YALE
INTERNATIONAL
CENTER
FOR FINANCE

Yale ICF Working Paper No. 00-51
August 2001

BUILDING A VENTURE CAPITAL INDEX

Liang Peng
Yale University

August 14, 2001

Yale SCHOOL of MANAGEMENT

Building a venture capital index*

Liang Peng

Economics Department
Yale University
Box 208268 New Haven
Connecticut 06520-8268
E-mail: liang.peng@yale.edu
Phone: (203) 624-4848
Fax: (203) 624-4848

First Draft: August 14, 2001

Comments Welcome!

Abstract

This paper builds a venture capital index from 1987 to 1999 that consists of 12,946 rounds of venture financing with 5,643 venture-backed firms. The paper uses two innovative techniques, a re-weighting procedure and a method of moment repeat sales regression, to mitigates three problems - missing data, censored data, and sample selection. We report the time series of capital flows, net asset value, and returns of the venture capital index. We find that the venture capital industry experienced dramatic growth in the sample periods, in terms of capital flows, the number of financing rounds and venture-backed firms, and the net asset value of the index. In addition, the returns to venture capital are high and volatile. The geometric average return is 55.18% per year in the sample periods, with the lowest annual return in 1990 (-5.94%) and the highest in 1999 (681.22%). The venture capital index has much higher volatility than SP 500 and NASDAQ. Moreover, we find significant correlation between the venture capital index and NASDAQ for returns and volatility.

JEL classification: C43, G24.

Keywords: Venture capital, Index estimation, Repeat sales regression, Re-weighting.

* I am grateful to Susan Woodward of OffRoad Capital for generously providing the data. I thank William Goetzmann and Matthew Spiegel for numerous constructive comments and discussions. I have also greatly benefited from the comments of Lingfeng Li, Yixiao Sun, Dean Takahashi, and participants in the workshops at Yale University. All errors are mine alone.

Building a venture capital index

1. Introduction

The venture capital industry in the United States has been growing tremendously over the past several decades. According to Venture Economics (2001), the annual inflow into venture funds increased from 3.34 billion in 1990 to 103.85 billion in 2000, and the number of firms funded by venture capital increased from 1,317 in 1990 to 5,458 in 2000. This dramatic growth has drawn increasing attention to the venture capital industry from investors, fund and endowment managers, economists, and policy makers. However, the understanding of venture capital investments is still limited. Among many questions regarding venture capital, the most fundamental one - the historic performance of venture capital - has not been addressed.

This paper builds a venture capital index consisting of 12,946 rounds of venture financing with 5,643 venture-backed firms from January 1987 to December 1999. We document the number of financing rounds, the capital flows into and out from the index, and the number of firms in the index. More importantly, we estimate the time series of returns and net asset value of the venture capital index. With the time series, we are able to thoroughly investigate the performance of venture capital, its volatility, and its correlation with major market indices such as SP 500 and NASDAQ.

Three problems stand in the way of building the venture capital index. The first is missing data. The database contains only compound returns from investments to pay out. No valuation during the interim is available. The second problem is sample selection. Returns are only observed for investments ending with an IPO and acquisition. An index based on the observed returns only would be upward biased. The third problem is censored data. Some investments had not paid out by the end of the sample periods, so their value is unknown. Simply omitting the unfinished investments would introduce a bias because the finished ones may not correctly represent all investments in the index. For example, if the unfinished investments tend to be less successful, omitting them leads to upward-biased estimates of the index returns.

The basic methods we use to overcome these problems are a method of moment repeat sales regression (MM-RSR) and a re-weighting procedure. Goetzmann and Peng (2000) and Peng (2001) propose the MM-RSR. The MM-RSR constructs period to period index returns based on observed compound returns of individual investments. The re-weighting procedure is justified by the fact that the return of a portfolio always equals the value-weighted average return of its components. This procedure consists of three steps.

The first step constructs two sub-indices: one for the successfully finished investments (IPO and acquisition), the other for the unsuccessfully finished investments (Out of business). The first one is called the *good* sub-index, and the second one is called the *bad* sub-index. We use the MM-RSR to overcome the missing data in constructing the sub-indices. When constructing the bad sub-index, we make assumptions regarding the returns to unsuccessfully finished investments because the true returns are not observed. Clearly, a pessimistic assumption leads to lower estimates of the bad sub-index: lower returns, lower net asset value, and lower weight of it in the venture capital index. Because the venture capital index is a weighted average of the sub-indices, lower return estimates and a lower weight of the bad sub-index tend to offset each other when taking averaging over the good and bad sub-indices. In fact, the estimated venture capital index is insensitive to the choice of assumption.

In the second step, we estimate the probability of success for each unfinished investment, then distribute its value into the good and bad sub-indices according to the probability of success. Specifically, we use qualitative response models - Logistic and Probit models - to identify variables helping to predict the success of venture capital investments. The active time, the number of financing rounds, and the relative size of the last financing round turn out to be predictive. Then, we use non-parametric method to estimate the probability of success for each unfinished investment and distribute its value into sub-indices and assume each component appreciates with corresponding sub-index.

In the last step, we estimate the venture capital index with the weighted averages of the sub-indices. The weight of each sub-index is proportional to its net asset value plus the fraction of the value of unfinished investments that is distributed into the sub-index. Therefore, the estimated venture capital index represents both the finished and the unfinished investments. We use simulations to show that the re-weighting procedure significantly reduces the upward bias caused by censored data and helps to improve the accuracy of estimation as well. In the simulations, on average, the re-weighting procedure reduces the upward bias by about 35% and the mean squared error by about 60% on average.

Our estimation suggests that venture capital grew dramatically and performed impressively from 1987 to 1999. The number and size of financing rounds, the amount of capital flows into the index, the number of firms, and the net asset value of the index all increased in the sample periods. The trend of increasing was more obvious after 1995. The geometric average return from 1987 to 1999 is 55.18%, with upper bound 60.93% and lower bound 28.28%. A dollar invested in the index in January 1987 became 291.66 dollars (with upper bound 433.87 and lower bound 25.45) in December 1999, compared with 5.36 dollars if invested in SP 500.

However, the venture capital returns are volatile. The lowest annual return is -5.94% in 1990, while the highest return is 681.22% in 1999. We measure the annual volatility with the standard deviation of monthly returns in the corresponding year. The venture capital index has much higher volatility than both NASDAQ and SP 500, virtually in each year from 1987 to 1999. For 12 out of 13 years, the volatility of the venture capital index is larger than 10%. The historical low is in 1989 (9.5%) and the historical high is in 1998 (70.31%). For NASDAQ, the historical low is in 1995 (2.76%) and the historical high is in 1987 (9.73%). For SP500, the historical low is in 1995 (1.48%) and the historical high is in 1987 (8.26%).

The returns are strongly correlated between the venture capital index and NASDAQ in yearly scale. The coefficient in the OLS regression of the venture capital index returns upon NASDAQ returns is 4.66 with a t-statistic 3.45. At the same time, the annual volatility of the venture capital index is also highly correlated with that of NASDAQ. The coefficient in the OLS regression of volatility is 4.30 with a t-statistic 2.46.

This paper is related to others that have tried to measure the risk and return of venture capital. Reyes (1990) uses a sample of 175 venture capital funds to report betas from 1 to 3.8. Bygrave and Tymmons (1992) find an average internal rate of return of 13.5% for 1974 to 1989. Gompers and Lerner (1997) find an arithmetic average annual return of 30.5% from 1972 to 1997. Long (1999) reports a standard deviation of 8.23% per year. Moskowitz and Vissing-Jorgenson (2000) report returns to all private equity including venture capital investments. Cochrane (2001) finds arithmetic average returns of about 53% and CAPM alpha of about 45% with selection bias controlled. However, we have found little work that tries to build venture capital indices and provide time series of returns, capital flows, and net asset value.

This paper proceeds as follows. Section 2 describes the data we use. Section 3 defines time series that characterize the venture capital index. Section 4 identifies the three econometric problems and overview our approach to address them. Section 5 builds the venture capital index. Section 6 presents the index. Section 7 summarizes and concludes.

2. Data description

2.1. Overview

This paper uses a data set provided by OffRoad Capital. The data set is compiled from several sources, including VentureOne database, SDC plantinum service, MarketGuide, and other online resources. The basic data on venture capital investments are from the VentureOne database, which collects data on venture capital financing that involves "at least one venture capital firm with $20 million or more in assets under management" (Cochrane 2001). According to VentureOne, the database is the most complete source for such data, and it has covered about 98% of such financing rounds since 1992. Consequently, the database dramatically mitigates a potential selection bias induced by only studying the successful projects. Still, the database is not completely bias-free because VentureOne sometimes searches back to find information for (more likely successfully) finished projects. However, Gompers and Lerner (2000) use Heckman sample selection approach to show that the VentureOne database may not suffer systematic biases induced by omissions of some valuation data.

2.2. Financing rounds

The data set we use has 16,720 clean observations of venture capital financing rounds. Each observation includes the ID of the associated venture-backed firm, the industry to which the firm belongs, the date of financing and the amount raised, the associated return of the investment,[1] the exit type of the firm and the associated date. Possible exit types are IPO, acquisition, out of business, remaining private, and IPO registered (but have not completed). The data set uses multiple observations to represent multiple financing rounds for one firm.

To be included in the index estimation, an observation of financing round needs to contain certain information. Specifically, a financing round that results in IPO or acquisition needs to include the date and amount of fund-raising and the date and associated return of the exit. A financing round resulting in out of business needs to include the date and amount of fund-raising and the exit date. A financing round for a private or IPO registered firm needs to include the date and amount of fund-raising. Since some observations in the data set do not contain the necessary information, the number of the observations that can be used in index estimation is 12,946.

[Table 1 about here]

[1] Returns of VC invested in IPO firms are calculated based on offering prices of the IPO firms.

Table 1 categorizes financing rounds according to their exit types. For all 16,720 observations, the largest category is Remains Private, which contains nearly 46% of all financing rounds. The second and third largest categories are IPO and Acquisition, which contain 21% and 20% of financing rounds respectively. The smallest two categories are Out of Business, 9%, and IPO Registered, 4%. For the complete observations - those containing the information needed for inclusion in the venture capital index, - the relative size of each category is almost the same except that the Out of Business is larger then the Acquisition.

[Table 2 about here]

Table 2 breaks down the financing rounds according to their starting years and associated industries. The time-span of the data is January 1987 to June 2000. Panel A reports the number and percentage of financing rounds starting in each year from 1987 to 2000, for the whole data set and for individual industries as well. Across time, the number of new financing rounds consistently increases for the whole data set and for each industry. Across industry, Information Technology has the most of new financing rounds, followed by Health Care, except for 1999 and 2000. Panel B represents only the financing rounds that terminate in an IPO, acquisition, or out of business. Since many venture-backed firms remain private at the end of the sample periods, there is no obvious growth of round numbers. Cross industry, Information Technology has the most of new financing rounds, followed by Health Care and Retail and Consumer Business. At the same time, Panel B shows that the observations are very sparse after January 2000 - only nine financing rounds that started after January 2000 have observed returns. Therefore, we only report the venture capital index from January 1987 to December 1999.

2.3. Venture-back firms

[Table 3 about here]

Table 3 reports descriptive statistics for venture-backed firms included in the index and having gone public, been acquired, and gone out of business. There are 818 firms that have gone public, 345 have been acquired, and 597 have gone out of business. Firms with different exit types are different in several respects. First, in terms of average annual returns, IPO firms are obviously more successful. Their average annual return is about 294%, while that of acquired firms is about 113%. The success of IPO firms is also obvious in each industry. In addition to realizing higher average returns, IPO firms receive more financing rounds. On average, an IPO firm receives 2.8 rounds, higher than 2.1 and 2.2 rounds for an acquired firm and a firm out of business. Moreover, in terms of total amount raised, a IPO firm receives 23 million on average, higher than 10 million for an acquired firm and 8 million for a firm out of business. Table 3 seems to show that venture capitalists have done a good job in allocating capital: more financing rounds and more capital for more successful investments. Table 3 shows another interesting pattern that more successful firms (IPO and acquisition) need a shorter time to exit. The average time to exit is 40 months for IPO firms, 38 months for acquisition, 72 months for out of business.

[Table 4 about here]

Table 4 compares earlier financing rounds and the last rounds for successful firms (IPO and acquisition) and unsuccessful firms (out of business). For successful firms, the amount of capital raised in the last round is obviously larger than the amount in earlier rounds. In contrast, for those out of business, the amount in the last round is similar to that in earlier rounds. Table 4 also shows that the time from the last round to exit is shorter for more successful firms. The time is 14 months for IPO, 20 month for Acquisition, but 51 months for Out of business. These phenomena may be related with the information asymmetry between venture capitalists and entrepreneurs. In later stages of investments, the magnitude of information asymmetry tends to be lower. Therefore, venture capitalists are able to better differentiate successful and unsuccessful firms and keep financing the successful ones but stop financing the unsuccessful ones. In addition, they may intentionally infuse a lot of money into successful firms to milk the to-be-realized high returns.

3. Characterizing a venture capital portfolio

The venture capital index in this paper is essentially a portfolio of venture capital investments. Portfolios of venture capital investments have unusual properties. First, across time, capital is called from investors to finance new investments, and the pay off from finished investments is distributed to investors. Second, across projects, investments are in different stages: some are getting started, some are mature and left to harvest, and others are between. Due to these properties, it takes more than one time series to completely describe a venture capital portfolio. For example, Takahashi and Alexander (2001) use capital contribution, capital distribution, and net asset value to model venture capital investing. We use four variables to characterize a venture capital portfolio. The first two are capital flows (into and out) of the portfolio. The third one is the capital appreciation of all on-going venture investments in the portfolio. The fourth one is the net asset value of the portfolio, which includes the value of all projects - starting, ongoing, and having been finished.

We first clarify several notations. For a venture capital investment, say i, denote by $Start^i$ the time when capital is infused and $Inflow^i$ the associated amount; denote by $Finish^i$ the time of exit and by $Payoff^i$ the associated payoff. Denote by $Ongoing^i$ the set of all time periods after (including) the time of capital infusion and before the exit time: $Ongoing^i \equiv \{t \mid Start^i \le t < Finish^i\}$. Denote by $Value_t^i$ the value of the investment at the end of period t. Obviously, the initial value of an investment equals the amount of capital infused in, $Value_{Start^i}^i = Inflow^i$, and its value at exit equals the pay off, $Value_{Finish^i}^i = Payoff^i$. The value is unobservable during the interim. As usual, the capital appreciation of an investment in period t is defined as $R_t^i \equiv Value_t^i / Value_{t-1}^i$.

The first two time-variant variables describing a venture capital portfolio are capital inflow and outflow, denoted by $Inflow_t^{Index}$ and $Payoff_t^{Index}$. They equal the summaries of capital flows into and out from individual investments.

$$Inflow_t^{Index} = \sum_{\{i|Start^i=t\}} Inflow^i \text{ , } Payoff_t^{Index} = \sum_{\{i|Finish^i=t\}} Payoff^i \text{ .} \tag{1}$$

The third descriptive variable of a venture capital portfolio is its net asset value. Denote by $Value_t^{Index}$ the net asset value of the index at the end of period t. We assume that the capital generated from an investment harvested in period t is not available for reinvestment until $t+1$. Then the net asset value of the index at the end of t equals the sum of the capital inflows, the net asset value of all on-going projects, and the payoff of finished projects in that period.

$$\begin{aligned} Value_t^{Index} &\equiv \sum_{\{i|Start^i \le t \le Finish^i\}} Value_t^i \\ &= \sum_{\{i|Start^i=t\}} Value_t^i + \sum_{\{i|Start^i<t<Finish^i\}} Value_t^i + \sum_{\{i|Finish^i=t\}} Value_t^i \text{ .} \\ &= Inflow_t^{Index} + \sum_{\{i|Start^i<t<Finish^i\}} Value_t^i + Payoff_t^{Index} \end{aligned} \tag{2}$$

The fourth variable is the capital appreciation return. Denote by R_t^{Index} the capital appreciation of the index in period t. It equals the value-weighted average of capital appreciation of individual investments that are ongoing at the end of $t-1$.

$$\begin{aligned} R_t^{Index} &\equiv \frac{\sum_{\{i|t-1\in Ongoing^i\}} Value_t^i}{\sum_{\{i|t-1\in Ongoing^i\}} Value_{t-1}^i} \\ &= \sum_{\{i|t-1\in Ongoing^i\}} \left(\frac{Value_{t-1}^i}{\sum_{\{i|t-1\in Ongoing^i\}} Value_{t-1}^i} \frac{Value_t^i}{Value_{t-1}^i} \right) = \sum_{\{i|t-1\in Ongoing^i\}} weight_t^i R_t^i \end{aligned} \text{ .} \tag{3}$$

Here $weight_t^i$ is the weight of investment i in period t.

These four descriptive variables are related to each other. For example, the capital appreciation of the index can be expressed as the ratio of the index value at the end of t with money in-flow subtracted, divided by the index value at the end of last period with money out-flow subtracted.

$$R_t^{Index} \equiv \frac{\sum_{\{i|t-1\in Ongoing^i\}} Value_t^i}{\sum_{\{i|t-1\in Ongoing^i\}} Value_{t-1}^i} = \frac{Value_t^{Index} - Inflow_t^{Index}}{Value_{t-1}^{Index} - Payoff_{t-1}^{Index}}. \quad (4)$$

4. Overcoming econometric problems

4.1. Identifying problems

Among the four descriptive variables, the most important variable, which is also difficult to estimate, is the index return. The capital flows are trivial to calculate and the net asset value of the index is also easy to estimate as long as we have the index return estimates. The index consists of 12,946 rounds of venture capital financing that can be catalogued as successfully finished investments (resulting in IPO and acquisition), unsuccessfully finished ones (ending with out of business), and unfinished ones (remaining private and having registered for IPO). Among the three categories, we only observe returns for successfully finished investments. In addition, the returns we observe are only the gross returns from the date of financing to the exit date - no value during interim is observable. Consequently, we have to overcome three econometric problems to estimate the index returns.

The first problem is censored data. Some investments have not finished by the end of the sample periods, so their value is unknown. Simply omitting the unfinished investments would introduce a bias because the finished ones may not correctly represent all investments in the venture capital index. For example, if unfinished investments tend to be less successful, omitting them will lead to upward-biased estimates of the index returns.

The second problem is missing data because value of investments is unobservable during interim between capital infusion and payoff. The missing data prevents us from directly calculating index returns.

The third problem is sample selection: successfully finished investments have observed returns while unsuccessfully finished ones do not have observed returns. Clearly, estimating index returns only based on the successfully finished investments will cause serious upward-biased estimates.

4.2. Control for censored data

We overcome the problem of censored data with a re-weighting procedure. It consists of following three steps. First, build the good sub-index consisting of successful investments (IPO and acquisition) and the bad sub-index consisting of unsuccessful investments (out of business), and calculate the returns and net asset value of the sub-indices. Second, estimate the probability for unfinished investments to eventually succeed, and distribute the value of unfinished investments into associated sub-indices according to their likelihood of success, which changes the net asset value of sub-indices and their weights in the index. Finally, average over the returns of the sub-indices using the adjusted weights and get the returns of the index that represent not only finished investments but also unfinished investments.

A simple example easily illustrates the rationale of the re-weighting procedure. Assume a portfolio consists of 100 dollars. Among them, 70 dollars are in successful investments and 30 dollars are in unsuccessful investments. Suppose we do not observe returns for all 100 dollars. Instead, we only observe the returns for 60 dollars in successful investments and 15 dollars in unsuccessful projects. Though we can estimate the return for the portfolio consisting of these 75 dollars, the return is systematically biased. In the original portfolio of 100 dollars, 70% percent are in successful investments, while in the index that only consists of dollars with observed returns the percentage is 80% (60 divided by 75). Re-weighting procedure can correct for this bias. First, we use the observed returns to estimate the average return of successful investments and that of unsuccessful investments. Second, we take average over the successful and unsuccessful returns with the correct weights, 70% and 30% respectively, instead of 80% and 30%. The re-weighting, from 80% to 70% for successful investments and from 20% to 30% for unsuccessful investments, obviously mitigates the bias.

4.3. Control for missing data

We use the method of moment repeat-sales regression (MM-RSR) to overcome the problem of missing data when estimating the period to period returns of the sub-indices. The MM-RSR has several merits [see Peng (2001)]. The most important one is that it provides estimators that strictly trace the actual value of the index. In fact, the return estimators have natural interpretations as arithmetic averages of individual investment returns. Moreover, when estimating a data set without missing observations, the RSR estimators virtually equal actual index returns.

For an example of the method, consider a very small data set consisting of two assets and three periods numbered from 0 to 2. The first asset was sold in each period, while the second one was sold only in period 0 and 2. Denote by $P_{1,0}, P_{1,1}, P_{1,2}$ the prices of the first asset in period 0, 1, and 2; and by $P_{2,0}, P_{2,2}$ the prices of the second asset in period 0 and 2. The data provide three repeat-sale observations. The first two are for the first asset and the last one is for the second asset:

$$\begin{bmatrix} P_{1,1} / P_{1,0} \\ P_{1,2} / P_{1,1} \\ P_{2,2} / P_{2,0} \end{bmatrix}.$$

Our task is to estimate the portfolio returns in period 1 and 2, which are denote by $\hat{\gamma}_1$ and $\hat{\gamma}_2$. In this example, estimators of the portfolio returns are

$$\hat{\gamma}_1 = \frac{P_{1,1} + P_{2,2} / \hat{\gamma}_2}{P_{1,0} + P_{2,0}}, \ \hat{\gamma}_2 = \frac{P_{1,2} + P_{2,2}}{P_{1,1} + P_{2,0}\hat{\gamma}_1}. \tag{5}$$

Obviously, the estimators have natural interpretations. For instance, the estimated portfolio return in period 1 equals the ratio of the portfolio value at the end of period 1 over the value at the end of period 0. Since the price of the second asset at the end of period 1 is unknown, the method replaces it with the price of the second asset in period 2 discounted back to period 1 with the estimated portfolio return from period 1 to period 2.

The calculation of the RSR estimators is easy because there are two equations and two unknown variables. In fact, by introducing new variables $\hat{\beta}_1 = 1/\hat{\gamma}_1$ and $\hat{\beta}_2 = 1/(\hat{\gamma}_1\hat{\gamma}_2)$, we can change the equations in (5) to linear equations thus solve them easily.

$$P_{1,0} + P_{2,0} = P_{1,1}\hat{\beta}_1 + P_{2,2}\hat{\beta}_2, \ P_{1,1}\hat{\beta}_1 + P_{2,0} = P_{1,2}\hat{\beta}_2 + P_{2,2}\hat{\beta}_2. \tag{6}$$

4.4. Control for sample selection

The third problem to overcome is sample selection. Among finished investments, we only observe returns for successfully finished ones. Therefore, we do not have observed returns to estimate the bad sub-index. However, we show that we can safely make reasonable assumptions regarding the returns of unsuccessfully finished investments yet the final result of the venture capital index estimation is insensitive to our choice of assumption.

The irrelevance of the returns of unsuccessfully finished investments may seem odd at first. However, it is justified by the properties of value-weighted portfolios. The return of a value-weighted index equals the weighted-average return of sub-indices, so it is not only the returns of sub-indices but also their weights that determine the return of the overall index. On one hand, lower is the return of the bad sub-index, lower the overall index return tends to be. On the other hand, lower is the return of the bad sub-index, smaller its net asset value is thus smaller its weight in the overall index is. These two effects - lower return of the bad sub-index and smaller weight of it in the overall index - obviously tend to cancel each other by pushing the weighted average in opposite directions. Fortunately, in the estimation of the venture capital index, these two effects cancel each other to such extent that the results are insensitive to our choice of assumption.

5. Building the venture capital index

5.1. Building the good sub-index

To estimate the venture capital index, we start with estimating the good sub-index that consists of the successfully finished investments (IPO and acquisition). We use the method of moment repeat-sales regression to estimate the returns.

The capital appreciation of a venture investment from the date of capital infusion to the exit date equals the product of single period returns.

$$\frac{Value^i_{Finish^i}}{Value^i_{Start^i}} = \prod_{\{t|Start^i < t \le Finish^i\}} R^i_t \,. \tag{7}$$

Assume that in each period, the return of an investment in the index equals the index return multiplied by an i.i.d. error with expectation 1.

$$R^i_t = R^{Index}_t \varepsilon^i_t \,. \tag{8}$$

Substitute equation (8) into (7),

$$\begin{aligned} \frac{Value^i_{Finish^i}}{Value^i_{Start^i}} &= \prod_{\{t|Start^i < t \le Finish^i\}} R^i_t \\ &= \prod_{\{t|Start^i < t \le Finish^i\}} R^{Index}_t \prod_{\{t|Start^i < t \le Finish^i\}} \varepsilon^i_t \end{aligned} \,.$$

Then, move the first component in the right side to the left side and take expectation,

$$E\left[\frac{Value^i_{Finish^i}}{Value^i_{Start^i}} \frac{1}{\prod_{\{t|Start^i < t \le Finish^i\}} R^{Index}_t}\right] = E\left[\prod_{\{t|Start^i < t \le Finish^i\}} \varepsilon^i_t\right] = 1 \,. \tag{9}$$

Equation (9) holds for all investments in the index. It provides moment conditions and yields a parameter-defining mapping. Sample counterparts to the moment conditions define the estimators of index returns.

$$\sum_{\{i|t-1\in Ongoing^i\}} weight_t^i \left(\frac{Value^i_{Finish^i}}{Value^i_{Start^i}} \frac{1}{\prod_{\{s|Start^i<s\leq Finish^i\}} \hat{R}_s^{Index}} \right) = 1 \text{, for } t = 1,...,T \text{ .} \quad (10)$$

Rearranging equation (10), the estimator of index return in time period t is

$$\hat{R}_t^{Index} = \sum_{\{i|t-1\in Ongoing^i\}} weight_t^i \left(\frac{Value^i_{Finish^i}}{Value^i_{Start^i}} \frac{1}{\prod_{\{s|Start^i<s\leq Finish^i \& s\neq t\}} \hat{R}_s^{Index}} \right). \quad (11)$$

The intuition of equation (11) is clear. The estimator of the index return in period t equals the weighted average of the returns in t (or their proxies) of the associated individual investments. In fact, if the value of investments is always observable, the return estimators exactly equal the actual portfolio returns.

The weight of a venture investment in the index in period t is proportional to its value at the end of $t-1$. Though that value may not be observable, the RSR actually provides an estimate, which is

$$Value^i_{Start^i} \prod_{\{s|Start^i<s<t\}} \hat{R}_s^{Index} \text{ .}$$

Therefore, an estimator of the corresponding weight is

$$Value^i_{Start^i} \prod_{\{s|Start^i<s<t\}} \hat{R}_s^{Index} \Bigg/ \sum_{\{j|t-1\in Ongoing^j\}} \left(Value^j_{Start^i} \prod_{\{s|Start^i<s<t\}} \hat{R}_s^{Index} \right).$$

Substituting the estimated weights into equation (11) gets

$$\hat{R}_t^{Index} = \frac{\sum_{\{i|t-1\in Ongoing^i\}} \left(Value^i_{Finish^i} \Big/ \prod_{\{s|t<s\leq Finish^i\}} \hat{R}_s^{Index} \right)}{\sum_{\{i|t-1\in Ongoing^i\}} \left(Value^i_{Start^i} \prod_{\{s|Start^i<s<t\}} \hat{R}_s^{Index} \right)}. \tag{12}$$

Equation (12) has a clear intuition. The estimator of the capital appreciation of the index in period t equals the ratio of the value of associated investments at the end of t over their value at the end of $t-1$. Equation (12) can be transformed into linear equations as we have shown in equation (6). Solving equation (12) leads to the estimates of the index returns.

Once we have return estimates of the good sub-index, we have associated estimates of its net asset value in every period. Rearrange equation (12), we get

$$\sum_{\{i|t-1\in Ongoing^i\}} \left(Value^i_{Start^i} \prod_{\{s|Start^i<s\leq t\}} \hat{R}_s^{Index} \right) = \sum_{\{i|t-1\in Ongoing^i\}} \left(Value^i_{Finish^i} \Big/ \prod_{\{s|t<s\leq Finish^i\}} \hat{R}_s^{Index} \right),$$

for $t = 1,...,T$. (13)

Both sides of equation (13) are equivalent estimates of the net asset value of the index in period t. The left side starts with the initial value of individual investments, and goes forward up to period t, while the right side starts with the exit value of individual investments, then discounted backward to period t. The equation shows that the MM-RSR provides an unambiguous and sensible estimate for the net asset value in period t.

5.2. Effectiveness of the re-weighting procedure: Simulations

Before we estimate the probability of success for unfinished venture capital investments, we use simulations to verify the effectiveness of the re-weighting procedure in reducing the upward bias caused by censored data. The simulation results confirm that censored data cause upward biased return estimates. In addition, they verify that the re-weighting procedure significantly reduce the magnitude of the bias.

In the simulations, following steps are performed 200 times.

1. Randomly draw 1,200 numbers from a lognormal distribution with mean 0.03 and standard deviation 0.3. The mean is equivalent to about 3% return, and the standard deviation is equivalent to about 34%.
2. Treat each of the 1,200 numbers as the mean return of an individual investment, and randomly draw 50 single period returns for each individual investment. The standard deviation of the distribution from which single period returns are generated is equivalent to 20% of the mean return of that asset.
3. Randomly draw 1,200 numbers from a uniform distribution with minimum 0.5 and maximum 10. These numbers are the initial value of each investment. In addition, randomly draw 1,200 numbers from a uniform distribution with minimum 1 and maximum 50 as the initial date of each investment.
4. Randomly generate a debt level for each investment from a uniform distribution with minimum 0 and maximum one fifth of the initial value of that investment. An investment goes out of business when its value is lower than its debt level.
5. For all investments that do not go out of business, calculate the probability of going public at period t as $1/(1+\exp(2-\log(V_t - V_0)))$. In this setting, when the value of a investment increases by 1, the probability of IPO is about 12%; when the value increases by 2, the probability is about 21%; when the value increase by 10, the probability is about 58%.
6. Generate IPOs based on the probabilities from step 5. Up to now, we have generated a market in which some investments have gone public, some have been out of business, and the rest are remaining private.
7. Calculate the actual returns of the market portfolio as if we observe returns for all investments in every period.
8. Estimate the market portfolio returns with the MM-RSR, but only use the investments that go out of business and result in IPO.

9. Use a simplified version of the re-weighting procedure to estimate the market portfolio. Specifically, first estimate the returns for good and bad sub-indices. Second, estimate the probability of success for unfinished investments and distribute their value into associated sub-indices. Here we only use the time to exit as the predictive variable to estimate the probability. Third, take average over sub-indices with adjusted weights.
10. Calculate the difference of the geometric average returns between the estimated and the actual market returns, for both the naïve estimators and the re-weighting estimators. In addition, calculate the Mean Squared Error (MSE) for both estimators.

[Table 5 about here]

Table 5 reports the simulation results. The simulations make three confirmations. First, censored data do cause an upward bias of estimated returns. Second, the re-weighting procedure significantly reduces the magnitude of the bias. Third, the re-weighting procedure also dramatically improves the accuracy of the return estimation. Panel A presents the bias of the naive method and the re-weighting procedure. For the naive method, in all 200 times of simulation, the geometric average returns are always higher than the actual ones. For the re-weighted procedure, the geometric average returns are still higher than the actual ones. However, the magnitude is much smaller. Actually, the re-weighting procedure dramatically reduces the upward bias by about 34% to 37 % on average. Panel B reports the Mean Squared Error of both the naive method and the re-weighting procedure. The re-weighting procedure dramatically improves the estimation accuracy by reducing the MSE by 48% (mean) to 60% (median) on average.

The reason why the re-weighting procedure does not totally eliminate the upward bias caused by censored data in the simulation may be two fold. First, the simulation design may not be completely realistic. For example, the number of time periods is small (50). Second, and more importantly, we use a very simple method to estimate the probability of success for unfinished investments. Though it is reasonable to do so to make the simulation manageable, the estimates may not be accurate enough. Nevertheless, The simulation results confirm the effectiveness of the re-weighting procedure in mitigating the upward bias caused by censored data.

5.3. Identifying predictive variables for success

After confirming the effectiveness of the re-weighting technique, we use qualitative response models to identify variables that predict the probability of success for venture-backed firms. The regressions show that the active time of the firm, the total number of financing rounds, and the relative size of the last financing round are significantly predictive. However, the industry, the time of the first financing round, and the relative size of the first round are not predictive.

[Table 6 about here]

First, we conjecture about ostensible candidates for variables that are capable of differentiating successful venture-backed firms from unsuccessful ones. The first candidate is the active time of firms, which is the length of time since the first financing round to the exit. The reason is that successful and unsuccessful venture-backed firms are very likely to have different distributions of active time. For example, more successful firms tend to perform well and go public or be acquired quickly, while unsuccessful firms perform poorly and could struggle for a long time before going out of business. Therefore, the firms that remain private at the end of the sample periods may mainly consist of old - consequently more likely unsuccessful - firms.

Table 6 reports the cumulative density functions of the active time for venture-backed firms ending with IPO, acquisition, and out of business, respectively. Firms ending with an IPO or acquisition have similar density functions. For example, nearly 50% IPO and acquisition are finished within three years since the first financing round. Approximately 80% are finished within five years. The ones ending out of business, on the other hand, have a different density function. Only 20% are finished within three years since the first financing round, and 32% within five years.

Another candidate of predictive variables is the number of total financing rounds before exit. The infusion of venture capital is staged: venture capitalists consistently monitor the progress of venture-backed firms and keep financing only if the firms still seem promising. Therefore, unsuccessful firms are less likely to receive continuous financing once their quality is revealed. Consequently, the number of total financing rounds is positively related with the quality of the venture-backed firm.

[Table 7 about here]

In Table 7, we use the Kolmogorov-Smirnov test to confirm that successful and unsuccessful firms have different distributions of active time and number of financing rounds. The two null hypotheses are that both successful (IPO and acquisition) and unsuccessful firms (out of business) have the same distribution of active time and the same distribution of number of financing rounds. The test rejects the equality of density function of active time with an almost 0 P-value. It also rejects the equality of density function of the number of financing rounds, with a 0.006 P-value. Therefore, the data verify that the active time and the number of financing rounds are predictive variables of the likelihood of success for a venture-backed firm.

Other candidates include the size of the first and the last round of venture financing, the date of the first financing round, and the industry to which the venture-backed firm belongs. The size of the first round could be informative because more promising firms could receive more capital even from the beginning. At the same time, as shown in Table 4, for successful firms, the amount of capital raised in the last round is obviously larger than the amount in earlier rounds. In contrast, for those out of business, the amount in the last round is similar to that in earlier rounds. Therefore, the size of the last financing round may be predictive. In addition to the size of the financing rounds, the date of the first financing and the industry to which the firm belongs may help us forecast the success of venture-backed firms. New technology, a dramatic increase of demand, favorable legal changes, and other common factors, could particularly benefit some industries in specific periods of time. Therefore, the industry and the time of the first round may be predictive.

We use both Logistic and Probit models to identify the predictive variables. The dependent variables are the exit types of venture-backed firms, 1 if IPO or acquisition, 0 if out of business. The independent variables include the active time, the number of financing rounds before the exit, the size of the first financing round,[2] the size of the last financing round,[3] and the joint dummies of the associated industry and the time of the first round. Since there are three categories of industries and 14 years in the sample, there are 52 joint dummies. Then there are 56 independent variables in total.

[Table 8 about here]

Table 8 presents the results for the qualitative response regressions. Both Logistic and Probit regressions have similar results. First, neither the industry nor the time of first round helps to predict the probability of success. Also, the size of the first round does not help us predict the probability of success. Second, the number of total rounds of financing is strongly predictive. The t-statistic is about 11 in both regressions. The active time is also significantly predictive. Its t-statistic is about -18. In addition, the size of the last financing round is significantly predictive.

5.4. Probability of success for unfinished investments

After identifying the predictive variables, we use non-parametric methods to construct the probability of success as a function of the predictive variables. The only exception is the relative size of the last financing round: though it is significantly informative, we simply can not tell if the last observed financing round for an unfinished firm is indeed the last round. We estimate the probability of success for each unfinished venture-backed firm by checking the value of its variables and the probability function.

[2] The size is normalized with the average size of all first rounds in the corresponding period.
[3] The size is normalized with the average size of all last rounds in the corresponding period

Assume that a random variable - *Quality* - determines the exit types of venture-back companies. All investments in the same firm have the same quality. Denote by $Quality^i$ the quality of firm i, which equals 1 if the exit type of the firm is IPO or acquisition and 0 if the exit type is out of business. Obviously, the quality of a firm is unobservable until the exit.

Our task is to estimate the probability for an unfinished venture-backed firm to eventually go public or be acquired conditional upon its active time and the total number of financing rounds. However, we only observe the lower bound of the active time, which is the time from the first financing round of the firm to the end of the sample periods. Similarly, we only observe the lower bound of the number of financing rounds, which is the number of the rounds by the end of the sample periods. Therefore, we are not able to directly use the coefficients estimated with the qualitative response models. Instead, we use a simple non-parametric method to estimate the probability of success as the function of the lower bound of the active time and the lower bound of the number of rounds.

Denote by N the number of the total rounds and by n the number of rounds before the end of the sample periods. Clearly, the probability of success for a venture-backed firm with active time longer than s and N larger than n is

$$\begin{aligned}&\Pr(Quality = 1 \mid ActiveTime > s, N > n)\\&= \Pr(Quality = 1, ActiveTime > s, N > n) / \Pr(ActiveTime > s, N > n)\end{aligned} \quad (14)$$

We can estimate $\Pr(Quality = 1, ActiveTime > s, N > n)$ directly from the finished firms. It equals the fraction of successfully finished firms with active time longer than s and the number of total rounds larger than n. At the same time, we can estimate $\Pr(ActiveTime > s, N > n)$ with the fraction of firms with active time longer than s and the number of total rounds larger than n.

[Figure 1 about here]

Figure 1 plots the estimated probability of success for a venture-backed firm conditional upon the lower bound of active time and the lower bound of the number of rounds. First, it shows the probability of success is lower for older venture-backed firms. For example, a new-started firm has the probability of 81% to eventually succeed. The probability monotonically decreases when time passes by. When a venture-backed firm is 88 month old and has received only one round of financing, its probability of eventually going public (or being acquired) drops under 50%. In addition, for two firms with equal active times, the one that has received more financing rounds has the higher probability of success. This is also consistent with the results of the qualitative response models and the intuition that more promising firms receive more financing rounds.

Given figure 1, we are able to determine the probability of success of all venture-baked investments that are unfinished at the end of the sample periods. For example, suppose we want to calculate the probability of success for an investment with active time larger than 50 months and more than 3 financing rounds. We draw a vertical line from the "50 month" at the X-axis, and check where the vertical line crosses the curve that pertains to $N > 3$. Then we draw a horizontal line from the intersect to the Y-axis to get the corresponding probability of success.

5.5. Estimating returns of the venture capital index

Since we do not observe returns of investments that have been out of business, we need to make some assumptions. Specifically, we repeatedly estimate the venture capital index based on 25 different assumptions regarding the returns of unsuccessfully finished investments. The assumptions are -98%, -96%, -94%, and so on, until -50%. Under each assumption, we make three estimates of the index returns. First, we estimate the upper bound of the returns by assuming that all unfinished investments will succeed eventually. Second, we estimate the lower bound by assuming that all unfinished investment will eventually go out of business. Finally, we estimate the index returns based on the estimated probability of success for each investment.

[Table 9 about here]

Table 9 presents the estimated index returns. The first column is our assumptions regarding the returns of unsuccessfully finished investments. The second column is the geometric average annual returns of associated bad sub-indices. Naturally, the average return of the bad sub-index is lower under more pessimistic assumptions.

In all three categories of index estimation: the upper bounds, the estimated, and the lower bounds, when the assumption is more pessimistic, the average return of the bad sub-index is lower and its weight in the index is smaller. The lower return and the smaller weight push the index estimates in opposite directions. As a result, the geometric average annual returns of the venture capital index are very similar under different assumptions. For example, in the category of upper bounds, the geometric average annual return is 60.02% under the most pessimistic assumption and 61.40% under the least pessimistic assumption. In the category of the estimated, the return ranges from 54.31% to 55.78%. In the category of lower bounds, the return ranges from 24.44% to 32.09%. Within each category, the net asset value of the index in December 1999 is also insensitive to the assumption. For instance, in the category of upper bounds, the net asset value ranges from 957.65 billion to 958.01 billion. In the category of the estimated, it ranges from 590.02 billion to 595.44 billion. In the category of lower bounds, the net asset value ranges from 26.47 billion to 49.52 billion.

6. The performance of venture capital: 1987 to 1999

6.1. Monthly series

We first describe some basic features of the venture capital index from 1987 to 1999: the number of financing rounds, the capital flows into and out from the venture capital index, and the number of firms in the index. They all suggest that the venture capital experienced a dramatic growth from 1987 to 1999.

[Figure 2 about here]

Figure 2 shows the numbers of financing rounds that started and finished in every month from January 1987 to December 1999. The figure suggests that the venture capital industry has experienced dramatic growth since 1987, and especially after 1995. For example, the number of new financing rounds increased through time, especially after 1995. In fact, not only the number of financing rounds increased, but also the average amount raised in each round increased. For example, the average amount raised in each round was 2.06 million in January 1987. It increased to 4.55 million in January 1996 and 17.2 million in January 1999. The figure also shows several interesting patterns. For example, both numbers are quite volatile, and the number of finished rounds is typically smaller than the number of started rounds, except in early 1995 and late 1997.

[Figure 3 about here]

Figure 3 plots the capital flows from January 1987 to December 1999. The figure confirms the dramatic growth of venture capital. Both the inflow and outflow of capital have been increasing since 1987, with more obvious trends after 1995. However, in contrast to that the number of finished investments is usually smaller than the number of started investments, the capital outflow is often larger than the capital inflow. This suggests that on average, a finished investment generates more capital than what is needed to finance a new investment.

[Figure 4 about here]

Figure 4 plots the number of firms entering the index and the number of firms in the index from January 1987 to December 1999. The number of firms entering the index was fairly stable until 1995, and has since increased. The number of firms in the index has increased smoothly, reaching 3,793 in December 1999.

[Figure 5 about here]

Figure 5 shows the number of venture-backed firms ending with IPO, acquisition, or out of business from January 1987 to December 1999. In 1997, a lot of venture-backed firms went out of business. The numbers of firms ending with IPO and acquisition, on the other hand, seemed usual in this year.

6.2. Annual series

[Table 10 about here]

Table 10 summarizes important characteristics of the venture capital index from 1987 to 1999. The venture capital index is estimated under the assumption that the returns to unsuccessful investments are -80%. Panel A reports the net asset value at the end of each year. The net asset value constantly grew in the sample periods. It started with about 1.1 billion, and increased to more than 10 billion the first time in 1993 (about 12.3 billion), and reached 592 billion in 1999. Figure 6 plots the net asset value of the venture capital index, and with the upper bound and the lower bound.

[Figure 6 about here]

Panel A also reports the annual capital inflow and outflow. Both inflow and outflow steadily increased over time. A dramatic growth took place in 1995. The capital inflow increased by more than 1 billion dollars in 1995 - from 3.3 billion to 4.8 billion. The outflow of capital also increased by more than 1 billion dollars in 1995 - from 3 billion to 6.3 billion. This dramatic growth is consistent with the hypothesis that an impressive performance of venture capital would attract more money. Panel A also reports the number of firms that entered the index, left the index because of IPO, acquisition, and out of business respectively, and the number of firms in the index at the end of each year. All numbers - except the number of firms going out of business - constantly increased over time. There were an unusually large number of firms going out of business in 1997 (227) and 1998 (164).

[Figure 7 about here]

Panel B presents the annual capital appreciation returns for the venture capital index, NASDAQ, and SP 500. Figure 7 plots the annual returns. There are several years in which the venture capital index enjoyed massive returns. In 1996, the return to venture capital was 168.75%; in 1999, the return was astounding: 681.22%. Still, there are years in which the venture capital index suffered loss. For example, in 1990, the return was -5.94%, and in 1992 and 1997, the returns were -4.42% and -0.38% respectively. Figure 8 plots the index appreciation, together with the upper and lower bound, in comparison with SP 500. Figure 9 reports the histogram of the monthly returns. It shows occasional astounding monthly returns.

[Figure 8 about here]

[Figure 9 about here]

Panel C reports the cumulative average capital appreciation returns for the venture capital index, NASDAQ, and SP 500. The cumulative average return in a year equals the geometric average return from 1987 to that year. In Panel C, the cumulative average return of the venture capital index was always higher than that of NASDAQ and SP 500 in the sample periods. In fact, the cumulative average return of the venture capital index is always in two digits. The cumulative average return ranges from about 20% to 35% except in 1999 when it reached the historical high - about 55%. Of course, this is due to the astounding 681% return in 1999.

Panel D reports the volatility of the venture capital index, NASDAQ, and SP 500. The volatility in a year is the standard deviation of the monthly returns in that year. Panel D clearly shows that the venture capital index was much more volatile than NASDAQ and SP 500 in the sample periods. The volatility of the venture capital index was almost always in two digits, with the historical low of 9.5% (in 1989) and the historical high of 70% (in 1998). Figure 10 plots the annual volatility from 1987 to 1999.

[Figure 10 about here]

6.2. Correlation with NASDAQ and SP 500

The time series facilitate the study of the correlation between the venture capital index and major market indices such as NASDAQ and SP 500. We regress the venture capital returns -

monthly, quarterly, and annul - upon the returns of NASDAQ, SP 500, and both. Table 11 reports the regression results. In monthly and quarterly scale, we do not detect statistically significant correlation. However, in yearly scale, the results suggest an unusually high correlation between the venture capital and NASDAQ. When regressing upon NASDAQ only, the coefficient of NASDAQ is 4.65 with a t-statistic of 3.45. The R2 is also high: 0.52. When regressing upon both SP 500 and NASDAQ, the coefficient of NASDAQ is 7.5 with a t-statistic of 4.89. The R2 is 0.72. However, the coefficient of SP 500 is not statistically significant when regressing upon it only. And the coefficient is negative when regressing upon both NASDAQ and SP 500.

[Table 11 about here]

We also regress the annual volatility of the venture capital index upon that of NASDAQ and SP 500. Table 12 presents the results. The volatility of SP 500 per se does not explain much of the volatility of the venture capital index. On the other hand, the volatility of NASDAQ has a coefficient of 4.3 with a t-statistic of 2.45. The corresponding R2 is 0.36. When regressing upon both NASDAQ and SP 500, the R2 increases to 0.67, the coefficient of NASDAQ is astoundingly 11.02 with a t-statistic of 4.37, while the coefficient of SP 500 is still negative, -10.09, with a t-statistic of -3.12.

[Table 12 about here]

The regressions of returns and volatility show that the performance of the venture capital index is closely related to that of NASDAQ but may not be so closely related to SP 500.

7. Summaries and conclusions

This paper builds a venture capital index consisting of 12,946 rounds of venture financing with 5,643 venture-backed firms from January 1987 to December 1999. We report the number of financing rounds, the capital flows, and the number of firms in the index. Moreover, we present the time series of returns, volatility, and net asset value of the venture capital index.

Three problems arise when building the venture capital index: missing data, censored data, and sample selection. Each problem induces serious estimation bias if not being properly controlled. We use a re-weighting procedure and a method of moment repeat sales regression to overcome these problems. The re-weighting procedure is justified by the fact that the return of a portfolio always equals the value-weighted average return of its components. We use simulations to show that this procedure significantly mitigates the bias caused by censored data and sample selection and improve the accuracy of index estimation. The MM-RSR deals with the problem of missing data. It constructs period to period index returns based on observed compound returns of individual investments. It provides sensible and unambiguous estimates of the index returns and the net asset value of the index.

Our estimates show that the venture capital has been performing impressively. The geometric average annual return from 1987 to 1999 is 55.18%, with the upper bound 60.93% and the lower bound 28.28%. In addition, the venture capital returns are volatile. The lowest annual return is -5.94% in 1990, while the highest return is 681.22% in 1999. We measure the annual volatility with the standard deviation of monthly returns in the corresponding year. The venture capital index has much higher volatility than both NASDAQ and SP 500. There is strong correlation between the venture capital index returns and the returns of NASDAQ in yearly scale. Moreover, the annual volatility of the venture capital index is also highly correlated with that of NASDAQ.

References

Bygrave, William D., and Jeffrey A. Timmons, 1992, Venture Capital at the Crossroads, Boston: Harvard Business School Press.

Cochrane, John H., 2001, The Risk and Return of Venture Capital, NBER working paper.

Goetzmann, William N., and Liang Peng, 2000, The Bias of the RSR estimator and the Accuracy of Some Alternatives, Real Estate Economics, forthcoming.

Gompers, Paul A., and Josh Lerner, 1997, Risk and Reward in Private Equity Investments: The Challenge of Performance Assessment, Journal of Private Equity (Winter 1997): 5-12.

Gompers, Paul A., and Josh Lerner, 2000, Money Chasing Deals? The Impact of Fund Inflows on Private Equity Valuations, Journal of Financial Economics 55, 281-325.

Long, Autsin M. III, 1999, Inferring Period Variability of Private Market Returns as Measured by δ from the Range of Value (Wealth) Outcomes over Time, Journal of Private Equity 5, 63-96.

Moskowitz, Tobias J. and Annette Vissing-Jorgenson, 2000, The Private Equity Puzzle, Working paper, University of Chicago.

Peng, Liang, 2001, A New Approach of Valuing Illiquid Asset Portfolios, Working Paper, Yale University.

Takahashi, Dean, and Seth Alexander, 2001, Illiquid Alternative Asset Fund Modeling, Working Paper, Yale University.

Venture Economics, 2001, Press release at http://www.ventureeconomics.com

Table 1. Venture Capital Financing Rounds: Exit Types

This table reports the numbers and percentages of financing rounds in different categories of exit type. A complete observation of a financing round needs to include the date of the financing, the amount raised, the date of exit if applied, and the pay off if the exit type is IPO or acquisition.

	All observations		Complete observations		Incomplete observations	
	Number	%	Number	%	Number	%
All Categories	16,720	100.00%	12,946	100.00%	3,774	100.00%
IPO	3,552	21.24%	2,675	20.66%	877	23.24%
Acquisition	3,381	20.22%	960	7.42%	2,421	64.15%
Out of business	1,492	8.92%	1,367	10.56%	125	3.31%
Remains private	7,674	45.90%	7,329	56.61%	345	9.14%
IPO registered	621	3.71%	615	4.75%	6	0.16%

Table 2. Venture Capital Financing Rounds: Starting Years and Industries

This table reports the numbers and percentages of financing rounds categorized according to starting years and industries.

Panel A: The number of financing rounds starting in each year

	All industries		Healthcare		Information Technology		Retail & Consumer Business		Other	
Total	16,720	100.00%	3,917	23.43%	9,232	55.22%	3,129	18.71%	442	2.64%
1987	652	3.90%	160	0.96%	399	2.39%	66	0.39%	27	0.16%
1988	616	3.68%	171	1.02%	369	2.21%	54	0.32%	22	0.13%
1989	693	4.14%	203	1.21%	391	2.34%	60	0.36%	39	0.23%
1990	712	4.26%	196	1.17%	425	2.54%	55	0.33%	36	0.22%
1991	732	4.38%	239	1.43%	399	2.39%	59	0.35%	35	0.21%
1992	845	5.05%	283	1.69%	437	2.61%	83	0.50%	42	0.25%
1993	848	5.07%	285	1.70%	417	2.49%	108	0.65%	38	0.23%
1994	962	5.75%	307	1.84%	503	3.01%	115	0.69%	37	0.22%
1995	1,135	6.79%	305	1.82%	633	3.79%	164	0.98%	33	0.20%
1996	1,659	9.92%	412	2.46%	944	5.65%	259	1.55%	44	0.26%
1997	1,809	10.82%	409	2.45%	1,061	6.35%	307	1.84%	32	0.19%
1998	1,962	11.73%	406	2.43%	1,146	6.85%	380	2.27%	30	0.18%
1999	3,066	18.34%	405	2.42%	1,632	9.76%	1,007	6.02%	22	0.13%
2000	1,029	6.15%	136	0.81%	476	2.85%	412	2.46%	5	0.03%

Panel B: The number of financing rounds that result in IPO, acquisition, and out of business starting in each year

	All industries		Healthcare		Information Technology		Retail & Consumer Business		Other	
Total	5,002	100.00%	1,303	26.05%	3,042	60.82%	549	10.98%	108	2.16%
1987	242	4.84%	59	1.18%	163	3.26%	16	0.32%	4	0.08%
1988	260	5.20%	68	1.36%	173	3.46%	14	0.28%	5	0.10%
1989	323	6.46%	97	1.94%	194	3.88%	20	0.40%	12	0.24%
1990	337	6.74%	97	1.94%	215	4.30%	17	0.34%	8	0.16%
1991	366	7.32%	130	2.60%	211	4.22%	17	0.34%	8	0.16%
1992	446	8.92%	163	3.26%	234	4.68%	34	0.68%	15	0.30%
1993	431	8.62%	157	3.14%	219	4.38%	38	0.76%	17	0.34%
1994	442	8.84%	154	3.08%	231	4.62%	44	0.88%	13	0.26%
1995	478	9.56%	141	2.82%	276	5.52%	54	1.08%	7	0.14%
1996	570	11.40%	131	2.62%	353	7.06%	79	1.58%	7	0.14%
1997	454	9.08%	62	1.24%	326	6.52%	62	1.24%	4	0.08%
1998	361	7.22%	27	0.54%	265	5.30%	64	1.28%	5	0.10%
1999	283	5.66%	15	0.30%	178	3.56%	88	1.76%	2	0.04%
2000	9	0.18%	2	0.04%	4	0.08%	2	0.04%	1	0.02%

Table 3. Venture-backed Firms: Exit Type and Industry

This table provides statistics for venture-backed firms in the sample that have gone public, been acquired, or gone out of business by June 2000. All reported numbers, except for the number of companies, are averages over firms within corresponding categories. The numbers in *Total amount raised* are calculated without being corrected for inflation. The *Time to exit* of is the time from the first financing round to exit. The *Realized annual return* of a firm is the value-weighted average of annualized returns of all associated financing rounds.♣

	Number of companies	Total number of financing rounds	Total amount raised (in million dollars)	Time to exit (month)*	Realized annual return**
IPO	818	2.8	23.26	39.5	293.60%
Healthcare	214	3.2	20.89	44.1	64.44%
IT	493	2.7	21.31	39.2	426.22%
Retail	98	2.6	38.49	29.3	164.27%
other	13	3.1	21.28	50.5	11.18%
Acquisition	345	2.1	10.22	38.1	113.14%
Healthcare	63	2.0	9.15	45.5	29.58%
IT	257	2.2	10.36	36.8	133.56%
Retail	21	1.6	12.76	29.8	139.15%
other	4	2.0	5.08	49.3	-19.52%
Out of business	597	2.2	8.28	72.3	NA
Healthcare	128	2.3	7.65	73.5	NA
IT	347	2.3	8.59	76.1	NA
Retail	95	2.0	9.13	61.1	NA
other	27	1.8	4.31	57.9	NA

♣ For a financing round with active time shorter than a year, we assume its return for the rest of months in that year is 0% The assumption prevents unreasonable exaggerations of short run trends of returns. As an example, suppose a firm raises 1 million dollars one month before IPO, and the return for that financing round is 200% a month. Under the assumption, the annual return for that financing round equals 200%, instead of the number calculated as if the 200% monthly return could sustain for the whole year, which is 53,144,000%.

* Numbers are calculated based on observations with exit dates.

** Numbers are calculated based on observations with return data.

Table 4. Venture-backed Firms: Industry, Exit Type, and The Last Financing Round

This table contrasts earlier financing rounds with the last financing rounds for firms with different exit types and in different industries. All numbers are calculated based on firms with more than one rounds of financing.

			Earlier financing rounds			The last financing round	
	Companies	Average rounds	Average amount raised (million)	First round to exit (month)	Second last round to exit (month)	Average amount raised (million)	Last round to exit (month)
IPO	635	3.4	6.12	44.3	27.4	13.36	13.7
Healthcare	186	3.6	5.27	48.4	27.4	9.43	12.8
IT	369	3.2	5.93	43.7	28.4	12.60	14.9
Retail	70	3.3	9.39	34.1	21.1	27.84	9.8
other	10	3.7	6.08	61.2	33.7	13.27	15.3
Acquisition	199	2.9	3.99	47.3	35.7	6.98	20.0
Healthcare	35	2.9	3.97	57.0	42.9	5.39	24.5
IT	154	2.9	3.96	45.4	34.1	7.39	18.9
Retail	8	2.5	5.01	38.9	33.9	7.22	22.3
other	2	3.0	2.80	59.0	34.5	2.4	18.0
Out of business	358	3.0	3.64	80.0	66.4	4.12	51.4
Healthcare	71	3.4	3.11	81.1	61.9	3.94	46.6
IT	216	3.0	3.72	83.1	69.6	4.17	55.1
Retail	57	2.6	4.08	70.1	61.5	4.43	45.9
other	14	2.5	3.25	66.2	58.8	2.83	41.0

Table 5. Simulations: The Effectiveness of Re-weighting Procedure

This table presents the results of the simulations that verify the effectiveness of the re-weighting procedure in correcting the bias caused by censored data. The following steps are performed 200 times in the simulations. First, randomly generate a market consisting of successfully finished, unsuccessfully finished, and unfinished investments. Second, calculate the actual market returns. Third, estimate the market returns without correction for censored data - in other words, use finished (both successfully and unsuccessfully) investments only. Finally, estimate the market returns with the re-weighting procedure. All numbers in this table are averages over 200 results. In Panel A, the *Naive* refers to the estimates without controlling for the censored data. The *Reduced* and *Reduced %* denote how much the re-weighting procedure reduces the upward bias, in value and percentage respectively.

Panel A: Upward Bias of Geometric Average Returns*					
	Min	median	mean	max	Standard dev.
Naive	2.517	20.456	20.203	27.318	3.209
Re-weighting	0.117	12.863	12.945	27.212	4.565
Reduced	-20.346	-7.492	-7.244	7.827	4.526
Reduced %	-99.43%	-36.88%	-34.39%	251.81%	30.37%
Panel B: Mean Squared Error**					
	Min	Median	mean	max	Standard dev.
Naive	0.634	41.844	41.841	74.626	12.328
Re-weighting	0.001	16.546	18.830	74.051	12.672
Reduced	-54.042	-23.471	-22.947	31.932	14.250
Reduced %	-100.00%	-60.16%	-47.77%	1137.72%	91.24%

* All numbers are in e-3 except for percentages.

** All numbers are in e-5 except for percentages.

Table 6. Empirical Cumulative Density Function of the Active Time

This table presents cumulative density functions of active time for firms with different exit types. All numbers are in percentage.

	All (%)	IPO (%)	Acquisition (%)	Out (%)
< 1 year	10.34	12.62	11.92	2.17
< 2 years	27.12	30.06	33.04	7.76
< 3 years	44.58	49.07	51.63	19.57
< 4 years	59.84	67.21	66.14	30.75
< 5 years	71.50	79.60	77.32	42.08
< 6 years	79.39	87.15	84.13	53.11
< 7 years	84.98	92.37	88.90	61.34
< 8 years	89.37	95.95	92.17	69.88
< 9 years	92.84	97.66	95.37	77.48
< 10 years	95.73	98.60	97.75	85.40

Table 7. Inequality of Density Function for Successful and Unsuccessful Firms

This table reports the Kolmogorov-Smirnov test of equality of the density functions of active time and number of financing rounds between successful firms (IPO and acquisition) and unsuccessful firms (out of business).

Kolmogorov-Smirnov test of equality of density function			
Active time		Number of financing rounds	
H_0 : IPO & Acquisition = Out of business		H_0 : IPO & Acquisition = Out of business	
KS	P-value	KS	P-value
0.3809	0.000	0.0742	0.006

Table 8. Identifying Variables Predicting the Success of Venture-backed Firms

This table reports the Logistic and Probit regressions that are used to identify variables predicting the success of venture-backed firms. The data are all venture-backed firms in the sample that have gone pubic, been acquired, or gone out of business by June 2000. The *Amount raised in the first round* and the *Amount raised in the last round* are all normalized with the average amount raised in all first and last rounds in corresponding years. The joint dummies of industries and starting years are not statistically significant and not reported.

Panel A: Logistic Regression				
Variable	Number of rounds	Amount raised in the first round	Amount raised in the last round	Active time (month)
Coefficient	0.6948	-0.1065	0.7855	-0.0899
Standard Dev.	[0.0618]	[0.0927]	[0.1097]	[0.0051]
t-statistic	(11.2444)	(-1.1498	(7.1607)	(-17.7179)

Panel B: Probit Regression				
Variable	Number of rounds	Amount raised in the first round	Amount raised in the last round	Active time (month)
Coefficient	0.3859	-0.0621	0.3768	-0.0489
Standard Dev.	[0.0333]	[0.0490]	[0.0571]	[0.0026]
t-statistic	(11.5998)	(-1.2668)	(6.5959)	(-19.0813)

Table 9. Robustness of the Estimation to Assumptions regarding Bad Investments

The estimated venture capital index is robust to the assumption regarding the returns for firms out of business. Each row in the table corresponds to a particular assumption, which is in the first entry of that row. The *Average bad return* denotes the geometric average return of the bad sub-index. The *Weight* denotes the average weight of the bad sub-index in the venture capital index. The *Geometric mean* denotes the geometric average annual returns of the bad sub-index from 1987 to 1999. The *Index value* denotes the net asset value of the venture capital index in December 1999. The *Upper bound* category assumes that all unfinished firms are successful. The *Estimated* category estimates the probability of success for unfinished firms. The *Lower bound* category assumes that all unfinished firms are unsuccessful.

		Upper Bound			Estimated			Lower Bound		
Assumption	Average bad return	Weight	Geometric mean	Index value	Weight	Geometric mean	Index value	Weight	Geometric mean	Index value
-98%	-42.1%	15.55%	60.02%	957.65	20.29%	54.13%	590.02	18.10%	24.44%	26.47
-96%	-37.6%	15.84%	60.22%	957.66	20.64%	54.35%	590.32	18.45%	25.08%	27.86
-94%	-34.5%	16.07%	60.37%	957.68	20.93%	54.52%	590.60	18.74%	25.64%	29.15
-92%	-32.0%	16.26%	60.49%	957.69	21.18%	54.66%	590.87	18.98%	26.15%	30.36
-90%	-29.9%	16.43%	60.59%	957.71	21.40%	54.78%	591.13	19.18%	26.61%	31.52
-88%	-28.1%	16.57%	60.68%	957.73	21.59%	54.88%	591.38	19.37%	27.04%	32.62
-86%	-26.5%	16.70%	60.75%	957.74	21.77%	54.97%	591.62	19.53%	27.43%	33.68
-84%	-25.1%	16.82%	60.82%	957.76	21.93%	55.04%	591.85	19.68%	27.80%	34.71
-82%	-23.7%	16.93%	60.88%	957.77	22.07%	55.11%	592.08	19.81%	28.15%	35.71
-80%	-22.5%	17.02%	60.93%	957.79	22.21%	55.18%	592.31	19.94%	28.48%	36.68
-78%	-21.4%	17.11%	60.98%	957.80	22.34%	55.24%	592.53	20.05%	28.79%	37.64
-76%	-20.4%	17.20%	61.02%	957.82	22.46%	55.29%	592.75	20.16%	29.09%	38.57
-74%	-19.4%	17.28%	61.06%	957.83	22.57%	55.34%	592.97	20.26%	29.37%	39.48
-72%	-18.4%	17.35%	61.10%	957.85	22.68%	55.39%	593.18	20.35%	29.64%	40.38
-70%	-17.6%	17.42%	61.13%	957.87	22.79%	55.43%	593.39	20.44%	29.90%	41.26
-68%	-16.7%	17.49%	61.17%	957.88	22.89%	55.47%	593.60	20.53%	30.16%	42.13
-66%	-15.9%	17.55%	61.20%	957.90	22.98%	55.51%	593.81	20.61%	30.40%	42.98
-64%	-15.2%	17.61%	61.23%	957.91	23.07%	55.55%	594.02	20.69%	30.63%	43.83
-62%	-14.4%	17.67%	61.26%	957.93	23.16%	55.59%	594.22	20.76%	30.86%	44.67
-60%	-13.7%	17.72%	61.28%	957.94	23.24%	55.62%	594.43	20.83%	31.08%	45.49
-58%	-13.1%	17.77%	61.31%	957.96	23.32%	55.66%	594.63	20.90%	31.29%	46.31
-56%	-12.4%	17.83%	61.33%	957.97	23.40%	55.69%	594.83	20.96%	31.50%	47.12
-54%	-11.8%	17.87%	61.36%	957.98	23.48%	55.72%	595.03	21.02%	31.70%	47.93
-52%	-11.2%	17.92%	61.38%	958.00	23.56%	55.75%	595.24	21.08%	31.90%	48.72
-50%	-10.6%	17.97%	61.40%	958.01	23.63%	55.78%	595.44	21.14%	32.09%	49.52

Table 10. The Venture Capital Index: Annual Series

This table presents the venture capital index estimated under the assumption that returns for unsuccessful investments are -80%. The *NAV* denotes the net asset value of the index at the end of a year (in billion dollars). The *Cumulative average annual return* for a year equals the geometric average annual return from 1987 to that year.

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Panel A: Net asset value, capital flow, and number of firms in the index													
NAV	1,112	2,471	5,073	5,760	8,687	8,669	1,2339	13,856	20,806	45,466	45,640	80,239	592,308
Inflow	1,053	1,068	1,324	1,479	1,576	2,165	2,598	3,330	4,800	7,214	9,500	12,381	34,495
Outflow	8	62	277	565	1,438	1,942	3,789	3,037	6,266	15,455	9,685	11,402	55,513
#All	318	535	699	869	1,002	1,167	1,340	1,536	1,743	2,132	2,426	2,892	3,793
#New	320	219	174	191	172	234	271	322	406	633	652	769	1,280
#IPO	2	2	5	13	32	46	82	73	108	154	96	64	212
#ACQ	0	0	7	8	8	15	26	35	61	65	63	66	95
#Out	0	0	0	0	2	5	1	14	49	10	227	164	90
Panel B: Annual returns													
VC	22.30%	24.28%	49.30%	-5.94%	46.23%	-4.42%	57.17%	10.04%	58.42%	168.75%	-0.38%	70.62%	681.22%
NASD.	-15.71%	15.40%	19.24%	-17.81%	56.86%	15.45%	14.75%	-3.20%	39.92%	22.71%	21.64%	39.63%	85.59%
SP500	-9.85%	12.40%	27.25%	-6.56%	26.31%	4.46%	7.06%	-1.54%	34.11%	20.26%	31.01%	26.67%	19.53%
Panel C: Cumulative average annual returns													
VC	22.30%	23.29%	31.41%	20.87%	25.56%	19.98%	24.70%	22.76%	26.29%	36.20%	32.28%	35.21%	54.74%
NASD.	-15.71%	-1.37%	5.07%	-1.19%	8.38%	9.53%	10.26%	8.48%	11.59%	12.66%	13.44%	15.42%	19.72%
SP500	-9.85%	0.66%	8.84%	4.77%	8.76%	8.03%	7.89%	6.67%	9.41%	10.45%	12.18%	13.32%	13.79%
Panel D: Volatility													
VC	17.10%	19.40%	9.48%	29.92%	19.12%	38.34%	18.08%	21.88%	21.67%	29.85%	38.39%	70.31%	58.95%
NASD.	9.73%	3.48%	2.98%	7.16%	5.48%	4.19%	3.37%	3.33%	2.76%	5.06%	6.06%	9.04%	8.41%
SP500	8.26%	2.95%	3.61%	5.24%	4.55%	2.15%	1.71%	3.06%	1.48%	3.13%	4.60%	6.20%	3.79%

Table 11. Return Correlation between the VC Index and Market Indices

The table reports the regressions of the (monthly, quarterly, and annual) venture capital index returns upon the returns of SP 500, NASDAQ. The associated standard deviations are in brackets. The associated t-statistics are in parentheses.

	Intercept	SP500	NASDAQ	R2	F	P-value
Regressions of monthly returns						
	-0.2193	1.2920		0.0236	3.698	0.0563
	[0.6804]	[0.6719]				
	(-0.3223)	(1.9230)				
	0.2650		0.8093	0.0185	2.8804	0.0917
	[0.4858]		[0.4768]			
	(0.5454)		(1.6972)			
	-0.1937	1.1271	0.1390	0.0238	1.8497	0.0238
	[0.7015]	[1.2429]	[0.8798]			
	(-0.2762)	(0.9069)	(0.1580)			
Regressions of quarterly returns						
	Intercept	SP500	NASDAQ	R2	F	P-value
	-0.7591	1.8894		0.0485	2.5464	0.1168
	[1.2289]	[1.1840]				
	(-0.6177)	(1.5957)				
	0.0534		1.0868	0.0433	2.2638	0.1387
	[0.7650]		[0.7223]			
	(0.0698)		(1.5046)			
	-0.6034	1.3304	0.4020	0.0501	1.2934	0.2835
	[1.3481]	[2.2415]	[1.3637]			
	(-0.4476)	(0.5935)	(0.2948)			
Regressions of annual returns						
	Intercept	SP500	NASDAQ	R2	F	P-value
	-0.8628	2.4138		0.0378	0.4326	0.5243
	[4.2417]	[3.6700]				
	(-0.2034)	(0.6577)				
	-3.8038		4.6552	0.5197	11.9042	0.0054
	[1.6953]		[1.3492]			
	(-2.2438)		(3.4502)			
	1.6088	-7.7704	7.5089	0.7165	12.6391	0.0018
	[2.4669]	[2.9490]	[1.5346]			
	(0.6522)	(-2.6349)	(4.8932)			

Table 12. Volatility Correlation between the VC Index and Market Indices

This table presents the regressions of annual volatility of the venture capital index upon the volatility of SP 500, NASDAQ, and both. The volatility in a year is defined as the standard deviation of all monthly returns in that year. The associated standard deviations are in brackets. The associated t-statistics are in parentheses.

	Intercept	SP500	NASDAQ	R2	F	P-value
	0.2233	2.0147		0.0472	0.5449	0.4759
	[0.1175]	[2.7293}				
	(1.9002)	(0.7382)				
	0.0668		4.3017	0.3551	6.0567	0.0316
	[0.1039]		[1.7479]			
	(0.6433)		(2.4610)			
	0.0935	-10.0874	11.0165	0.6731	10.2936	0.0037
	[0.0780]	[3.2345]	[2.5179]			
	(1.1984)	(-3.1187)	(4.3753)			

Figure 1.

The probability for a firm to exit successfully (IPO or acquisition) conditional upon the observed lower bounds of its active time and the number of financing rounds.

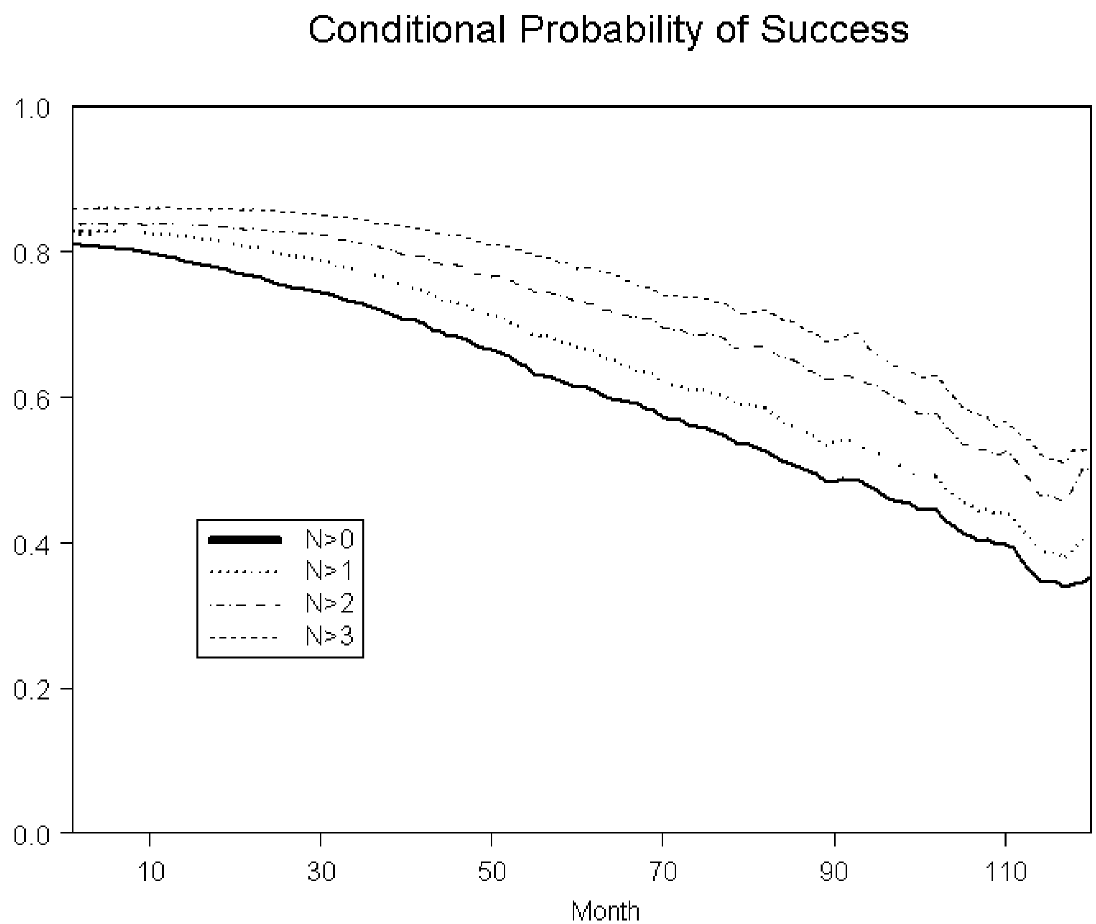

Figure 2.
Starting and finishing VC financing rounds from January 1987 to December 1999.

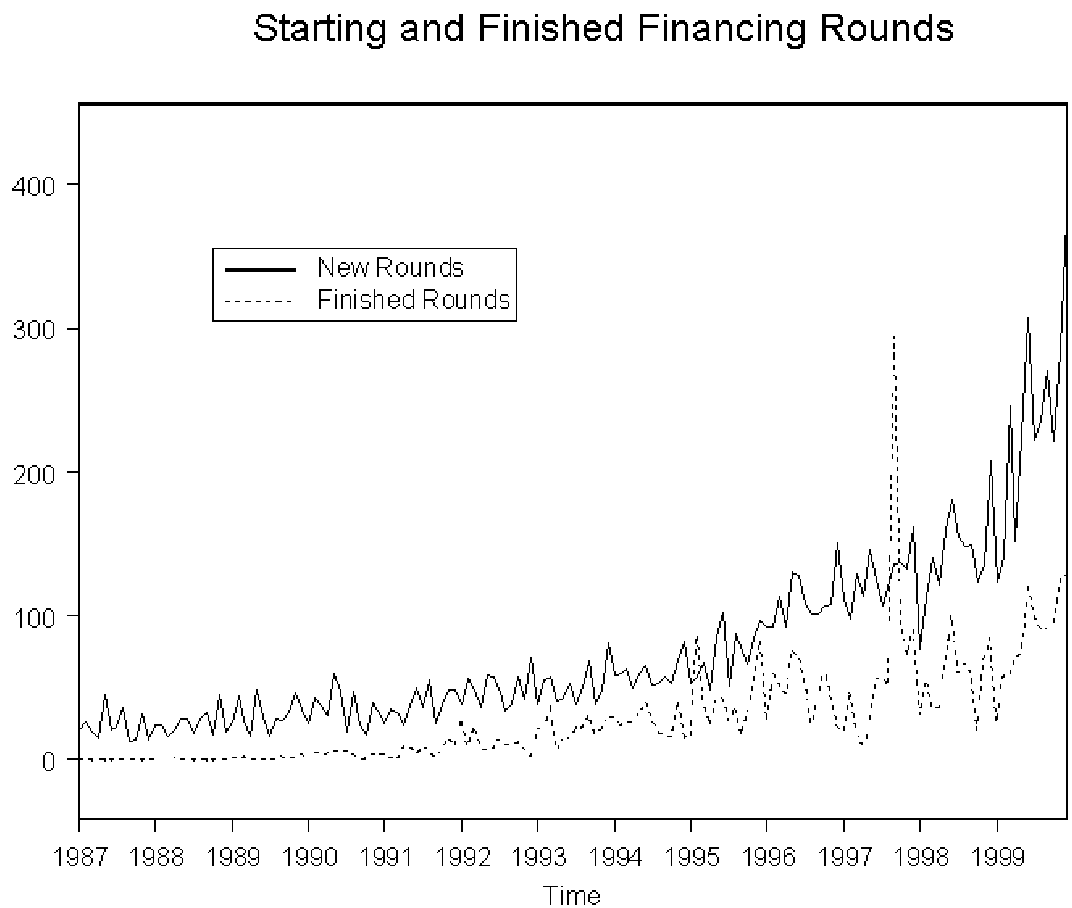

Figure 3.

Capital flows into and out from the VC index from January 1987 to December 1999.

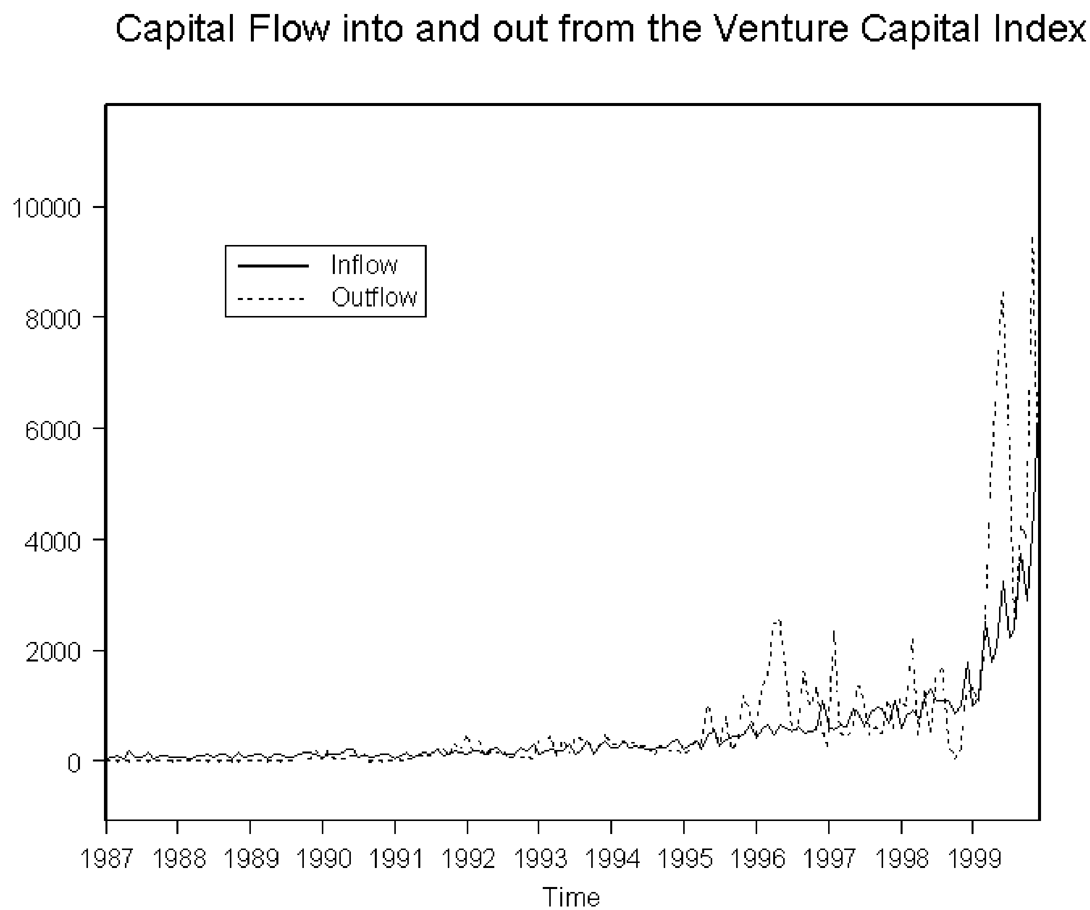

Figure 4.

The number of new firms and all firms in the VC index from January 1987 to December 1999.

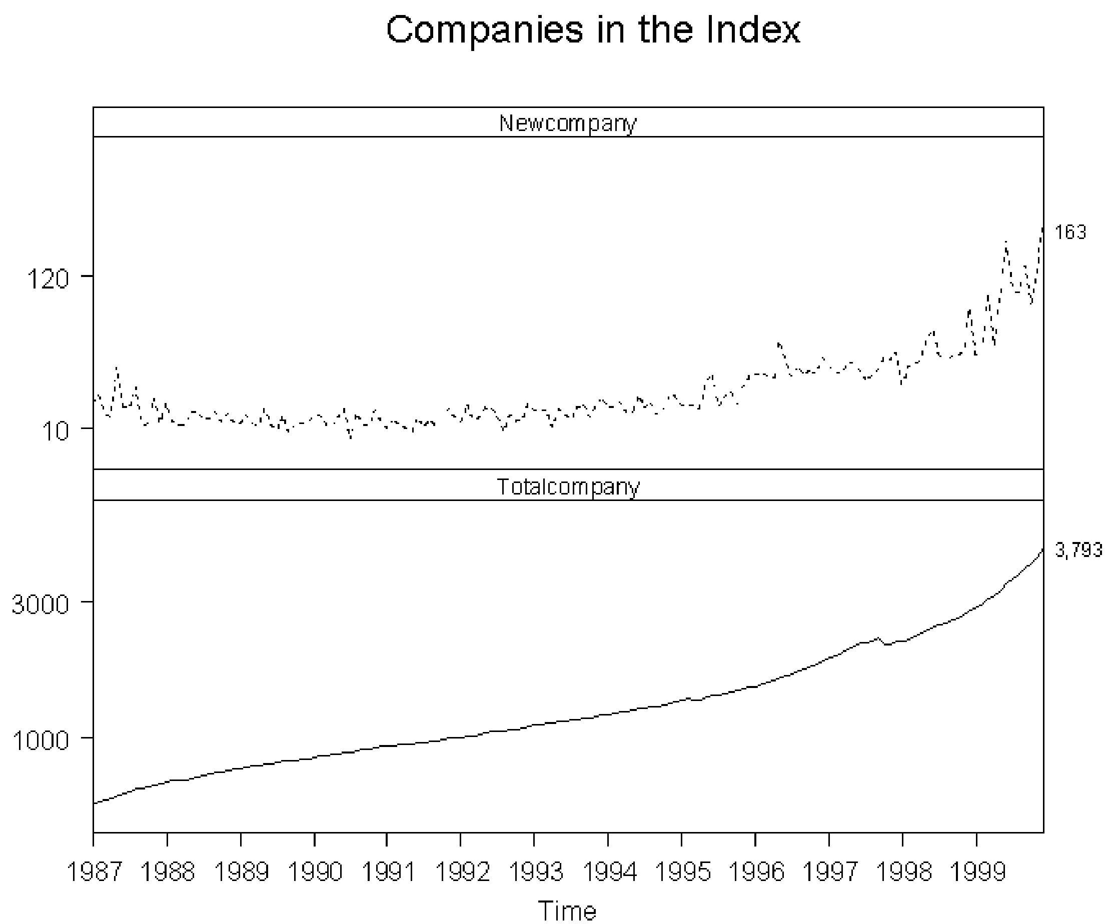

Figure 5.

The number of firms leaving the VC index with different exit types from January 1987 to December 1999.

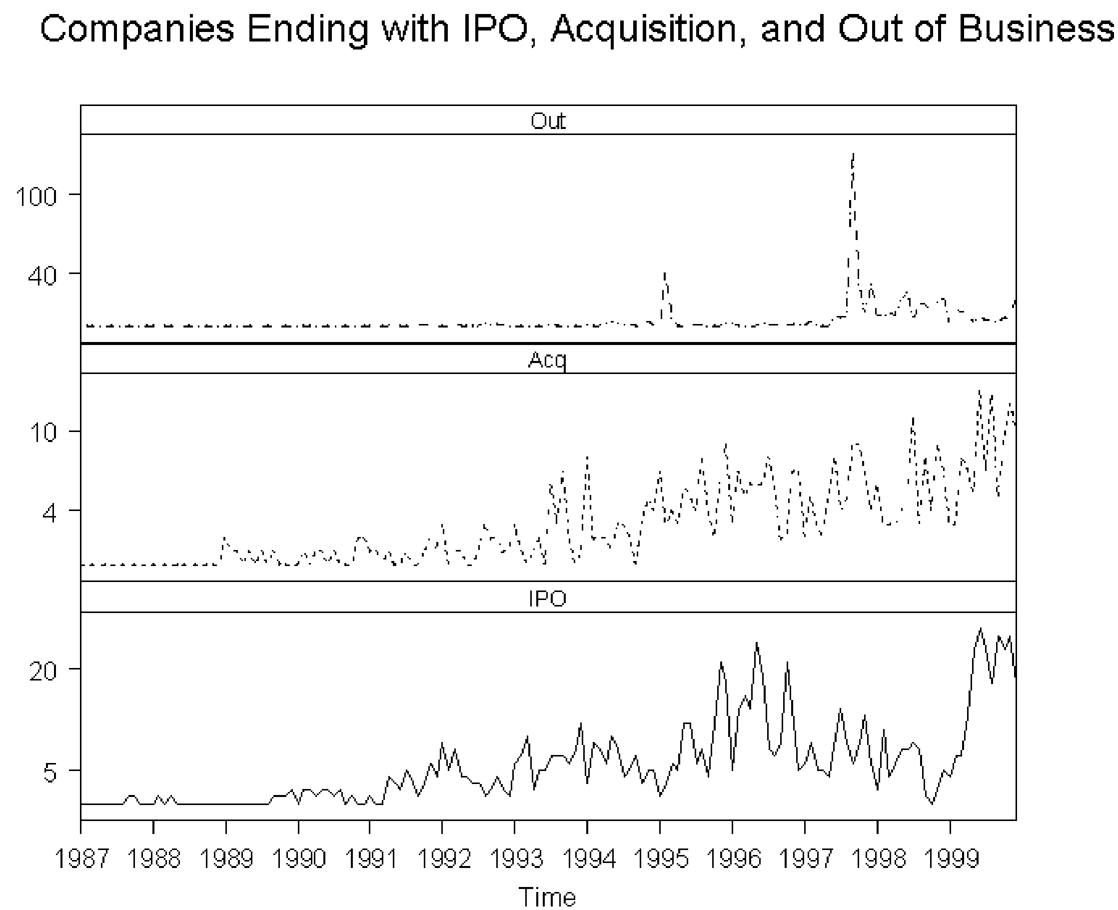

Figure 6.
The upper bound, estimated, and lower bound of the net asset value of the VC index from January 1987 to December 1999.

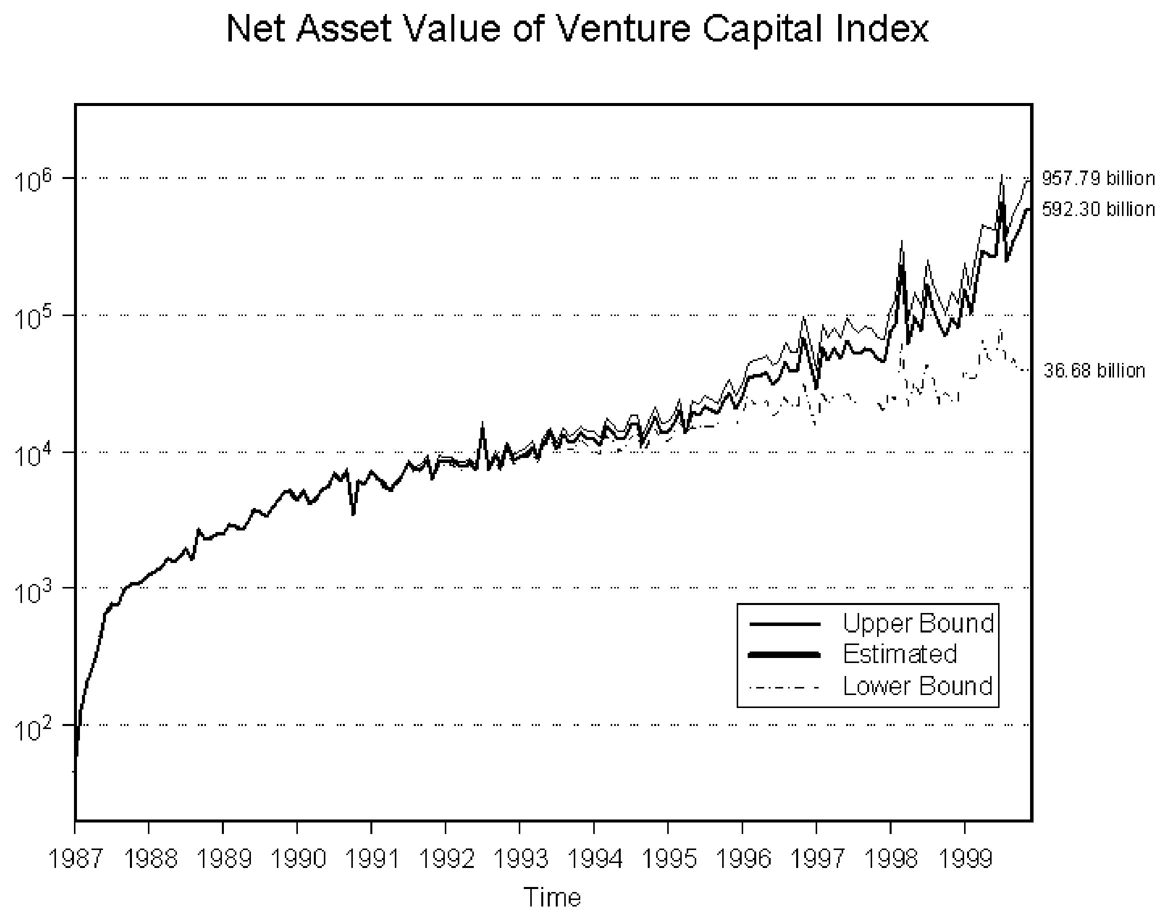

Figure 7.
The annual capital appreciation returns for the VC index, SP 500, and NASDAQ from 1987 to 1999.

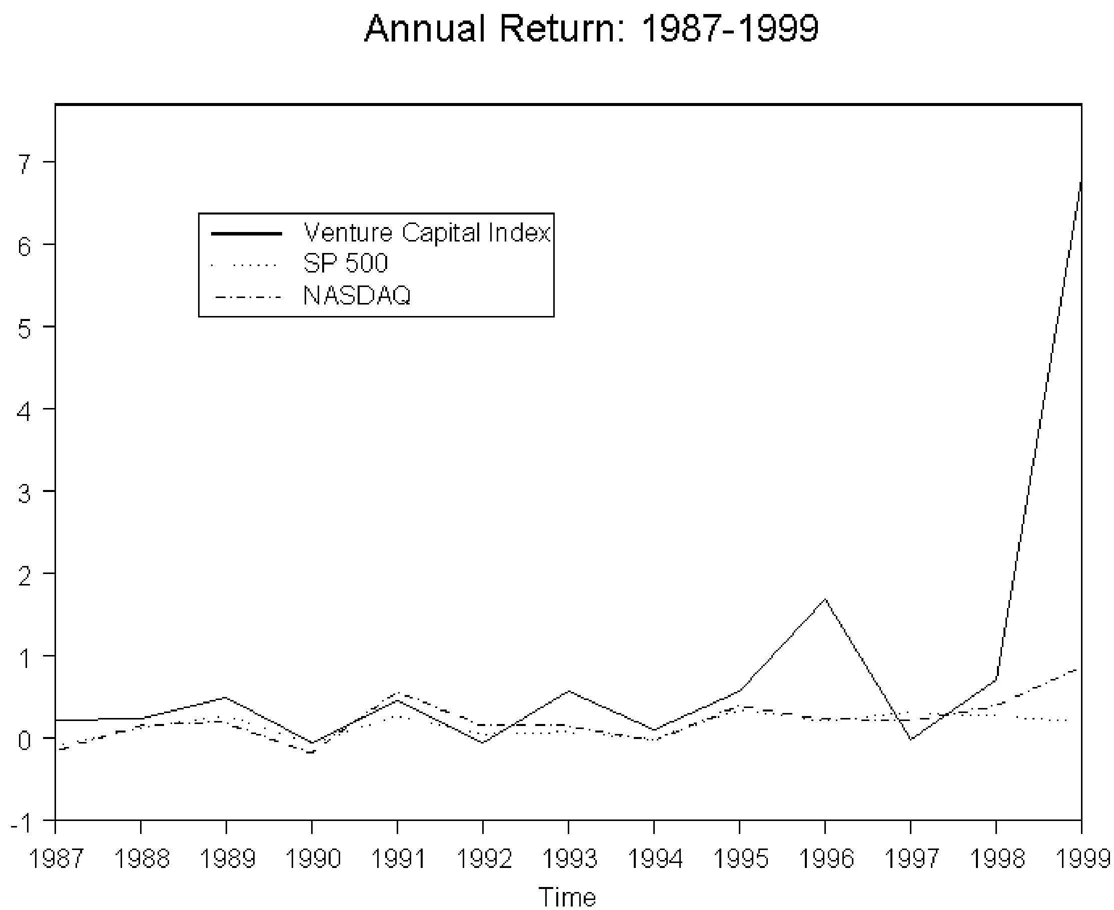

Figure 8.
The capital appreciation indices of venture capital and SP 500 from 1987 to 1999.

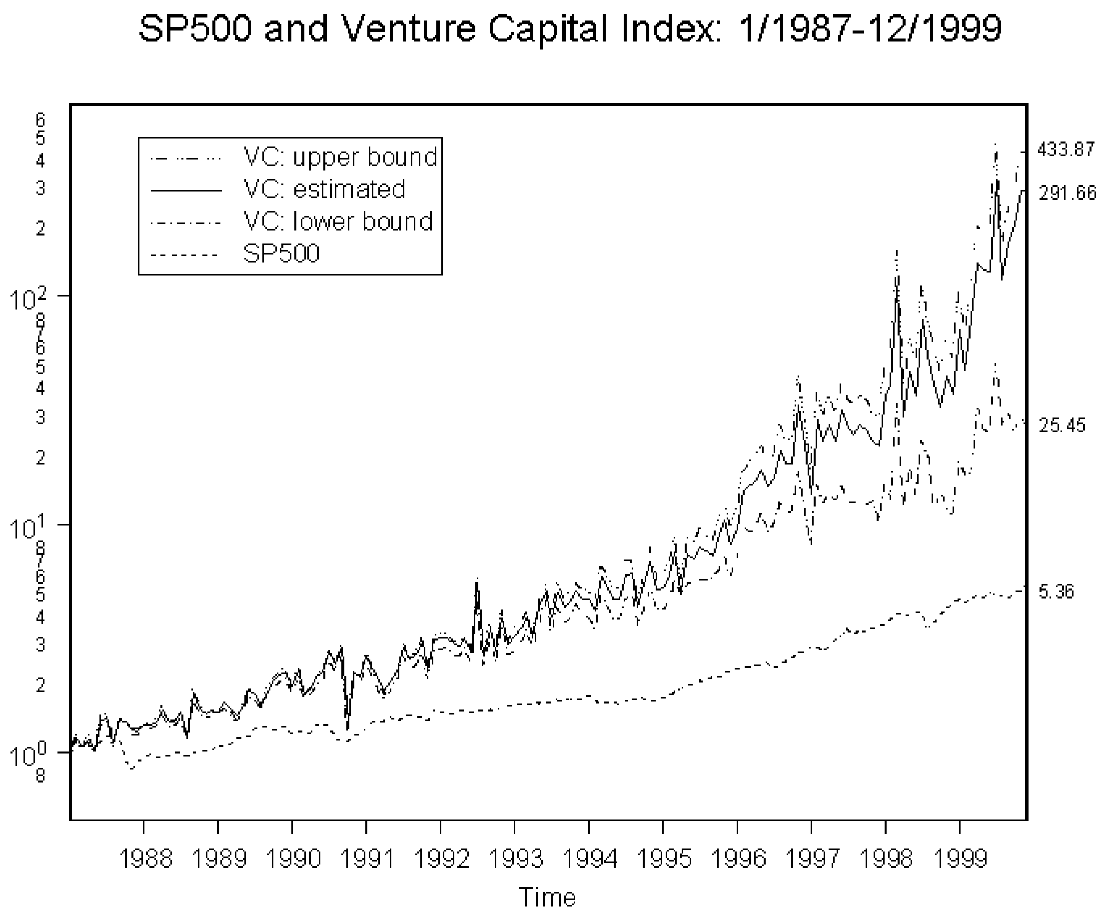

Figure 9.

Distribution of monthly capital appreciation returns from January 1987 to December 1999. The capital appreciation returns are estimated under the assumption that unsuccessful investments have -80% returns.

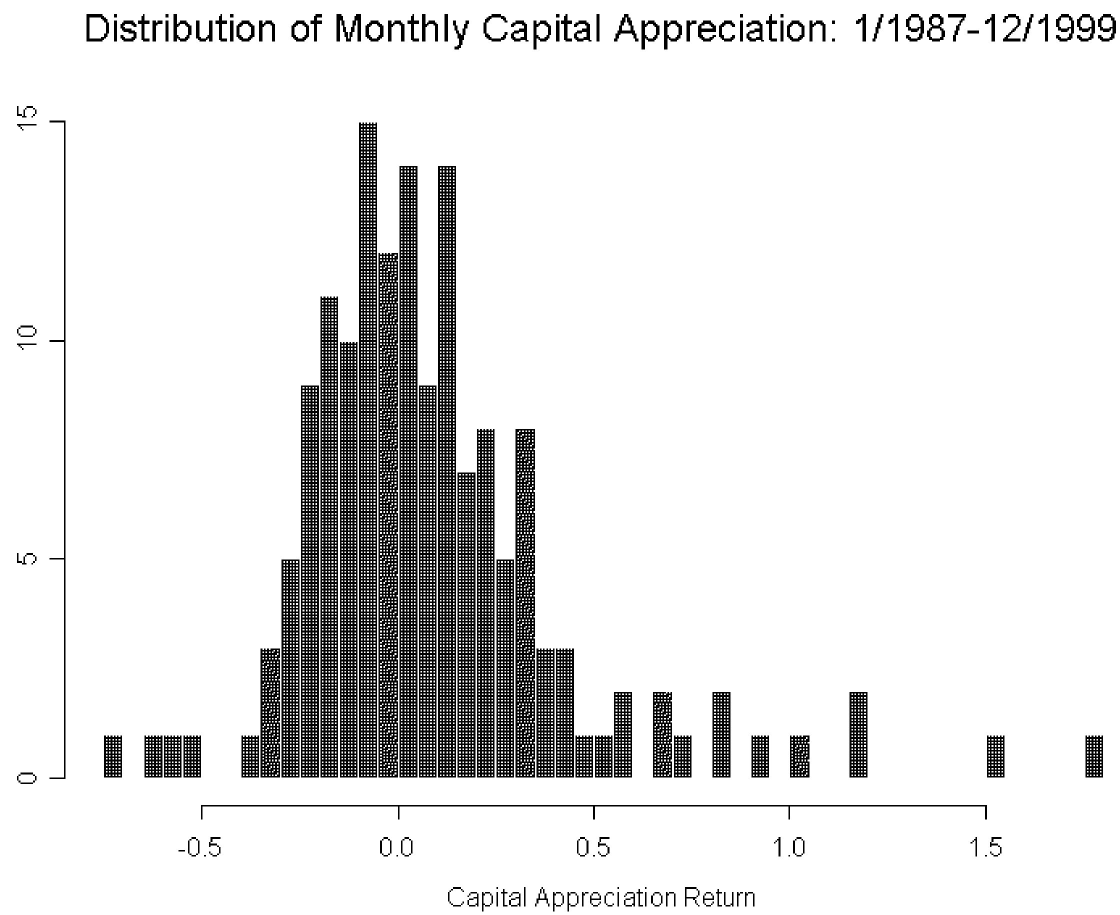

Figure 10.

The annual volatility of the VC index, SP 500, and NASDAQ from 1987 to 1999. The volatility of a year is defined as the standard deviation of the monthly returns in that year.