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# Interurban Variation in Venture Capital Investment Characteristics

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**Summary. This paper describes interurban variations in venture capital investment characteristics. Regional, funding, and industrial sector preferences are characterised for ten of the most active venture capital centres. Investment data document the importance of these centres as importers and exporters of venture capital and shows interurban market linkages. An attempt is made to describe these linkages by a traditional gravity model. Poor fits result in the adoption of an alternative technique; the median polish that provides a more detailed description of venture capital spatial investment behaviour.**

## Introduction

Neoclassical theories of firm location implicitly assume that investment capital is both perfectly mobile in space and equally available everywhere within a developed country. Regional capital accumulation is thought to be determined through perfectly competitive supply, demand and market clearing functions. As Airov (1963), Gertler (1984) and others have noted, these assumptions preclude the consideration of capital accumulation models that include determinants that are uniquely geographic. Further, they have contributed to the lack of meaningful descriptions of the regional characteristics of capital markets.

Another barrier to such regional description is the paucity of pertinent data. As Kieschnick (1979) pointed out, the lack of acceptable evidence on how capital market characteristics and problems vary geographically is largely due to the lack of financial data collected on a less than national basis. Without a reliable database upon which to base rigorous description, differential capital accumulation has become a neglected aspect of regional theory and modelling (Bolton, 1980).

A few researchers have moved beyond the neoclassical framework to suggest that the multiregional market for investment capital is far from perfect and that a perfectly competitive, nationally integrated market exists only in a limited sense. The overwhelming evidence for this assertion is presented in an excellent review by Gertler (1984), and need not be reiterated here.

Of particular concern have been imperfections in the development of new and specialized investment capital markets oriented toward the early development financing of new products and processes (Obermeyer, 1983; Pryde, 1984). These new markets were spawned by changes in the broader economy that placed increased demands on existing monetary and human capital markets. In turn, this demand created a need for new financial services that capitalize on the opportunities offered by rapid technological change.

Rising to fill this need, the venture capital industry has found success in organizing the process of finding, evaluating and funding promising ideas. 'It is thought of as a type of direct investment in the securities of new speculative firms or technologically oriented enterprises undergoing internal expansion (Dominguez, 1974, p. 1).' Venture capital is further distinguished from traditional investment forms by

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its concurrent provision of business and managerial advice to the borrower.

Like those of other capital markets, most studies of the venture capital market have been at highly aggregate levels and few have considered the geographic pattern of venture cpaital investment except in the grossest of terms. Anecdotal descriptions, based on informal observation, have suggested two characteristics of venture capital investment patterns: (1) concentration, and (2) regional parochialism. Tribus (1970), Dominguez (1974), Pratt (1983), and Oakey (1984) have all noted regional variations in the importance and availability of venture capital financing. Pence (1979), Wetzel and Seymour (1981), and Silver (1985) have each noted that propinquity is the first step in adding value and efficient monitoring to an investment and that as a result, venture capital firms have a strong tendency to invest in their own regions.

Silver (1985) further suggested that in fact there are two market types: (1) localized regional markets, and (2) nationally oriented markets. Localized regional markets experience enhanced performance because they are the first funds in their areas and receive the benefits typically afforded monopolists. Nationally oriented markets both attract and invest capital in all regions. They are more typical of the price-taking, integrated markets described by neoclassical theory.

McNaughton and Green (1986) have added empirical credence to these anecdotal observations. They showed the distribution of both venture capital firms and their financings to be highly concentrated in a few states including New York, Massachusetts, and California. A log-linear model, fitted to an origin-destination matrix of preferred investment locations, provided evidence of regional parochialism for all census regions except the Middle Atlantic.

This parochialism was attributed to aggregate risk averse behaviour. Geographic space impedes venture capitalists' access to perfect information regarding investment opportunities. In attempting to control for this uncertainty, and manage their risk factors, venture capitalists place spatial constraints on their investment activity. Within these spatial bounds, access to information is increased by specializing in the funding of certain industrial sectors or stages of the funding cycle. Thus, it is the ability of investors to access informational resources that is the primary determinant of market integration.

This paper presents a characterization of the venture capital market at a finer geographic scale than previously available. Regional, industrial sector and funding stage preferences are described for ten of the most active venture capital centres. Investment data document the importance of these centres as importers and exporters of venture capital. Exploration of the structure of interurban market linkages is undertaken in the context of a traditional gravity model and by an alternative model; the median polish. Review of the literture in the next section generates four primary expectations:

(1) Venture capital firms are highly concentrated in a few centres, including New York, San Francisco, Boston, Minneapolis, and Dallas-Ft. Worth.
(2) Each of these centres have differing preferences among industry sectors and funding stages, implying specialization.
(3) The investment of venture capital funds can be described by a negative spatial elasticity function.
(4) The degree of elasticity is not a constant for all centres, rather it is related to the maturity of the market.

## Literature Review

Several attempts have been made in the business literature to model the decision making behaviour of venture capitalists. One of the earliest was a dissertation by Wells (1974). In a case study of seven firms, perceived risk/return tradeoffs were analyzed in terms of three variables; operating risk, man-time risk, and stock market risk. A study of the aggregate market by Hoban (1976) attempted to predict the ultimate success or failure of individual portfolio investments by reducing several operational risk factors to a single scale. Poindexter (1976) examined risk acceptance within the formal structure of the Capital Asset Pricing model. All three of these efforts suffered a common problem; no one definition of risk would universally characterize all portfolio investments. The individuality and uniqueness of each investment prevented the creation of a constant set of either descriptive or predictive factors. All agreed, however, that venture capitalists are highly risk averse.

The work of Pence (1979) attempted to control for the large number of potentially relevant variables that may comprise a definition of market risk by limiting the universe of financings to those involving early-stage start-up companies displaying a high degree of technological innovation. Pence concluded that venture capitalists' investment behaviour is based on the same fundamentals as are most financial decisions; those of risk, return, and liquidity. A set of predictive variables still did not emerge. Pence suggested that a further restriction of the study universe, particularly by geographic location might be appropriate. According to her, 'it would be interesting to conduct a more intensive study using similar techniques in one geographic location.' This because 'the entrepreneur should first consider investors who are located close to a new enterprise ... if they want both to benefit from the financier's expertise and to improve their chances of finding adequate financing quickly' (1979, p. 53).

The addition of a geographic component to the consideration of venture capital investment behaviour is also motivated by studies of corporate information flows. Risk is a direct function of uncertainty and uncertainty is a direct function of the ability to access and use informational resources. The work of Thorngren (1970), Tornquist (1979), Goddard (1971) and Taylor (1975) suggests that the spatial extent of areas to which the firm has informational linkages is quite limited. The space within which the information may be reliably used is even more limited due to imperfect transmission and filtering. Thus, both uncertainty and risk have spatial manifestations.

To minimize uncertainty and risk, access to information flows must be maximized. This constrains the activity space of the firm and limits the distance over which transactions take place. Compared with corporate activities such as joint ventures, mergers and interlocking directorates, the venture capital investment process is even more contact intensive and its activity space even more constrained.

The transmission of information is affected by a number of factors. For the venture capital firm one important factor is the extent of the personal contacts and business acquaintances possessed by its management team. Personal referrals are often a major consideration in the investment decision. Further, venture capitalists invest primarily in small firms and such firms cannot afford the high cost of informing investors nationwide about the characteristics and soundness of small, relatively unknown investments.

An even more restrictive spatial limit is imposed by what Thorngren (1970) has termed the 'planning network'. Planning networks affect changes to existing linkages structures and are equated with the provision of managerial and business assistance by the venture capitalist. Effective assistance is provided through close monitoring and relatively frequent face to face interchanges. In as much as distance represents cost in terms of time and money, investment propinquity will both lower overhead and help to insure the success of a venture.

Pred (1977) and others have demonstrated that the transmission of information becomes less affected by distance over time. The early dominance of the Middle Atlantic region (and specifically of New York City) has afforded it a more pervasive contact network and better access to informational resources. Further, as already noted, urban size may also be an important consideration. This leads to less uncertainty when transacting at a distance, and less restrictive spatial bounds. The location of branch offices and the syndication of deals are also used to expand the informational network.

Within the spatial bounds set by the processes outlined above, risk aversion is further demonstrated by specialization in certain industrial sectors and stages of the funding cycle. A review of sectoral disbursements is provided by the Office of Technology Assessment (1984), and McNaughton and Green (1986). Venture capital firms prefer to invest in 'high-tech' sectors such as computers, electronics, communications, medicine and genetic engineering. The concern is for products that can be easily commercialized and that have large market growth potentials.

The funding cycle can be broken down into five critical points: (1) development, (2) manufacturing, (3) marketing, (4) management, and (5) growth. Silver (1985) suggested that venture capitalists accept no more than two of these risks. Development risks are usually borne by the entrepreneur. Manufacturing risks are shunned as it may turn out that the product cannot be produced at a price low enough to make it attractive or competitive. Neither development nor manufacturing risks are easily controlled or influenced by the venture capitalist. The most acceptable risks are those resulting from marketing and management. These risks are the best understood and the most easily influenced by the venture capitalist. The final risk, that due to growth, is typically borne by public investors after the venture capitalist has liquified his investment. Risk averse behaviour typically requires the venture capitalist to invest in start-up businesses with prototype developed and in the early stages of growth and expansion. As the market becomes more competitive for these stages, interest has also grown in riskier, but potentially more profitable seed capital and in the more conservative debt financing of leveraged buyouts.

Implicitly combining the notions of spatial constraints and market specialization, Pratt (1983) suggested the following characterization of venture capital centres:

(1) New York and Chicago specializing in leveraged buyouts.
(2) Minneapolis/St. Paul specializing in medical and computer related ventures.
(3) Dallas/Houston specializing in energy related ventures.
(4) San Francisco/Los Angeles, and Boston specializing in seed capital and computer related ventures.

If this is true, the market characteristics of concentration and regional parochialism are not only a function of spatial constraints, but of the need to maintain highly specialized contact networks. The overall effect is to create a poorly integrated investment market, where discrepancies may occur between profitability and the existence of barriers to obtaining long-term debt and equity (Kieschnick and Daniels, 1978). In the broader context of the economy, this implies imperfections and inefficiencies. These imperfections are further compounded when the regional biases arising from differential rates of capital accumulation, job creation (Kieschnick, 1979) and industrial diversification (Peterson, 1977) are taken into account.

## Data

Two sets of data are employed in the ensuing analyses. The first is a directory of venture capital firms compiled by Pratt (1983). This directory is one of a series published periodically since the early 1970s. It provides information on office location, geographic, industrial sector and funding stage preferences, and a number of other characteristics for a survey of venture capital firms. The second is a unique listing of all investments made by government licensed Small Business Investment Companies (SBICs) during the 1983 fiscal year.

The SBIC program represents the continued interest of the US government in the equity financing of small business (Bennett, 1982). SBICs are licensed by the Small Business Administration (SBA) under the Small Business Investment Act of 1958 and are eligible for long-term loans or SBA purchased or 100 per cent guaranteed debentures, with which to finance small businesses. SBICs may borrow at a ratio of 3 to 1 up to a maximum of $35 million. These investment companies are constrained by the requirement that not more than 20 per cent of their capital may be invested in any single concern and no more than one-third of their investments may be in the real estate sector (Waldmann and Cohn, 1980).

There are currently some 390 licensed SBICs, accounting for approximately 30 per cent of total venture capital investment. While this is a substantial market share, it must be noted that SBICs are not generally similar to the independent private venture capital firms or venture capital funds that comprise the rest of the market. Because of their reliance on SBA funds, SBICs tend to be oriented toward debt-like financing structures to pay off their leveraged funds. Private venture capitalist firms, on the other hand, rely on equity financing with options such as convertible debentures. In addition, the relatively limited capital bases of SBICs promote investment in smaller firms. The overall effect is greater risk aversion manifested in a greater diffusion of firms, smaller investments and greater regional parochialism. Discussions of the operation of SBICs and of the related Minority Enterprise Small Business Investment Company (MESBIC) program are found in Chambers (1962), Hayes (1963), Rosenbloom and Shank (1970), Allen (1971), Karuna-Karan and Smith (1972), Osborn (1973), Gupta (1983), and Wilson (1985).

The annual reports of SBICs to the SBA represent a data source, the completeness of which is unique to the venture capital industry. Aggregated data from these reports are published in two summaries; *The Annual Financing Summary*, and *The Annual Directory of SBICs*. In addition, a subset of the information available in the original reports was obtained from the SBA. This subset consisted of a complete listing by firms' license number of the amount and zip code destination of their investments. An expanded data set was created by collating *The Annual Directory* with this listing. This resulted in a highly disaggregate origin-destination matrix for 2335 investments made during the 1983 fiscal year.

When the SBIC investment data were collated, it was found that a number of firms had established branch offices, presumably in an attempt to serve a more geographically diverse market. As it was not possible to distinguish within the data set at which location financing decisions were made, all were assigned to the headquarters location. This is a realistic assignment as branch offices represent a forward projection of the corporation into a new geographic location. The purpose of this projection is the expansion of the corporation's information field, allowing for geographic diversification, while reducing uncertainty and thereby risk. This problem represents approximately 9 per cent of the firms and a fractional percentage of the number of financing cases.

Use of the Pratt directory presents a problem in that it is not known whether the preferences coded in the survey can be equated with actual investment characteristics. Actual investment characteristics may be influenced by the availability of sound business proposals that have an acceptable risk/return mix. This problem can, in part, be answered by merging the Pratt directory with the SBIC database and checking for concordance between preferred and actual investment regions. There are 189 SBICs listed in the Pratt directory, of which 106 actively made investments in 1983. These firms made 646 investments, 419 of which the actual location matched the preferred location. This concordance is significantly different from that expected under the assumption of randomness at the 0.01 probability level on the binomial distribution. Thus, actual investment locations are equivalent to stated regional preferences.

## Analyses

### *Diffusion*

Table 1 illustrates the spatial development of the SBIC program over time. The cumulative importance to the total is reported by year of establishment. This gives a crude indication of changes in the importance of venture capital centres. Only those firms surviving through to 1983 are represented, restricting consideration to net additions. Eleven firms were omitted because no year of establishment was available. Their spatial distribution was not significantly different from that of the rest of the survey.

Row totals indicate the distribution of SBICs among the top ten venture capital centres. Together the top ten centres account for 53 per cent of the firms, with New York and San Francisco alone accounting for 23 per cent. Recent literature

**Table 1**

*Distribution of Survivors by Year of Establishment (in Percentages)*

| | 1958–62 | 1963–67 | 1968–73 | 1974–78 | 1979–82 | N |
|---|---|---|---|---|---|---|
| New York | 3 | 4 | 7 | 10 | 15 | 27 |
| San Francisco | 0 | 0 | 3 | 6 | 88 | 14 |
| Minneapolis | 2 | 2 | 3 | 4 | 5 | 9 |
| Houston | 1 | 1 | 1 | 1 | 5 | 9 |
| Los Angeles | 0 | 2 | 2 | 3 | 5 | 9 |
| Boston | 0 | 1 | 2 | 2 | 4 | 7 |
| Chicago | 0 | 0 | 3 | 3 | 3 | 7 |
| Miami | 0 | 0 | 1 | 2 | 3 | 5 |
| Dallas | 2 | 2 | 2 | 2 | 2 | 4 |
| Washington D.C. | 0 | 0 | 2 | 2 | 2 | 4 |
| Other | 12 | 117 | 222 | 28 | 47 | 83 |
| N | 44 | 13 | 30 | 31 | 60 | 178 |

attributes the dominance of these two centres to early involvement in venture financing and proximity to a few large research centres.

Hambrecht (1984) cites the Radiation Lab at MIT and the Radio Research Lab at Harvard as nodes of innovation attracting entrepreneurs and venture capital investment to the Boston-New York city corridor. In California, Cal Tech and Stanford are seen as important sponsors of innovation and entrepreneurial activity. Row by column percentages are an indication of a centre's changing importance over time. New York has increased from 3 to 15 per cent in the last 14 years and San Francisco from 0 to 8 per cent. The proportion attributed to all other centres has increased from 12 to 47 per cent, indicating a diffusion of firms to other centres.

Column totals indicate the number of firms established during each of the five time periods. Four distinct stages are evident: (1) initial growth, (2) shakeout, (3) maturation and (4) late growth. The early 1960s represented a period of rapid growth for the SBIC program, fed by an appreciation of venture capital firms' stock prices and an intensive promotional effort by the Kennedy administration. At the height of this growth period the SBA realized that relatively loose licensing policies were attracting an undesirable element to the program. First, venture capital had become a tool for real estate brokers to leverage their own equity base and a number of SBICs were found to specialize solely in real estate speculation. Second, some SBICs were making an increasing number of high interest loans rather than equity investments. In response, the SBA began to tighten its interpretation of the program's regulatory policies and new rules restricted SBICs that were not licensed as real estate specialists to a maximum of one-third of their portfolio in the industry (Noone and Rubel, 1970).

The tightening of SBA regulations began a number of changes that were to cause a shakeout of the industry after 1962. Loose licensing requirements had led many inadequately prepared venture capitalists into the marketplace. Unduly optimistic expectations had caused the index of publicly held SBIC stock prices to climb when overall stock prices were in a downturn. In the spring of 1962, the securities prices of many venture capital supported companies began to fall sharply. Following this was a collapse in the SBIC speculative bubble, a general feeling of disillusionment among venture capitalists and an increased reluctance to invest in the equity shares of small business (Noone and Rubel, 1970). As a result, few SBICs were formed, the underwriting of new publicly held SBICs came to a temporary halt and many firms withdrew from the program. The number of active SBICs peaked at 649 in 1964 and declined steadily throughout the late 1960s to a low of 248 in 1973 (Venture Capital Journal, 1983).

In the late 1960s, a combination of legislative changes in tax laws, and an upward trend in the securities market for small companies acted to stabilize the industry. Throughout the 1970s the industry reached a level of relative maturity, with most of the inadequately trained venture capitalists having been weeded out and market conditions allowing for a modest return. In 1978 a rapid expansion of the market began, owing to a cut in the top capital gains tax rate from 49 per cent to 28 per cent. Further cuts in 1981 brought the rate down to 20 per cent.

### *Specialization*

Tables 2, 3 and 4 present an index of specialization for each of the top ten venture capital centres. This index is reported for 27 variables collected into three dimensions: (1) preferred census region for investment (Table 2), (2) preferred funding stage (classified after Pratt, 1983) (Table 3) and (3) preferred industrial sector (Table 4). The index itself is based on a 'coded table' method for classifying deviations from the median suggested by Tukey (1977) and operationalized by Velleman and Hoaglin (1981). The coded table analysis proceeds as follows. First the data are ordered and the median value found. The median between this value and either extreme is calculated. These two values are referred to as the 'hinges' of the distribution and the difference between them is called the 'H-spread'. Finer breakdowns of the distribution are then undertaken in 'steps' that are 1.5 times the H-spread. Finally, values in the original distribution are assigned symbols that correspond to one of the following categories:

(1) Between the hinges.
(2) Within the inner fence — 1 step outside either upper or lower hinge.

**Table 2**

*Regional Preference*

| | MA | NE | WNC | MTN | PAC | WSC | ESC | SA | ENC | US |
|---|---|---|---|---|---|---|---|---|---|---|
| New York | c | c | c | c | c | c | c | c | c | d |
| San Francisco | c | c | c | c | f | c | c | c | c | c |
| Minneapolis | c | c | f | c | d | c | c | c | d | d |
| Houston | c | c | c | c | c | f | c | c | c | c |
| Los Angeles | c | c | c | c | e | c | c | c | c | c |
| Boston | d | e | c | c | c | c | c | c | c | d |
| Chicago | c | c | e | c | c | c | c | c | e | c |
| Miami | d | d | c | c | c | c | d | d | c | d |
| Dallas | c | c | c | e | c | f | c | c | c | c |
| Washington D.C. | d | d | c | c | c | c | d | d | c | c |

c = between hinges
d = above upper hinge but within inner fence
e = above high inner fence
f = far outside high

MA = Middle Atlantic
NE = New England
WNC = West North Central
MTN = Mountain
PAC = Pacific
WSC = West South Central
ESC = East South Central
SA = South Atlantic
ENC = East North Central
US = All of US

**Table 3**

*Funding Stage Preference*

| | Seed | Startup | 1st | 2nd | 3rd | 4th | Acq. | Buyout |
|---|---|---|---|---|---|---|---|---|
| New York | b | c | c | c | c | c | c | c |
| San Francisco | d | d | d | b | c | c | c | e |
| Minneapolis | b | d | d | c | c | c | b | d |
| Houston | b | b | b | c | c | c | c | b |
| Los Angeles | f | d | d | b | b | b | c | c |
| Boston | d | d | d | c | c | c | c | e |
| Chicago | b | c | c | c | c | c | c | d |
| Miami | b | c | c | c | b | b | c | b |
| Dallas | b | c | d | c | b | b | c | e |
| Washington D.C. | b | c | d | c | c | c | c | d |

b = below lower hinge but within inner fence
c = between hinges
d = above upper hinge but within inner fence
e = above high inner fence
f = far outside high

Seed = seed capital
Startup = startup capital
1st = first stage
2nd = second stage
3rd = third stage
4th = fourth stage
Acq. = acquisition
Buyout = buyout

(3) Within the outer fence — 2 steps outside either upper or lower hinge.
(4) Far outside — more than 2 steps outside either upper or lower hinge.

The hinge is thus comparable to the quartile, the inner fence the eights and the outer fence the sixteenths of the distribution. The coded table analysis is analogous to Nelson's (1955) method for classifying cities according to standard deviations from the mean. The primary difference, of course, is that here the median is the preferred measure of central tendency because of its relative insensitivity to a few extreme values. Thus, a more robust classification is achieved. A further difference is that while Nelson classified cities according to actual

**Table 4**

*Industrial Sector Preference*

| | Com | Dis | Mfg | Med | Nat.Res. | R.E. | Retail | Ser | Tech |
|---|---|---|---|---|---|---|---|---|---|
| New York | c | c | c | c | c | c | c | c | c |
| San Francisco | d | b | c | c | c | b | b | b | c |
| Minneapolis | d | b | c | d | a | a | a | c | c |
| Houston | b | b | c | b | d | c | b | b | c |
| Los Angeles | d | d | c | d | c | c | c | c | d |
| Boston | d | b | c | d | c | b | c | c | c |
| Chicago | b | c | c | c | c | b | b | c | c |
| Miami | b | b | c | d | c | e | d | c | c |
| Dallas | d | d | c | c | d | c | d | c | d |
| Washington D.C. | c | d | c | c | d | c | c | c | d |

a = below inner fence
b = below lower hinge but within inner fence
c = between hinges
d = above upper hinge but within inner fence
e = above high inner fence
f = far outside high

com = natural resources
dis = distribution
mfg = manufacturing
med = medical
nat.res. = natural resources
r.e. = real estate
retail = retailing
ser = services
tech = technology

sectoral employment, the data here give an indication of the potential a city has to support the development of certain industries and thus to create jobs in those sectors.

The index codes for the regional preference dimension display a fairly high degree of regional parochialism. Most cities prefer to invest in their own region and perhaps in a contiguous one as well. There are a few exceptions, notably that New York specializes in no one region and only slightly for all of the US. Codes for the funding dimension demonstrate the aversion of most centres to seed capital. Only Los Angeles, and to a lesser degree, San Francisco and Boston specialize in this stage. Most centres specialize in start-up, early growth financing and leveraged buyouts. Houston and Miami are conspicuously averse to funding leveraged buyouts. The legislated aversion to real estate is demonstrated by the industrial sector preference codes. Miami's specialization in this sector is a conspicuous exception. San Francisco specializes in computer related ventures. Minneapolis specializes in computer and medical related ventures. Houston and Dallas specialize in resource related ventures. In general, Pratt's (1983) characterizations are confirmed.

*Investment Flows*

Table 5 reports the distribution of venture capital funds originated and received by each of the most active venture capital centres in 1983. New York both originated and received by far the most funds. Dallas originated and received the second largest amount of funds. This is of interest because of the relatively small number of firms operating in this centre. Comparison with the actual number of investments made reveals that the average size of investments made in Dallas is substantially higher than for other centres. This may be another characteristic of specialized investment in the resource sector. While most of the centres are net exporters, San Francisco, Boston, Miami and Other are net importers. Of these centres, San Francisco is conspicuous for having generated only 52 per cent of its own investment. Clearly there is a disparity between the ability to generate funds and the demand for funds.

Figure 1 illustrates the interurban flow of venture capital funds. The pattern is dominated by outflows from New York. All centres except Washington D.C. invest in San Francisco, though there were few reciprocal investments. Given that only the most

**Table 5**

*Investment Amounts ($ million)*

| | Originated | Received | Net | Class |
|---|---|---|---|---|
| New York | 107 | 42 | 65 | exporter |
| San Francisco | 13 | 25 | −12 | importer |
| Minneapolis | 33 | 11 | 22 | exporter |
| Houston | 22 | 18 | 4 | exporter |
| Los Angeles | 25 | 22 | 3 | exporter |
| Boston | 16 | 21 | −5 | importer |
| Chicago | 13 | 0.9 | 12 | exporter |
| Miami | 6 | 10 | −4 | importer |
| Dallas | 48 | 27 | 21 | exporter |
| Washington | 6 | 2 | 4 | exporter |
| Other | 114 | 224 | −110 | importer |

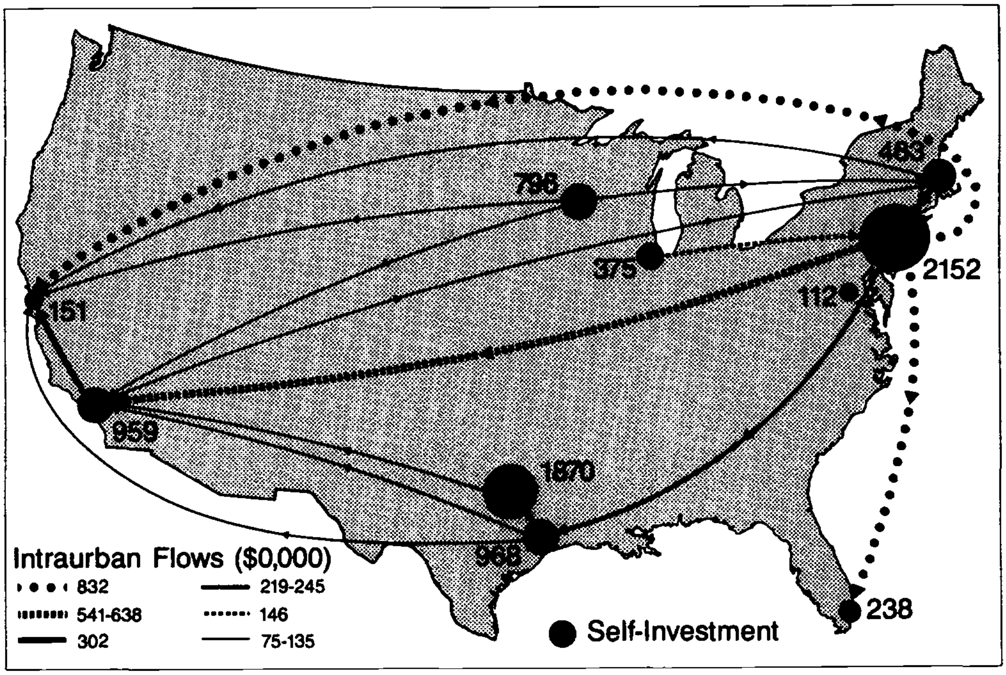


*Fig. 1. Interurban flows of venture capital funds.*

active centres are considered, the market appears poorly integrated with only 66 per cent of possible ties completed and many of these having a very low level of interaction.

*Investment Elasticity*

A traditional gravity model was used to estimate the spatial elasticity function for the investments of each centre. The model was defined to be of the form:

$$I_{ij} = [M_i M_j / d_{ij}] \quad (1)$$

$I_{ij}$ = size of investment
$M_i$, $M_j$ = total investment in centres i and j
$d_{ij}$ = spherical distance between centre i and centre j, calculated from their latitudes and longitudes.

Recent discussions in the literature (Johnston, 1976; Curry, Griffith and Sheppard, 1975; Sheppard, Griffith and Curry, 1976; Fotheringham, 1983a, 1983b) suggest that the structure of this simple model may confound the effect of distance with the differential accessibility of origins and destinations; the so called 'map effect'. Cliff, Martin and Ord (1975, 1976) argue that estimates of the distance parameters of interurban interactions are unlikely to be seriously biased by this map pattern effect. However, an alternative model; the competing destinations model, proposed by Fotheringham (1983a, 1983b) was also fitted in case the map effect was manifest in this particular spatial structure. The competing destinations model is generated through the addition of an accessibility term to the traditional gravity model. As this term was not significant for any of the venture capital centres, the results of fitting this model are not presented.

Since the consideration has been restricted to the most active centres, an origin-specific model using logarithms of the terms was used. The model was calibrated using ordinary least squares.

The estimates of the gravity model parameters are presented in Table 6. The model provides a poor characterization of the data with the conspicuous exceptions of New York, Washington D.C., Houston and Dallas. In the case of New York and Washington D.C., the distance effect is not significant. This result is not surprising (especially for New York) because of its preference for nationally oriented investment. The maturity and size of its market afford it a more pervasive information network. The consequence is a spatially inelastic investment market. In the case of Dallas and Houston, both the mass and the distance effects are significant. These centres have markets that are negatively spatially elastic. Significant negative spatial elasticities were also generated for Minneapolis, San Francisco and Miami. No significant effects were found for either Los Angeles or Chicago.

The poor descriptive power of the gravity model may be related to the few degrees of freedom available. This results in unreliable, biased estimates of the model's parameters. In addition, it indicates there are few potential destinations for venture capital investment. Thus, the investment 'surface' is not best conceived of as having a relatively continuous declining slope, but as having a discrete nodal structure. This suggests that the distance effect must be examined at a more disaggregate scale than can be provided by the distance parameter of the gravity model. The distance effect may be unique for each set of interactions between venture capital centres.

### *Spatial Effect*

The preferred technique for estimating disaggregated spatial effects from an origin-destination interaction matrix is the log linear model. Willekins (1983) demonstrated that a log linear model when fitted to an origin-destination contingency table is analogous to a constrained gravity model. The geometric mean is equivalent to a constant of proportionality. The independent effects of the rows and columns are balancing factors associated with origin and destination constraints, and the interaction effects are equivalent to the distribution function of a gravity model. The advantage of the log linear interaction model is that the effect of distance is disaggregated. Instead of the average

**Table 6**

*Parameter Estimates for Gravity Model*

| City | Constant | LMass | LDist | $R^2$ | df |
|---|---|---|---|---|---|
| New York | 1.16 | 0.86* | −0.23 | 65 | 48 |
| Minneapolis | 4.76* | 0.53* | −0.50* | 27 | 27 |
| Houston | 4.97* | 0.48* | −0.47* | 75 | 24 |
| Los Angeles | 4.01 | 0.35 | −0.18 | 5 | 20 |
| San Francisco | 5.37* | 0.48* | −0.59* | 28 | 26 |
| Dallas | 5.13* | 0.62* | −0.60* | 70 | 27 |
| Chicago | 5.38 | −0.01 | 0.14 | 0 | 12 |
| Miami | 5.01* | 0.30 | −0.44 | 40 | 30 |
| Boston | 0.04 | 0.70 | −0.08 | 25 | 19 |
| Washington D. C. | 3.29* | 0.45* | −0.20 | 62 | 10 |

* = p 0.05.

distance effect represented by the distance exponent in a traditional gravity model each interaction pair has a parameter value. The interaction term is thus a standardized measure of the true distance effect.

The drawback to the log linear technique is that the iterative proportional scaling algorithm used to generate the model cannot achieve a solution when there are more than a few cells in the data array that have a frequency of zero. Attempts to overcome this difficulty by adding a constant to all cells are questionable as parameter values are sensitive to changes in the constant.

The use of the log linear technique is precluded when the interaction matrix is sparse. In the case of venture capital investment interaction between the ten most active centres, 33 per cent of the cells have a value of zero. When all centres originating and receiving venture capital are considered, over 90 per cent of the cells have a value of zero. If disaggregated distance effects are to be studied, then an alternative method of estimating origin, destination and interaction effects must be used.

The median polish procedure operationalized by Velleman and Hoaglin (1981) provides such an alternative. This procedure was used to fit an additive effects model of the following form to the origin-destination matrix of investment flows between the ten most active venture capital centres:

$$y_{ij} = t + r_i + c_j + z_{ij} \qquad (2)$$

$y_{ij}$ = data array element in row i and column j
$t$ = a constant
$r_i$ = a row effect
$c_j$ = a column effect
$z_{ij}$ = the residual effect of element ij.

The procedure begins by finding the medians of each column in the data matrix and subtracting it from all elements in the column. This operation 'sweeps' a contribution from the column into the fit. This produces a row of column medians and a new table from which a partial effect has been removed. This process is repeated for all rows, including the newly created one of the partial column effects. This sweeping of the data continues in an iterative fashion until the change in the sum of the magnitudes of the residuals reaches a specified amount. In this case a 1 per cent change is the cutoff value. This procedure results in a two-dimensional tableau containing a constant common effect, row effects, column effects and residual effects.

It should be readily apparent that the median polish is analogous to both a two way analysis of variance (ANOVA) and the additive form of the log linear model. The primary difference is that the two way ANOVA uses the row and column means to find a solution. The median is a prefereable measure of central tendency because of its insensitivity to a few extreme values (Tukey, 1977).

Having established the tableau for the additive model, the residuals are examined for remaining structure. The investment interaction tableau at this stage was characterized by high values along the main diagonal, indicative of exreme self bias. Velleman and Hoaglin (1981) suggest that this 'saddle' pattern indicates that a reexpression of the data would improve the fit of the model. To determine the degree of reexpression that is necessary, a comparison value is computed for each cell of the table:

$$C_{ij} = (r_i)(c_j)/t \qquad (3)$$

where:

$C_{ij}$ = the comparison value
$r_i$, $c_j$, and $t$ as previously defined.

These comparison values are then regressed against the corresponding residuals. The quantity $(1-b) = p$ is an estimate of the power to which the data should be reexpressed, where b is the slope of the relationship between the residuals and the comparison values (Velleman and Hoaglin, 1981). When $p = 1$ no reexpression is needed.

The slope of the relationship between the comparison values and residuals for the investment interaction tableau was 1.1, thus, $p = 0.1$, or approximately 0.0 and the logarithmic reexpression was indicated. Taking the logarithms of each element in the additive model yields:

$$\text{Log } y_{ij} = t + \text{Log } r_i + \text{Log } c_j + \text{Log } z_{ij} \qquad (4)$$

where:

Log $z_{ij}$ is appoximately Log $C_{ij}$
$y_{ij}$, $r_i$, and $c_j$ as previously defined.

Equation (4) is the log multiplicative model. Its form invites comparison with the reexpression suggested by Tukey (1949) to improve the fit of two way ANOVA analyses, and the log linear interaction model. The log multiplicative model provides a fit that is equivalent to adding an interaction term to the additive model (Hoaglin, Mosteller, and Tukey; 1985).

When there are cells in the data array with a value of zero, a starter value must be given to take the logarithms. Several values ranging from 0.25 to 2 were tried to determine the sensitivity of the parameter values. As expected, the procedure is very robust and insensitive to changes in the starter value. A value of one was chosen to return the logarithm of such cells to 0.0.

Finally, the relative contribution of the independent row and column effects are compared with the residual interaction effects. To do this, the H-spreads of both the original data array and the residual array are calculated. The ratio of these two measures indicate the degree to which the row and column effects have reduced (or accounted for) the variation in the table (McNeil, 1977). The origin and destination effects accounted for 58 per cent of the variation in the venture capital investment interaction matrix. Table 7 presents the tableau for the median polish of the logarithmically reexpressed interaction array. Origin effects represent the importance of a centre as a generator of venture capital investment. Destination effects represent the attractiveness of a centre to venture capital investment. Interaction effects represent the unique characteristics associated with each interaction pair, of which the distance between them is a major component. Of primary interest is that even after reexpression the residuals along the main diagonal have the highest values. This indicates extreme self-bias in the investment pattern. Residual values are also very high for centres that are contiguous; San Francisco and Los Angeles, and Dallas and Houston, for example. Negative values demonstrate aversion to investment between the interaction pair.

A second median polish with all possible destinations grouped together into fifty mile zones for distances up to 2500 miles and a final group of over 2500 miles provides Figure 2. The use of distance defined zones is a well established tradition in the calibration of gravity models (Taylor, 1975). In this case, zones represent a convenient method for transforming the nodal structure of venture invest-

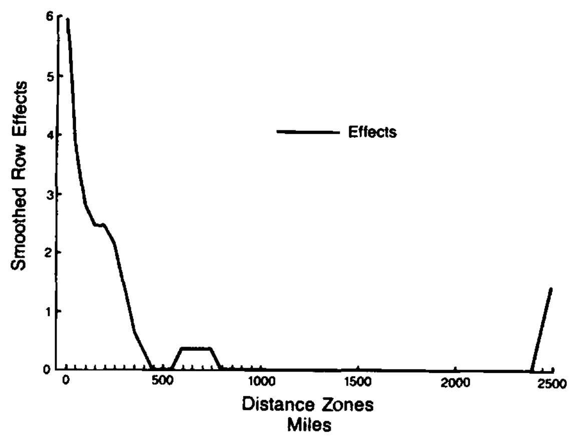


*Fig. 2. Smoothed venture capital flow surface.*

**Table 7**

*Median Polish of Origin-Destination Matrix of Dollar Flows*

| Destination | Origin | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | NY | LA | SF | BO | HO | DA | MIN | MI | DC | CH | Destination Effects |
| New York | 1.2 | 0.0 | −4.3 | 0.0 | 2.0 | 0.5 | −0.8 | −5.7 | −2.4 | 0.6 | 0.8 |
| Los Angeles | −0.7 | 2.2 | 2.9 | −7.7 | 1.8 | 0.2 | −0.2 | −1.9 | 4.2 | −1.8 | 1.4 |
| San Francisco | 0.0 | 1.4 | 3.3 | 0.6 | 2.1 | −1.6 | 0.0 | −1.3 | −2.7 | −2.6 | 1.2 |
| Boston | −0.1 | 0.2 | 2.5 | 1.9 | −5.0 | −0.6 | −0.3 | −5.8 | 3.9 | 0.1 | 0.9 |
| Houston | −0.3 | −2.6 | 1.0 | −6.6 | 5.4 | 2.7 | 0.3 | 1.6 | −1.8 | −6.9 | 0.3 |
| Dallas | −0.5 | 0.3 | −3.3 | 1.5 | 4.3 | 4.7 | −6.4 | 1.1 | −1.3 | −0.3 | −0.3 |
| Minneapolis | 0.6 | 3.3 | −0.6 | −3.4 | −1.3 | −3.2 | 5.9 | −2.0 | 1.3 | 2.8 | −2.9 |
| Miami | 3.1 | −4.0 | −1.3 | 1.3 | −1.9 | −3.8 | 2.0 | 5.9 | 7.6 | −4.4 | −2.3 |
| Washington D.C. | 0.6 | −3.3 | −0.6 | 1.5 | −1.2 | −3.1 | −3.7 | 3.3 | 9.1 | 3.4 | −3.0 |
| Chicago | −2.9 | −5.0 | 1.6 | −5.0 | −2.8 | 0.9 | 0.3 | 2.8 | −0.3 | 2.4 | −1.3 |
| Origin Effects | 2.5 | 0.1 | −2.6 | 0.1 | −2.0 | −0.1 | 0.4 | −1.3 | −4.6 | 0.5 | 5.5 |

ment into a smoother surface. Zonal aggregation allows for an examination of the average conditions as distance increases from the origin. As well, aggregation allows for the relaxation of the assumption that venture capital firms are sensitive to small variations in distance, as they are assumed to be spatially indifferent within each zone (Stetzer and Phipps, 1978). Fifty mile zones were chosen because they create approximately the same number of possible destinations as there are actual recipient venture capital centres.

The median polish followed the same procedure outlined above. The distance defined destination zones also lend a unique structure to the data. As both the destination and residual effects are influenced by distance, the destination effect is able to capture both the fit attributed to its attractiveness as a destination and that normally attributed to the residual. As well, the destination effects are ordered and of equal intervals, making patterns easy to discern. This gives an interesting result; the fitted log multiplicative model accounts for 84 per cent of the variation in the table without residual effects. The residuals are very small and exhibit no structure. The constant effect is 0.0, as are all origin effects except New York which is 1.0. The power of the model is, therefore, almost all contained in the destination effects.

The destination effects represent the attractiveness of a zone, based on the total amount of venture investment it received and the distance it is from the origin of investment. A plot of the destination effects will thus be a trace of the average investment surface for the ten most active venture capital centres. Figure 2 shows the destination effects after adjustment by a compound smoother to clarify the underlying trend. The smoothing operator used (4253H) is described in detail by Velleman and Hoaglin (1981). It consists of a running median of four, recentred by two, resmoothed by running medians of spans 5 and 3 and polished by a Hanning. The residual 'rough' was examined for remaining structure through a series of box plots as described by Tukey (1977) and McNeil (1977). No residual structure was apparent. The attractiveness of the zones declines very rapidly from 0–500 miles. Investment becomes zero at 900 miles and increases slightly after 2400 miles. This rise at the furthest distance may be attributed to a characteristic of the original data set; all branch office investments were attributed to the headquarters and branch offices are usually located at extreme distances, for example, New York based firm's branch office in San Francisco.

## Conclusions

This paper has described interurban variations in venture capital investment characteristics, for the ten most active venture capital centres. A coded table analysis of regional, industrial sector, and funding stage preferences gave the following results:

(1) Most centres display a high degree of regional parochialism in their investment preference. New York is a notable exception in that it is not specialized for any one region, and only slightly for all of the US.

(2) Los Angeles, and to a lesser degree San Francisco and Boston specialize in seed capital. Most centres were shown to specialize in start-up, early growth, and leveraged buyout financing.

(3) All centres except Miami were averse to investment in the real estate sector.

(4) San Francisco specializes in the computer sector, and Minneapolis in computers and medical related ventures. Houston and Dallas specialize in resource related ventures.

Investment data documented the importance of each centre as an exporter or importer of venture capital. New York by far both originated and received the most funds. Dallas originated and received the second largest amount of funds. San Francisco, Boston and Miami are net importers of venture capital. A clear disparity exists between the ability to generate funds and the demand for funds.

An attempt was made to describe the spatial pattern of venture capital investment by a traditional gravity model. This model was found to provide a generally poor characterization of the data. This resulted in the adoption of an alternative technique, the median polish, as a robust estimate of the disaggregate multiplicative relationship between the origin, destination and interaction effects for each centre. The first model presented using this technique demonstrated extreme self bias in the investment pattern of venture capital centres. The second model, based on a 50 mile zonal aggregation of destinations, showed that the attractiveness of these zones to venture capital investment declined rapidly over the first 500 miles.

These results support the expectations generated from a literature review of the business literature on venture capital investment decision-making and studies of corporate investment flows. Geographic space impedes venture capitalists' access to perfect information regarding investment opportunities. In attempting to control for this uncertainty and manage their risk factors, venture capitalists place spatial constraints on their investment activity. Within these spatial bounds, access to information is increased by specializing in the funding of certain industrial sectors or stages on the funding cycle.

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