massachusetts	1941	1004	2420	347	204	211	125	57

Source: Authors' database as compiled from "News of Venture Capital Companies" (1984–87).

for San Jose (Silicon Valley), New York, and Boston are provided in Figure 3. As these data show, New York venture capitalists, for example, coinvested frequently with California (3434) and Massachusetts (1004) venture capitalists, using these outside coinvestments to participate in investments initiated and supervised by "lead" venture capitalists in Silicon Valley and Route 128. Massachusetts venture capitalists coinvested frequently in California (1941) and New York (1004). While California capitalists also coinvested frequently with their counterparts in New York and Massachusetts, they engaged in a much higher level of internal coinvestment, placing more than 12,000 investments with other California venture capitalists. High levels of networking, investment pooling, and local investment among California venture capitalists further highlight the embeddedness of VC in the Silicon Valley high-technology complex.

The geography of the VC industry can be theorized as follows. VC originally grew up around established concentrations of financial institutions where resources were plentiful. This is in line with traditional economic geographic theory, which suggests that established concentrations of finance incubate new forms of financial services. But VC developed gradually within the new outposts of high-technology industry. It did so as the more general processes of regional technological and industrial development accelerated the process of regional capital accumulation, thereby generating indigenous pools of capital. The nature of the process enhanced this spatial shift. The uncertain, high-risk nature of venture investing required local financiers to identify, monitor, supervise, and assist with investments. Local venture capitalists emerged to reduce investment risk and compensate for ambiguous information by providing specialized knowl-

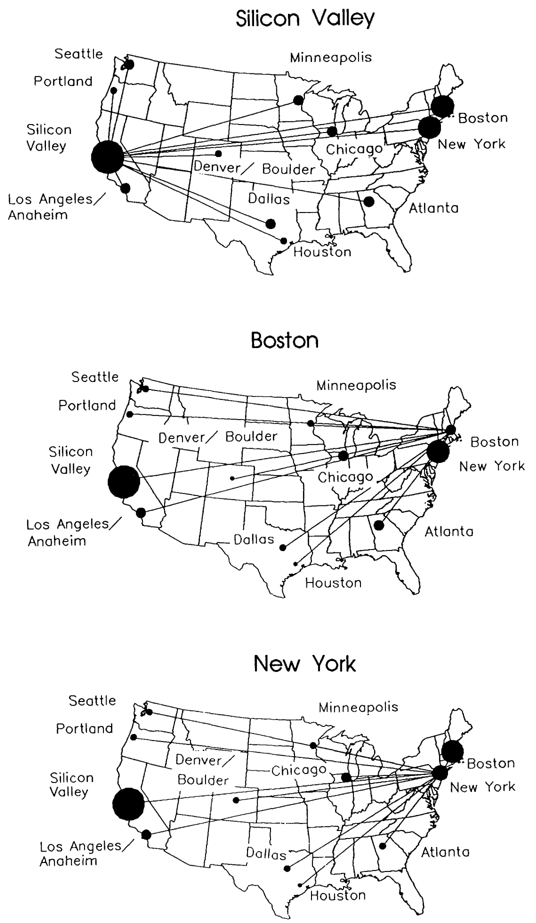

Figure 3. Coinvestments by Silicon Valley, Boston, and New York venture capitalists in leading MSAs. Source: Authors' database as compiled from "News of Venture Capital Companies," *Venture Capital Journal* (Monthly, January 1984–December 1987).

edge, supervision, and hands-on assistance for emerging industries and investments, becoming a central component of local high-technology networks. As new VC centers developed alongside regional high-technology complexes, the industry as a whole took on an increasingly specialized and spatially-differentiated form. A network system developed connecting venture capitalists in regional high-technology complexes to their counterparts in leading financial centers. Ultimately, the venture capital system developed as a network system showing increased geographic specialization.

The Model, Data, and Estimation

We developed statistical models to test a series of hypotheses regarding the geography dimensions of VC location and investment. These models are based on the underlying conceptual premise that VC is a central component of an area's technological infrastructure—a special form of an agglomeration economy comprised of specialized economic, technological, and financial networks that support high-technology industrial and technological development. The location model tests the hypothesis that the location of VC is determined by both the concentration of high-technology business and the concentration of financial resources. The investment model tests the hypothesis that VC investment is drawn to major concentrations of high-technology business. These models are estimated at the MSA level to avoid the ambiguity or aggregation problems that can come from state or regional-level data. Both models are cross-sectional and drawn across a two-year time series.

Venture Capital Location Model

The location model examines the factors that affect the location of VC funds. The dependent variable (LOCATE) is the number of VC offices in an MSA. While we would have preferred to run two models of location—one using offices, the other using the dollar volume of VC resources they control—reliable data on resources were unavailable below the state level. There are four independent variables in the model; they are measures of (1) the size of the overall banking or financial sector (FINCAP), (2) the presence of high-technology industry (HTEMP), (3) VC coinvestment (NETWORK), and (4) transportation access (TRANS). Descriptive statistics for the variables are presented in Table 7.[2]

A measure of the high-technology base (HTEMP) is included to explore the relationship between VC and high-technology industry. This variable is measured as total high-technology employment in an MSA for 1984 and 1986. We define high-technology employment using the U.S. Bureau of Labor Statistics "hybrid" definition, which combines two measures of high-technology intensity: the ratio of R&D ex-

Table 7. Descriptive Statistics for Dependent and Independent Variables[a]

Variable	Mean	Standard Deviation	Minimum	Maximum
LOCATE 84	2.4	10.3	0	121
LOCATE 86	2.5	10.7	0	125
INVEST 84	1.6	7.8	0	114
INVEST 86	1.3	5.4	0	68
FINCAP 84	3557.0	15700.0	0	212900
FINCAP 86	4921.7	13770.0	0	201000
HTEMP 84	17602.0	38147.0	77	373100
HTEMP 86	19512.0	41352.0	72	407900
HTSTART 84	73.0	163.0	0	1312
HTSTART 86	81.0	172.0	0	1413
R&D 84	1460.5	4954.8	0	63830
R&D 86	2223.7	6824.6	0	78300
NETWORK 84	80.7	517.7	0	6804
NETWORK 86	155.1	961.6	0	12830
TRANS 84	11286.0	20427.0	0	205700
TRANS 86	12324.0	21413.0	0	212900

N = 301

[a]All figures based on 301 observations. No significant collinearity (>.6) is present between the independent variables, except between the TRANS and HTEMP variables, which have a .83 correlation coefficient.

penditures to sales and the percentage of the labor-force who are scientists and engineers (see U.S. Office of Technology Assessment 1984; Markusen, et al. 1986).

A measure of the concentration of financial institutions (FINCAP) is included to test the hypothesis that VC concentrates in areas with established concentrations of financial institutions. Generally speaking, we expect that a large base of financial institutions and assets provides the capital base required to raise capital for a fund. In addition, proximity to financial institutions and to large concentrations of financial assets also facilitates connections to outside financial sources, which give venture capitalists access to later-stage financing provided by banks and other institutional investors. We use the amount of commercial bank deposits within an MSA to measure financial concentration.

A measure of VC coinvestment explores the idea that coinvestment increases investment by allowing venture capitalists to diversify their investment portfolios and pool risk. Venture capitalists who are well connected to local and national networks are expected to attract new offices either through new fund formation or spin-offs from established funds. The coinvestment network variable (NETWORK) is measured as a cumulative count of coinvestments engaged in by venture capitalists in a given MSA.[3]

A transportation variable (TRANS) examines the importance of access to investments. Surveys of venture capitalists indicate that such access is an important consideration in the location of VC funds (U.S. Congress, Joint Economic Committee 1984). Given the hands-on character and proximity requirements of VC investing, it is important to explore to what degree venture capitalists choose locations based upon transportation access to outside investments. In other words, if a venture capitalist is based in a given MSA and invests elsewhere, that individual has to be able to visit those outside investments. Thus the home base for all operations is likely to depend upon air access to potential investment sites. Reflecting this, the transportation variable is a measure of air accessibility represented by the number of commercial airport operations (takeoffs and landings) within an MSA. This measure represents an improvement over the "hub airport" variable employed by Markusen and her collaborators (1986) in that it is continuous and includes nonhub airports.

The dependent variable is characterized by a large number of zero observations, since many MSAs do not have any VC firms. In this case, zero is the censoring point in the distribution of firms, since an MSA cannot have fewer than zero firms. Not all MSAs with zero VC firms can be assumed to be equal. Attempting to estimate a model with data from a censored distribution, using ordinary least squares regression, would result in biased estimates for the parameters. The TOBIT method of estimation is designed to yield consistent estimates in the case of such a censored regression. It does so by estimating a two-part likelihood function, taking into account the likelihood of being above zero and estimating the parameters in those cases.[4] To better understand the nature of our limited dependent variable, envision a normal distribution. Then place a lower limit of zero on the distribution, which slices all observations below that point and reports them as a zero observation. Hence we have data on y, the observed data, and wish to make inference about y*, the unrevealed true distribution. We observe $y = y^*$ for $y^* > 0$, and $y = 0$ for $y^* <= 0$. TOBIT estimates both the effect of a variable on the probability of being above the zero censoring point and the effect on the positive observations of y (in this case either the number of VC offices or investments).[5] We used Limdep version 5.1 to perform the estimation. Limdep uses the iterative, Newton method of maximum likelihood estimation of the parameters. The model of VC location that was estimated is specified as follows:

$$\text{1.1} \quad LOCATE = B_0 + B_1{*}FINCAP + B_2{*}HTEMP + B_3{*}NETWORK + B_4{*}TRANS + E_1$$

where Bs are coefficients to be estimated and E is the disturbance (or error) term.

Venture Capital Investment Model

A second model explores the factors that influence the geography of VC investment. It examines investment in light of the underlying high-technology base, the local supply of VC, and the presence of VC networks. This model also operates at the MSA level for 1984 and 1986. The model is set up as a recursive, simultaneous system with the location equation, in order to separate out the direct effects of the independent variables on investment from the indirect effects that work through the location variable.

The dependent variable in the model is the number of VC investments (INVEST). The investment data were compiled from information published monthly in *Venture Capital Journal,* the trade journal of the industry. While the data cover the period 1982–87, limitations in the independent variables made it necessary to limit the analysis to 1984 and 1986. The data comprise a representative (40–45 percent) sample of all VC investments made by institutional intermediaries over the study period, according to Venture Economics, the organization that collects the raw data.

Although we would have liked to run two models, the first on the number of investments and a second on the dollar volume of investments, the data are unavailable. There are a significant number of missing observations on the dollar volume of VC investments. Furthermore, using the number of investments avoids the bias imparted by a measure of the dollar volume of investments or dollar volume per transaction, which may be skewed toward a small percentage of large-scale financing, e.g., leveraged buy-outs of existing companies, which are not representative of the "start-up" investments associated with VC. Ultimately, what we want to measure is the level of VC activity, not the size of the deals being financed. Thus the number of investments is the appropriate measure.

The investment model includes the following independent variables. Three separate measures capture the high-technology base: high-technology employment (HTEMP), high-technology start-ups (HTSTART), and industry-funded R&D at universities (R&D). Together these variables examine the flow of VC toward established concentrations of high-technology industry. High-technology employment provides a measure of the size of the high-technology sector. High-technology start-ups are a more specific measure of potential investment opportunities; we expect that the number of actual investments will be a function of potential investment opportunities. These two variables are adapted from the Small Business Administration's establishment data, and as such suffer from some limitations. The limitations of the start-up data are more severe, given the underreporting of new firms in and the overcounting of change of ownerships as new starts. But both phenomena are unlikely to be geographically correlated, and as such are not likely to impart systematic bias to the results. The limitations of the data can reasonably be assumed to amount to adding "white noise" to the model.

The R&D variable is defined as industry-funded R&D at universities, in order to capture potential university-based spill-overs to commercial technology development (see Jaffe 1989). In addition, R&D expenditure contributes to the development of the underlying technological base and supply of scientific and technical labor power, and thus is part of the broader infrastructure for innovation and new technology development.[6]

The number of VC offices (LOCATE) is included to test the hypothesis that venture capitalists invest locally; it is the same as the dependent variable in the location model. VC coinvestments (NETWORK) are used to explore the relationship between networks and investment. We expect that centers that have a high level of coinvestment will be more active investors.

A transportation variable (TRANS) tests the hypothesis that accessibility influences investment. Survey research suggests that venture capitalists frequently visit their investments (U.S. Congress, Joint Economic Committee 1984). Furthermore, the need for access is heightened due to the information-intensive and interactive nature of VC investing, where financiers provide managerial assistance as well as capital. It is also expected that investments are less likely to be discovered in areas that have relatively poor transportation and, when discovered, post significant opportunity and transaction costs for investors, thereby reducing their attractiveness.

The investment model is specified as follows: VC investment (INVEST) is a function of: (1) the size of the high-technology employment base (HTEMP), (2) the number of high-technology start-ups (HTSTART), (3) the amount of industry-funded R&D at universities (R&D), (4) the number of VC offices (LOCATE), (5) VC coinvestments (NETWORK), and (6) transportation access (TRANS).

The model is specified in terms of recursive system of equations to account for the separate effects on location and investment. It is estimated in its reduced form and solved for the structural coefficients in order to separate the direct effect of variables on investment from the indirect effect on investment that occurs through the variables that effect the location of VC supply. Thus the model is specified in terms of the following recursive system of equations; where the Bs and Cs are parameters to be estimated, and the Es are disturbances:

1.1 $$\text{LOCATE} = B_0 + B_1{*}\text{FINCAP} + B_2{*}\text{HTEMP} + B_3{*}\text{NETWORK} + B_4{*}\text{TRANS} + E_1.\ \text{AND}$$

2.1 $$\text{INVEST} = C_0 + C_1{*}\text{LOCATE} + C_2{*}\text{HTEMP} + C_3{*}\text{NETWORK} + C_4{*}\text{TRANS} + C_5{*}\text{R\&D} + C_6{*}\text{HTSTART} + E_2.$$

In this system, each of the dependent variables is best treated as a (censored) limited dependent variable, due to a large mass of observations which are zeroes. As such, both equations are treated as censored regression and utilize the type-1 TOBIT procedure to estimate the parameters via maximum likelihood estimation. Since there is some reason to suspect that the error terms are correlated, and it is likely that some of the unobserved effects picked up by the disturbance terms are indeed coincident, the TOBIT procedure is performed on the reduced forms of each equation, listed below:[7]

1.2 $$\text{LOCATE} = B_0 + B_1{*}\text{FINCAP} + B_2{*}\text{HTEMP} + B_3{*}\text{NETWORK} + B_4{*}\text{TRANS} + E_1.$$

2.2 $$\text{INVEST} = C_0 + C_1{*}[B_0 + B_1{*}\text{FINCAP} + B_2{*}\text{HTEMP} + B_3{*}\text{NETWORK} + B_4{*}\text{TRANS} + E_1] + C_2{*}\text{HTEMP} + C_3{*}\text{NETWORK} + C_4{*}\text{TRANS} + C_5{*}\text{R\&D} + C_6{*}\text{HTSTART} + E_2.$$

This reduces to:

2.3 $$\text{INVEST} = (C_0+(C_1B_0)) + (C_1B_1){*}\text{FINCAP} + (C_1B_2+B_2){*}\text{TEMP} + (C_1B_3+C_3){*}\text{NETWORK} + (C_1B_4+C_4){*}\text{TRANS} + C_5{*}\text{R\&D} + C_6{*}\text{HTSTART} + (C_1E_1 + E_2).$$

Using Gs for the reduced form parameters and V for the reduced form disturbance yields:

2.4 $$\text{INVEST} = G_0 + G_1{*}\text{FINCAP} + G_2{*}\text{HTEMP} + G_3{*}\text{NETWORK} + G_4{*}\text{TRANS} + G_5{*}\text{R\&D} + G_6{*}\text{HTSTART} + V.$$

Statistical theory tells us that consistent estimators of parameters that are continuous functions of other, consistently estimated parameters are obtainable from continuous functions of the estimators of those parameters. We obtain estimates for the G coefficients, but it is the C coefficients that are the parameters of interest. Noting that $G_1 = C_1{*}B_1$ is a continuous function and that we have consistent estimates of the parameters G_1 and B_1 from TOBIT estimation applied to the first equation and the reduced form of the second equation, we obtain a consistent, asymptotically efficient estimator for C1 by dividing the estimator of G1 by the estimator of B1. Similarly, we solve uniquely for each of the other parameters of interest, namely the structural parameters of the investment equation (the Cs). Estimated standard errors for the structural coefficients in the investment equation are obtained using the

Delta Theorem for continuous functions of consistent estimators.

Empirical Results

The main findings for the VC location model are presented in Table 8. The model performed well and the findings are robust. The results suggest that the geography of VC supply is driven by the following factors. First, the spatial distribution of supply is directly related to the size of the existing financial base, specifically by the volume of bank assets. This confirms the hypothesis that VC is concentrated near established financial centers. We conclude that a relatively large concentration of financial assets and institutions provide the capital base required to raise a VC fund. In addition, a significant number of VC funds in large financial centers like New York and Chicago are divisions of large financial institutions or "spin-offs" from those institutions. Proximity to financial institutions and to large concentrations of financial assets also allows venture capitalists to gain access to the sources of later-stage financing provided by banks and other institutional investors.

Second, and not surprisingly, the location of VC funds is positively related to high-technology employment. The model confirms the hypothesis that VC is located near high-technology industry. We attribute this to the specialized, information-intensive and transactional nature of VC activity, particularly the hands-on nature of investment in high-technology industry. This finding further suggests that VC and high-technology industry are mutually reinforcing.

Third, the spatial distribution of supply is strongly related to linkages to and networks with outside venture capitalists. Here it appears that ties to outside venture capitalists matter in location decisions, as funds locate in proximity to others that are well integrated in national networks or near other funds with which they have coinvested before.

Fourth, the transportation variable is not related to the spatial distribution of supply. This coefficient is insignificant and negative in the 1984 sample and insignificant and positive in the 1986 sample. This result implies that transportation access is not an important factor in venture capitalists' location decisions. But we are cautious in interpreting this finding. The analysis indicates some degree of correlation between the variables, TRANS and HTEMP. Such collinearity can effect the statistical significance of the estimates. It does not, however, affect the consistency of the estimates, and the coefficients have opposite signs in the two equations. Thus collinearity alone cannot explain the seemingly anomalous result. This result may reflect the limitations of our "depar-

Table 8. Results of Venture Capital Location Model

Variable	Year	Coefficient	Standard error	T-ratio
FINCAP	1984	.00035	.00003	11.225
	1986	.00031	.00003	11.998
HTEMP	1984	.000055	.000013	4.290
	1986	.000035	.000012	3.013
NETWORK	1984	.011480	.000681	16.854
	1986	.006483	.000350	18.537
TRANS	1984	–.000001	.000026	–.049
	1986	.000032	.000024	1.356
INTERCEPT	1984	–5.833	.57789	–9.315
	1986	–4.344	.55051	–7.891
SIGMA	1984	4.753	.35878	13.248
	1986	4.574	.34349	13.317

N = 301		
–Log likelihood	1984	–362.48
	1986	–344.14
–Log likelihood	1984	–533.73
w/**B** = 0	1986	–506.62
Likelihood ratio	1984	324.96
	1986	342.50
P(Reject H_0)	1984	.999
[H_0:**B** = 0]	1986	.999

Table 9.
Results of Venture Capital Investment Model

Variable	Year	Coefficient	Standard Error	T-ratio
HTEMP	1984	.000161	.000087	1.851
	1986	.000101	.000046	1.198
HTSTART	1984	.044369	.013037	3.403
	1986	.020756	.009280	2.237
R&D	1984	.000292	.000131	2.235
	1986	.000199	.000071	2.798
VCLOC	1984	–.83523	.209000	–3.996
	1986	–.52427	.134600	–3.895
NETWORK	1984	.016415	.003330	4.929
	1986	.006617	.000750	8.780
TRANS	1984	–.000160	.092700	–0.0021
	1986	–.000053	.000049	–1.1300

N = 301		
–Log likelihood	1984	–339.4
	1986	–281.04
–Log likelihood	1984	–417.83
w/**B** = 0	1986	–356.47
Likelihood ratio	1984	156.1986
	1986	150.1986
P(Reject H_0)	1984	.999
[H_0:**B** = 0]	1986	.999

tures and arrivals" data, and we are willing to entertain the notion that a more robust metric—perhaps flight time weighted by MSA—might yield a different result. But given our understanding of the industry and the previous analysis of coinvestment patterns, we conclude that transportation access is mitigated by the coinvestment process. Simply put, the need for access is minimized, since venture capitalists located close to investments act as "lead investors," allowing the remainder to participate as long-distance investors.

The results of the VC investment model are portrayed in Table 9. This model also performed well and the findings are again robust. First, investment is positively related to the high-technology industry. All three measures, high-technology employment, high-technology start-ups, and industry-funded R&D at universities, are positive and significant for both 1984 and 1986. This finding confirms the hypothesis that VC flows to specialized centers of high-technology industry.

Second, investment is positively related to the level of VC coinvestments in an area. Here it appears that VC investment is stimulated by a highly networked VC community which provides access to outside capital. Such networks help venture capitalists identify investments and obtain access to outside capital.

Third, transportation access is not significantly related with VC investment. It is negative and the estimated coefficient has a very small t-ratio. This result suggests that transportation access does not affect venture capitalists' investment decisions. Indeed, transportation access does not appear to affect the flow of VC across space. This finding apparently contradicts the findings of survey research, which indicate that venture capitalists have a preference for investments which are easy to access. The lack of significance of this variable might also be explained, in part, by the significant degree of collinearity between TRANS and the high-technology variables HTEMP and HTSTART. We conclude that this lack of significance can be explained as the outcome of the coinvestment process, where lead investors identify, monitor and provide hands-on assistance to new ventures, loosening the overall spatial constraint, while confirming the need for proximity. These lead investors are embedded within the local technological infrastructure, and as such can access embedded information and provide the face-to-face contact required to reduce investment risk for themselves and for other, external investors. Given the lack of significance of the transportation variable in any of the models, the models were rerun, excluding this variable. While the magnitudes of the coefficients changed slightly, their signs and significance were unchanged in all cases.

Fourth and perhaps most significantly, VC investment is not related to the distribution of VC supply. The coefficients for the location of offices are negative and significant in both samples, indicating that investment is not determined by the location of funds. This contradicts both academic theory and the underlying rationale for public policy intervention, viz., that local supply generates local investment, leading ultimately to high-technology economic development. We believe that this finding reflects the operation of the VC network as coinvestment loosens the spatial constraint on investing. While we would expect this result to be statistically insignificant, the negative result is somewhat surprising. A number of factors appear to drive this result. Part of the explanation lies in the high level of export venture capitalists in New York and Chicago. Furthermore, while Boston area and Silicon Valley venture capitalists do invest a higher percentage of their capital locally, venture capitalists in both areas, especially the Boston-Route 128 area, do export some of their capital. This result may also reflect the fact that Silicon Valley is comprised of a series of separate MSAs. The model may be picking up the local export of capital from San Francisco-based venture capitalists to investments in the San Jose, Santa Clara, and Santa Cruz MSAs.

Summary and Discussion

Research has suggested that VC is unevenly distributed, that it is clustered in high-technology innovation complexes, and that it has a catalytic effect on the development of such complexes. The data and analysis presented here confirm some aspects of the conventional wisdom, contradict others, and shed new light on the geography of venture capital.

Our findings indicate that supply clusters around concentrations of financial institutions and assets, concentrations of high-technology industry, and the presence of VC coinvestment networks. Investment is related to concentrations of high-technology businesses and employment and VC coinvestment. It is not, however, related to the existence of VC supply, which contradicts a major notion in the literature that a local supply of VC leads to high-technology development. It also contradicts the underlying premise upon which much public policy in this area rests, viz., that "gaps" in the VC supply are a major reason for the lack of high-technology development in certain places.

These findings lead to the conclusion that VC is both highly mobile and highly local. On the one hand, investment flows to the areas of greatest opportunity and return on investment; this is exactly as economic theory would predict. But also note the development of specialized sources of supply around both established financial centers and centers of high-technology industry, a finding in line with theories of agglomeration and regional specialization (Krugman 1991a, b). The demand for VC is geographically concentrated, as VC flows mainly toward established high-technology regions. Geographic proximity functions to reduce uncertainty, compensate for ambiguous information, and minimize investment risk. Coinvestment facilitates capital flows and, in doing so, loosens the spatial constraint on investment. Capital mobility occurs, not through the operation of free market, but through the network structure of the VC industry, which is strongly rooted in specific places. In contrast to the economist's concept of perfectly mobile capital markets, VC is characterized by strong geographic effects.

It is important to point out that the geographic structure of the industry developed gradually over time. Capital was initially mobilized by actors located in major financial centers (e.g., New York and Chicago). The growth of new regional centers of high technology created both the demand and the indigenous capital base to support local institutions. VC emerged as part of the general developmental trajectory of U.S. high technology, moving from an external source of finance capital to become a central element of emerging high-technology complexes. A set of linkages then developed connecting the various nodes and peripheries in an integrated system of information sharing and investment flows. A complex network system of institutions thus evolved with increasing specialization of functions over time.

Our research also sheds light on the broader processes of capital formation, investment, and regional development. It suggests that these processes are cumulative and self-reinforcing. New mechanisms for providing capital emerge alongside new technologies and new industries as part of the more general development process. Successful waves of innovation and regional industrial development feed the development of larger pools of local capital, which are in turn reinvested in new rounds of innovation and economic development. Here the fundamental insights of Schumpeter (1934) regarding the relationships between technological change, finance, and economic development can be placed in an explicitly spatial context. Major technological changes and shifts in the organization of production set in motion a regional economic take-off, creating the expanding economic base, vibrant investment climate, and opportunities for regional capital accumulation. The initial opportunities are filled by financiers and investors in established financial centers. Yet over time, the developmental trajectory of the new regional complex creates a momentum of its own, generating an indigenous pool of regional finance capital. The evolving regional complex is now able to finance itself and embarks on a period of self-reinforcing growth, while at the same time retaining connections to outside capital sources. Thus the processes of regional industrialization and regional capital formation work together and in tandem over time.

We hope our research has helped to advance the understanding of VC and the broader relationship among regional capital formation, investment, and regional industrialization. It remains for future research to provide further tests and refinements of the conceptual approach we have outlined here, using other cases and sectors in the U.S. and other technologically-advanced nations.

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Notes

1. For Schumpeter (1934), economic development is a process of discontinuous evolution which is driven by technological change. Major innovations—or clusters of innovations—set in motion strong "gales of creative destruction" that revolutionize industrial production and industrial organization. The risks associated with these major innovations are sufficient to deter average firms, so "exceptional entrepreneurs" are required to set such "gales" in motion. According to Schumpeter, a new group of "financiers" emerges to finance those endeavors that are too risky for traditional financial institutions. In formal language, Schumpeter's risk-taking entrepreneurs require a symmetric counterpart in the financial structure. Contemporary venture capitalists provide that function for high-technology industry.
2. The variables in the model are based on the following sources. HTEMP is based upon U.S. Small Business Administration (SBA) data which are a revised version of the Dun and Bradstreet establishment data for 1984–86. Much has been written about the limitations of the Dun and Bradstreet data, particularly with respect to inaccurate representation of firm births and firm deaths. The SBA data have been revised to minimize such biases. Furthermore, there is no evidence that the limitations in the data are geographically biased. Therefore the effect of these data limitations on our statistical analyses is likely to be small, and appear as "white noise" rather than as systematic bias. FINCAP is based on data from the Federal Deposit Insurance Corporation for the period 1984–86 and covers the total population of commercial banks in the U.S. Data on financial assets held by other types of financial institutions are unavailable at the MSA level. The volume of commercial bank deposits covers roughly 70 percent of nonequity financial assets held in the U.S. (U.S. Census Bureau 1986). TRANS is based upon data provided by the Federal Aviation Administration (FAA) for the period 1984–86.
3. The coinvestment variable requires additional clarification. For example, when venture capitalist x from MSA A participates in an investment with 2 others, venture capitalist y from MSA A and venture capitalist z from MSA B, this is counted as 4 coinvestments for MSA A (1 between x and y, 1 between y and x, 1 between x and z, and 1 between y and z), and 2 for MSA B (1 between z and x, and 1 between z and y). These data are measured from 1981 to the year in question to minimize contemporaneous correlation between coinvestment totals and the number of deals completed in a given year. It is important to note that this is a measure of the total number of coinvestment decisions rather than a measure of investment decisions (which, in the example above, would count the relationship between x and y as 1 investment for MSA A); and further, that it is a measure of VC coinvestment as opposed to the final destination of the investment itself. The coin-

vestment variable is from our VC database outlined above.

4. For a complete treatment of limited dependent variables, Tobit models, and the consistency and asymptotic efficiency of maximum likelihood estimation under these conditions, see Amemiya (1984).
5. The likelihood function is as follows:

$$L = \prod_{0} [1 - \Phi(x'\beta / \sigma)] \prod_{>0} \sigma^{-1} \phi[y_i - x'\beta / \sigma]$$

6. The R&D variable is based on data reported by the National Science Foundation on university R&D, and is the best available measure of R&D at the MSA level.
7. Since the equations are recursive in structure, standard methods for Tobit estimation of each equation in isolation are appropriate only when the disturbance terms can be assumed to be uncorrelated. If they are not, then the variable, LOCATE, in the investment equation would be correlated with the disturbance term (E2) in that equation violating the conditions for consistency.

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