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An Index For Venture Capital, 1987-2003

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Abstract

In this paper we build an index of value for venture capital. Our approach overcomes the problems of intermittent, infrequent pricing of private company deals by using a repeat valuation model to build the index, and it corrects for selection bias in the reporting of values. We use a unique data set from Sand Hill Econometrics which reports 50,734 funding events, which include the contemporaneous valuations of 9,092 private equity firms disclosed 19,208 times over almost 17 years. The resulting index measures the return and risk for venture capital. Its covariance with other asset classes from 1987 through 2003 enables us to explore the role of venture capital in diversified portfolios during a period of increased importance of venture capital in the economy.

KEYWORDS: Private Equity, Price Index

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I. Introduction

Over the past decade, venture capital has grown enormously in economic importance. It was estimated that in 1990 about $3 billion flowed into venture funds. A decade later the corresponding figure was $103 billion. At the same time, the outstanding total value of such firms was roughly $500 billion; in comparison, the market value for companies listed on US stock exchanges was roughly $10 trillion. The economic importance of the privately held companies that seek financing from outside investors probably exceeds their current share of business value, because some of today's private companies will become high-value public companies in the future. Roughly two-thirds of the companies that go public had venture capital funding prior to their public offering.

Some of the ownership interests in private companies are held directly as stock in the issuing company, and some are held as limited partnerships in venture capital funds. Holders are primarily pension plans, endowments, corporations, and wealthy individual investors. Companies funded by primary investors and by venture capital funds find their way to the public markets. During the late 1990s, roughly two-thirds of the companies making initial public offerings had backing from venture capital funds, and many of the others had substantial funding from outside primary investors. Investment in pre-public companies[1] is no longer experimental or exploratory, but is a permanent feature of the U. S. financial landscape.

There is little systematic information on the results of venture investments. By contrast, for publicly traded holdings, quantitative performance evaluation is straightforward. Standard indices, such as the S&P500 and the Wilshire 5000, provide measures of overall market returns. For non-traded holdings, such as venture capital, investors have no similar benchmark.

This paper builds an index for venture capital to provide a clear benchmark. Such a benchmark is useful: for evaluating the performance of particular venture holdings; for evaluating the performance of specific funds, including venture capital limited partnerships, corporate venture funds, and venture holdings of pension and endowment funds; for comparing the performance of venture capital with that of other asset classes; for determining the

[1] By private equity we mean equity in *pre-public* companies. These firms raise money from outside investors with the hope and intention of becoming public corporations. We do not include leveraged buy-outs (LBOs), management buy-outs (MBOs), or private placements in otherwise public companies (PIPEs) in our analysis, although they are private in the sense that there are restrictions on the sale of these types of securities to the general public. Further, by common usage, "venture capital" refers to investments in pre-public companies made through venture capital funds and those made directly by primary investors. We thus use venture capital and private equity as synonyms.

appropriate portfolio allocations of different asset classes; and for other applications as well.

There are several major problems in constructing such an index. To begin with, pricing events for private companies are intermittent and infrequent, not regular and almost continuous as for traded securities. A price is set for stock in an individual company when it raises new capital, when it sells shares to the public (through an IPO), when it is acquired, or when it ceases operations. These companies are "private" — their stock is not registered with the Securities and Exchange Commission (SEC); they do not report financial results to the SEC or to the public unless they choose to, and their stock is not traded in any organized market. Nearly all such companies are organized as C-corporations (and are thus themselves taxable entities). These companies may be valued only a handful of times during the interval between establishment and IPO, acquisition, or cessation of operations.[2] Moreover, because they are private, disclosures are voluntary. Hence, even when firms are valued, they need not reveal the price at which they sold stock in their most recent round. More important for our analysis is the fact that companies may simply forgo an opportunity to raise money if they find the available terms unappealing. In other words, some trades happen and the prices at which they occur are reported, some trades occur but prices are not reported, and some potential trades do not occur at all.

To measure movements in the value of these privately held firms over time, we develop a method for creating a standardized price index for such firms. We build the index using a modern hybrid version of the repeat-sales technique introduced by Bailey *et al*. (1963) for measuring price changes for real property sold infrequently, and we correct it for selection bias. There are two steps to building the index. In the first step, to measure the sample selectivity in the transactions that do reveal value, we construct the histories of pricing events for all of the companies for which we have data (those events that reveal value and those that do not) to estimate the probability that a company will reveal value (through an IPO, acquisition, private funding, or by ceasing operations). We then use this estimated probability in constructing the index by a hybrid version of the repeat-valuation method that uses information on the transactions for companies which revealed value and for which we can observe a price or a return in some interval. The approach is similar to that used to construct price indices for residential real estate by government agencies (OFHEO), government-sponsored enterprises (Freddie Mac and Fannie Mae), and private firms such as MRAC, Inc.

[2] Private companies that raise money from outside investors and cease operations can do so either through windup or shutdown (in principle, creditor's bills are paid in full in this event) or through Chapter 7 bankruptcy liquidation. If there is no hope for a company, the board of directors is obliged to wind it up rather than continue struggling until remaining assets can no longer satisfy creditors. Windups (or shutdowns) are far more frequent than bankruptcies.

The novelties in our application lie in the extension of the hybrid repeat sales approach to private companies, the correction for selection bias made necessary by the non-random nature of the reporting of transactions, and --importantly-- the analysis of a timely and unique data set which spans the recent period of volatility in asset markets.

The unit of observation is a pricing event for a private company. This includes any private round of fund raising, which necessarily produces a company value (reported or not) determined by negotiation between the issuing company and its investors (which may include venture capital limited partnerships, individuals, and corporations). Pricing events also include IPOs, acquisitions, and windups or bankruptcies. The index thus reflects gross returns from direct investments in the companies, not the returns to venture fund limited-partner investors after the fees and expenses of their funds.[3]

Others have acknowledged the importance and difficulty of estimating returns for private equity investments. Bygrave and Tymmons (1992) calculated average internal rates of return for completed venture funds; they reported an average annual return of 13.5 percent from 1974 to 1989, using an approach that provides no risk measurement. Reyes (1997) used a set of 175 completed venture capital funds to calculate betas, and found them to lie between 1 and 3.8. Gompers and Lerner (1997) reported an arithmetic average annual return of 30.5 percent on completed venture funds from 1972 to 1997. Long (1999) calculated risk by inferring the shorter-term standard deviation from variations in longer-term returns, and reported an estimate of the annual standard deviation of 8.23 percent per year for completed venture funds. This analysis was based upon nine unidentified, successful VC investments. Moskowitz and Vissing-Jorgenson (2002) measured returns to all private equity, conceived very broadly to include closely-held businesses with no intention of going public and no money from outside investors. They used data from the Survey of Consumer Finances, including self-reported valuations. They were puzzled that the returns were so low.[4] Chen, Baierl, and Kaplan (2000) examined completed venture funds to calculate average annual arithmetic and geometric returns, standard deviations, and correlations with market indices. They reported a geometric average return of 13 percent, an annual standard deviation per fund of 115.6 percent, and a

[3] Venture capital funds typically charge their limited partner investors an annual management fee of two to three percent of net asset value, and then also take 20 to 35 percent of the gains (20 percent is a standard "carry," while 35 percent is a "premium carry") on the companies with positive returns when they are acquired or go public.

[4] Companies issuing pre-public private equity are a tiny fraction of private businesses. There are more than 20 million companies that file income tax returns. Roughly 5 million have a payroll. Of these, roughly 1.5 million are organized as C corporations.

correlation with the public stock market of 0.04. None of this work considers selection bias.

Two pieces of research on venture risk and return that do address the selection issue are Cochrane (2005) and Peng (2001). Both empirical analyses rely upon a subset of our data that was available in 2000 covering the period 1987-2000. These data are for venture-backed firms only, primarily from the VentureOne database (described below). Peng (2001) builds a venture valuation index accounting for selection by combining two sub-indices, one for shutdowns and the other for successful exit. He corrects for selection bias approximately, by assigning weights to these two indices based on the likelihood that companies will go out of business or will succeed, estimated from observable characteristics.

Cochrane analyzes 16,613 observations on 7,765 startup firms observed between January 1, 1999 and June 30, 2000. He uses a maximum likelihood approach to estimate returns, standard deviation, and correlation with the market, accounting for probability of new funding rounds as a function of firm values, and correcting for selection bias in the reporting of valuations. His approach estimates risk and return directly, but does not build an index of valuation. He finds that the selection-bias-corrected log return is 15 percent during 1987-2000, compared to the bias-uncorrected return of 108 percent, and that alpha from the log market model is -7 percent, compared to the bias uncorrected alpha of 92 percent. He also finds that log returns are still quite volatile, with standard deviation of 89 percent.[5]

In Section II we describe the economic problem and review models that have been employed in analogous settings to develop indexes of value. Section III provides a detailed description of observations on 50,734 rounds of financing for 9,092 start-up firms during the period January 1, 1987 through June 30, 2003. These data are used to estimate a valuation index for this sector of the economy. Section IV reports our principal empirical results, measurement of a price index for private equity corrected for selection bias. Section V explores an application of this analysis to portfolio allocation. Section VI is a brief conclusion and discussion of future work.

II. Venture Firm Values, Index and Selection Bias

2.1 A Hybrid Index Model with Selection Bias Correction

Methods for estimating market prices for heterogeneous goods or for items traded infrequently have received considerable attention among applied

[5] However, the arithmetic return is still large and volatile even after correcting for selection bias. He finds that the mean arithmetic return is 59 percent with a standard deviation of 107 percent. The arithmetic alpha is as high as 32 percent.

econometricians and finance professionals. Methods to account for the heterogeneity of goods were extended in the early 1970s (Kain and Quigley, 1970, Griliches, 1971) and have been applied quite widely in the analysis of durables, such as automobiles (Otha and Griliches, 1975), housing (Kain and Quigley, 1975), home appliances (Hausman, 1979), and computers (Pakes, 2003). Hedonic price models account for the heterogeneity of commodities by relating the observed transaction prices or market values, V_t, (or sometimes, in the case of automobiles, list prices) to a vector, $X_t=(x_{1t}, x_{2t}, \ldots, x_{nt})$ describing the qualitative and quantitative attributes of the goods. The estimated coefficients, b, represent the implicit marginal prices of each attribute.

$$(1) \qquad V_t = b_0 + \sum_{i=1}^{n} b_i x_{it} + \sum_{\tau=1}^{t} p_\tau \delta_\tau + \xi_t = b' x_t + p' \delta_t + \xi_t$$

where δ_τ is an indicator variable with a value of one for all time periods up to t, and p_τ is the change in prices during period τ. ξ_t is a random error with mean zero.

It is often assumed that the statistical relationship is semi-logarithmic. The underlying logic is that market value V is the product of price P times quantity X, i.e.,

$$(2) \qquad V_t = X_t P_t .$$

The logarithm of the transaction price is regressed upon variables measuring the physical characteristics of the commodities x_{it} and dummy variables representing time δ_t. In this formulation, $\exp \sum_{\tau=1}^{t} p_\tau \delta_\tau$ is the price index at t.

Despite the popularity of the semi-log form, few economically meaningful restrictions can be placed on the form of the hedonic relationship (Rosen, 1974). Because theory provides little guidance in the formulation of statistical models of hedonic prices and because many durables are traded infrequently in thin markets, repeat-sales methods have been developed to abstract from measuring the hedonic characteristics of these goods.

Consider the difference between transaction prices measured at t and T.

$$(3) \qquad V_t - V_T = b'(x_t - x_T) + p'(\delta_t - \delta_T) + \xi_t - \xi_T .$$

If the form of the hedonic price function is semi-logarithmic and if the characteristics of the commodity are unchanged between sales, the model reduces to

$$(4) \qquad V_t - V_T = p'(\delta_t - \delta_T) + \xi_t - \xi_T ,$$

where the left hand side is a logarithmic difference.

The advantage of this formulation is that, for repeat sales of unchanged commodities, it is not necessary to measure the detailed characteristics of the commodities to estimate the price index implied by equation (1). In the forty years since they were introduced (Bailey, *et al.*, 1963), these models have been applied extensively to the housing market, and they form the basis for most commercially developed measures of local housing price variation (for example, indexes marketed by Fiserv CSW, Inc.) as well as the regional housing price information produced by the Federal Government (the OFHEO house price series for states and metropolitan areas). Goetzmann (1993) applied the same technique to valuing fine art.

The repeat-sales method encounters two major challenges. First, multiple sales may be non-random samples of the underlying population (Hwang and Quigley, 2004). If the objective is to estimate the value of the stock of the asset, rather than merely the value of those units that have been sold in any period, this selection bias may be important. In an application to private companies, it seems clear that firms receiving financing at any point in time are those whose prospects are more promising than are those of other firms. Thus, bias in sample selection is potentially quite important. Second, characteristics of the product may change.

To address these issues, a variety of hybrid models have been developed. These models combine the desirable properties of hedonic and repeat sales estimators. For example, joint estimation of equations (1) and (3) for single sales and repeat sales combine hedonic adjustments with changes in market value.

(5a) $V_{it} = b'x_{it} + p'\delta_{it} + \xi_{it}$

(5b) $V_{it} - V_{iT} = \hat{b}'(x_{it} - x_{iT}) + \hat{p}'(\delta_{it} - \delta_{iT}) + \xi_{it} - \xi_{iT}$

(5c) $b = \hat{b}$ and $p = \hat{p}$.

More general hybrid specifications with more realistic specifications of the error structure are also possible. (See Englund, *et al.*, 1998, for a survey and application.) A sensible specification of the error structure in (5) may be a first-order autogressive process,

(6) $\xi_{it} = \varepsilon_{it} + \eta_{it}$ and $\varepsilon_{it} = \lambda\varepsilon_{i,t-1} + \mu_{it}$

where η_{it} and μ_{it} are white-noise innovations.

$$E(\eta_{it}) = E(\mu_{it}) = E(\eta_{it}\mu_{it}) = 0$$

(7) $E(\eta_{it}^2) = \sigma_\eta^2$

$$E(\mu_{it}^2) = \sigma_\mu^2$$

The original Bailey, *et al*. (1963) model assumes the λ = 0 while the Case-Shiller (1987) model assumes λ = 1.

In this formulation, the error variances in equations (5a) and (5b) are:

(8a) $$\mathrm{Var}(\xi_{\mathrm{it}}) = \frac{\sigma_\mu^2}{1-\lambda^2} + \sigma_\eta^2 \quad .$$

(8b) $$\mathrm{Var}(\xi_{\mathrm{it}} - \xi_{i\tau}) = \frac{2\sigma_\mu^2(1-\lambda^{t-\tau})}{1-\lambda^2} + 2\sigma_\eta^2$$

(8c) $$E\left[(\xi_{it} - \xi_{i\tau})(\xi_{ig} - \xi_{i\gamma})\right] = \left(\frac{\sigma_\mu^2}{1-\lambda^2}\right)\left(\lambda^{t-g} - \lambda^{t-\gamma} - \lambda^{\tau-g} + \lambda^{\tau-\gamma}\right)$$
$$+\sigma_\eta^2\left(I(t=g) - I(t=\gamma) - I(\tau=g) + I(\tau=g)\right)$$

Now consider selection bias. Successful firms are more likely to attract additional rounds of private equity finance, are more likely to reveal value when they do attract money, are more likely to be acquired by publicly traded firms, and are more likely to raise capital through an initial public offering.

In any period, we observe that firm *i* takes one of the following actions: (1) it ceases operations; (2) it is acquired by another firm which does not reveal its value; (3) it undertakes no funding event; (4) it obtains a new round of private equity financing, but chooses not reveal its valuation; (5) it obtains a new round of financing, revealing its value; (6) it is acquired by another firm which reveals its valuation; (7) it sells shares through an IPO, "going public" and revealing its value. These alternatives form a natural ordering, from the least desirable (1, a shutdown) to the most desirable (6 or 7, an IPO or an acquisition revealing value). Of these seven events, only four of them result in an observation on the valuation of the firm (1, 5, 6 and 7).

We assume there is an unobserved revelation index, I_{it}, for each firm and unobserved thresholds, I^k, such that if $I_{it} \le I^1$, the firm is shut down; if $I^1 < I_{it} \le I^2$, the firm is acquired without revealing value; if $I^2 < I_{it} \le I^3$, the firm undertakes no funding event; if $I^3 < I_{it} \le I^4$, the firm obtains a new round of private equity financing, without revealing value; if $I^4 < I_{it} \le I^5$, the firm obtains a new round of financing and reveals its valuation; if $I_{it} > I^5$, the firm goes public through an IPO or is acquired with revelation of its value. Note that I_{it}

may vary over time and with the characteristics of firm (e.g. the state of firm development).

Suppose

(9) $I_{it} = z'_{it}\gamma + \varsigma_{it}$,

where $z_{it} = (z_{1it},\ z_{2it}, \ldots, z_{mit})$ are the characteristics of firm i at time t that affect funding and other aspects of value revelation, and ς_{it} is a random error. The revelation index depends positively on the firm's need to obtain funding and negatively on the firm's value in relation to its earlier value. We observe a firm's value only at the time of a revelation event, $I_{it} > I^4$ or $I_{it} \le I^1$. Thus, the expectation of equation (1) for firm i is

(10) $E(V_{it}) = b'x_{it} + p'\delta_{it} + E(\xi_{it} \mid Funding\ event\ for\ firm\ i\ at\ t)$,

where a funding event is either $\{\omega \mid I_{it} > I^5\}$, $\{\omega \mid I^5 \ge I_{it} > I^4\}$ or $\{\omega \mid I_{it} \le I^1\}$.

Similarly, from equation (3)

(11) $E(V_{it} - V_{iT}) = b'(x_{it} - x_{iT}) + p'(\delta_{it} - \delta_{iT})$

$+ \left(E(\xi_{it} \mid Funding\ event\ for\ firm\ i\ at\ t) - E(\xi_{iT} \mid Funding\ event\ for\ firm\ i\ at\ T)\right)$

Clearly, the coefficients estimated from equation (10) or (11) are biased if the conditional expectation of the error term is not zero. Following Heckman (1979), we model the process that selects firms into the set of observations of those funded.

Denote the correlation of the random element of this selection model, ς_{it}, with the random element of value, ξ_{it}, by ρ. Without loss of generality, we assume that the variance of ς_{it} is one. Then equation (10) becomes:

(5d) $E(V_{it}) = b'x_{it} + p'\delta + \rho\sigma_{\xi}\varpi_{it}$

where

$$\varpi_{it} = \frac{\phi(I^5 - z'_{it}\gamma)}{\Phi(-(I^5 - z'_{it}\gamma))} \quad \text{when } I_{it} > I^5$$

$$\varpi_{it} = \frac{\phi(I^4 - z'_{it}\gamma) - \phi(I^5 - z'_{it}\gamma)}{\Phi(I^5 - z'_{it}\gamma) - \Phi(I^4 - z'_{it}\gamma)} \quad \text{when } I^5 \ge I_{it} > I^4$$

and

$$\varpi_{it} = -\frac{\phi\left(I^1 - z'_{it}\gamma\right)}{\Phi\left(I^1 - z'_{it}\gamma\right)} \quad \text{when } I_{it} \le I^1 .$$

ϕ denotes the pdf and Φ denotes the cdf of the standardized normal distribution. Thus, ϖ_{it} is the inverse Mills ratio in the context of ordered probit. Its inclusion in the valuation regression yields unbiased estimates of the parameters in the presence of non-random sample selection. The selection bias-corrected valuation model associated with equations (10) and (11) is

(5e) $V_{it} - V_{iT} = b'(x_{it} - x_{iT}) + p'(\delta_{it} - \delta_{iT}) + \theta(\varpi_{it} - \varpi_{iT}) + (\xi_{it} - \xi_{iT})$ for a firm with multiple funding events, and

(5e') $V_{jt} = b'x_{jt} + p'\delta_{jt} + \theta\varpi_{jt} + \xi_{jt}$ for a firm with a single funding event,

where θ is the parameter $\rho\sigma_{\xi}$.

Estimation of the model can be accomplished in a two-step procedure. First, an ordered probit with the seven alternatives is estimated to calculate Mills ratio, ϖ_{it}, for each observation. Second, with the Mills ratios computed in the first stage, equations (5e) and (5e') are estimated jointly by maximum likelihood using the error structure assumed in (6), (7) and (8). We can thus obtain unbiased estimates of the price movement of private equity firms using the non-random sample of firms whose valuations are actually observed.

2.2 Cochrane's Model with Selection Bias Correction

As noted above, there exist few approaches to venture firm valuation which take into account selection bias. The closest work to ours is Cochrane (2005), which uses a subsample of preliminary data from the same source as ours, but there are several differences between his approach and ours.

First, for valuation of venture firms, Cochrane uses a CAPM type market model in logarithms while we use a hybrid hedonic pricing model. Cochrane's market model does not allow for the idiosyncratic differences of individual firms, but only the market-wide alpha and beta for venture investment, while the hybrid model presented here allows separate estimates of market-wide valuation and idiosyncratic components of individual firms.

Second, in the selection bias correction, Cochrane does not differentiate among very different types of exits and financing rounds, enforcing a single threshold for various valuation events. In contrast, our correction procedure allows different thresholds for various types of funding events.

Third, in the selection bias correction, in Cochrane, the threshold is derived from the returns of individual firms during the specified intervals without reference to market conditions. In our approach, thresholds are derived with direct reference to market conditions since our ordered probit equation includes a complete set of indicator variables for time.

Fourth, Cochrane's analysis is based on information only up to the second quarter of 2000, which is the very peak for public and private equity valuations. Our dataset covers three additional years, up to the second quarter of 2003, which reflects a complete cycle of firm valuations, for both private and public equity firms.

III. Data

The data used to estimate the venture index come from the Sand Hill Econometrics database and cover the period from January 1, 1987 through June 30, 2003 -- the period covering the rise in the importance of private equity and the substantial market declines beginning in the second quarter of 2000. Construction of this database began with data purchased from proprietary data vendors (initially VentureOne) and has since been substantially augmented by Sand Hill's own research. Substantial effort was invested to make the data suitable for analytical purposes – eliminating duplicate rounds of funding (by matching company names, dates of funding, and amounts raised, and by consolidating multiple closings of the same round) and obtaining precise exit dates for companies that have been shut down, been acquired, or gone public.

The data contain records on 15,583 private firms with a total of 50,734 rounds of financing. Of these, 19,208 rounds include information on post-round valuation, including 14,012 rounds of private-equity financing, 2,116 IPO's, 1,905 acquisitions, and 1,175 shut downs. Table 1 reports the number of observations of valuation by stage of business development and type of financing. About 2,900 financing rounds took place during the product development phase, and 6,700 took place when the firm was delivering product to customers.

The average firm valuation at these financing rounds varies systematically. At later rounds of financing, average firm valuations are higher. Not surprisingly, valuations for IPOs are substantially higher than for other funding events, and valuations of firms further along in the development process are also considerably higher.

Table 2 reports more detail on the firms that exited from the private equity data set through IPO, acquisition, or shut down. The table indicates that the average valuation at exit for IPOs is $319 million, more than twice as large as the reported value at exit for acquisitions ($129 million). At the penultimate round of financing, firms that exited through IPO had almost twice the value as those exiting through acquisition. Significantly, firms exiting through bankruptcy were not much different from those exiting through acquisition in their valuation, as

Table 1.
Summary of Private Financing Information:
By Rounds of Financing and Businses Development Stage

A. Number of Rounds

	Startup	Product Development	Beta Testing	Clinical Trials	Shipping	Profitable	Unknown	**Total**
Seed	316	147	2	3	62	0	47	577
First	358	1,240	103	42	1,300	119	1,743	4,905
Early	18	993	169	121	2,476	201	2,846	6,824
Late	0	68	16	29	658	116	512	1,399
Mezzanine	0	35	5	23	182	59	3	307
IPO	0	117	5	85	746	460	703	2,116
Acquisition	5	131	31	21	719	211	787	1,905
Shutdowns	8	124	25	11	531	37	439	1,175
Total	705	2,855	356	335	6,674	1,203	7,080	19,208

Table 1. (continued)
Summary of Private Financing Information:
By Rounds of Financing and Businses Development Stage

B. Mean Value of Firms with Revelation of Values ($M)

	Startup	Product Development	Beta Testing	Clinical Trials	Shipping	Profitable	Unknown	All Stages
Seed	$6.04	$4.70	$10.24	$1.70	$15.34	----	$6.09	$6.69
First	$13.85	$16.66	$25.26	$28.44	$24.47	$28.52	$27.56	$22.96
Early	$11.76	$40.85	$35.88	$34.55	$55.28	$43.47	$64.39	$55.67
Late	----	$74.82	$48.58	$53.06	$90.19	$57.09	$80.82	$82.02
Mezzanine	----	$76.32	$241.80	$66.77	$134.01	$65.22	$22.40	$109.84
IPO	----	$171.79	$157.60	$150.23	$366.23	$167.13	$272.64	$271.93
Acquisition	$104.00	$314.59	$413.60	$53.85	$133.56	$62.68	$114.61	$133.93
Shutdowns	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total	$10.78	$45.88	$68.21	$66.73	$93.29	$93.69	$78.37	$76.81

Table 2.
Summary of Private Financing Information at Final Financing Round for Firms that Have Exited

	For Preceding Round:				At Exit:
	Total Number of Firms	Mean Number of Days between Exit and Preceding Rounds	Mean Valuation Pre-Round (Million)	Mean Valuation Post-Round (Million)	Mean Valuation (Million)
IPOs whose preceding round was:					
Seed	4	1150	$2.53	$3.20	$127.65
First	177	874	$28.55	$38.58	$234.41
Early	634	648	$76.07	$88.90	$331.79
Late	260	482	$124.90	$142.33	$409.48
Mezzanine	213	315	$87.16	$100.10	$244.31
Average		592	$81.00	$94.36	$318.99
Acquisitions whose preceding round was:					
Seed	22	917	$4.08	$5.90	$33.14
First	245	896	$17.64	$23.78	$76.03
Early	450	890	$48.72	$58.59	$142.28
Late	114	806	$49.17	$58.36	$199.38
Mezzanine	33	645	$95.35	$109.77	$152.23
Average		872	$40.61	$49.30	$128.63
Shutdowns whose preceding round was:					
Seed	27	1785	$5.79	$7.62	$0.00
First	196	1202	$16.41	$23.11	$0.00
Early	331	1401	$49.51	$61.96	$0.00
Late	66	1521	$61.44	$74.07	$0.00
Mezzanine	14	1429	$154.07	$173.41	$0.00
Average		1369	$40.96	$51.36	$0.00

reported after the round immediately preceding exit ($49 million versus $51 million)

For IPOs, on average, the penultimate round of financing raised about $13 million, while the public offering raised $225 million. For acquisitions, the penultimate round of financing raised about $6 million, while the acquisition raised $80 million. For firms that exited through bankruptcy, the last round of financing raised about $10 million, and more than $51 million was lost, on average, in shutdowns.

For firms that exited through an IPO, the average time between rounds of financing was 592 days. For firms that were ultimately acquired, the average time between rounds was significantly higher, 872 days. For firms exiting through bankruptcy, the elapsed time between rounds was higher still, 1,369 days.

IV. Empirical Analysis

For each firm, we observe the dates of all funding events and exits beginning on January 1, 1987 (or when the firm is first recorded in the data set) and ending with its last valuation before June 30, 2003 (or when the firm exited by acquisition, IPO, or windup). At these dates, we observe the business group of the firm in one of four categories (the healthcare industry, information technology, retail and services, and "other"), its stage of development in seven categories (as reported in Table 1), and its region of the country. At each of the funding dates, we observe the type of valuation event (IPO, acquisition, private equity funding, shutdown). For some of these events, we also observe the valuation of the firm. (We always observe firm valuation when it has been funded through a public offering or it has gone bankrupt; sometimes we observe a valuation when it is acquired or when it receives a round of private equity finance.)

4.1 The Selection Model: The Probabilities of Private Equity Financing and Exits

We estimate the probability that a firm will be valued and that valuation will be revealed at any point in time by constructing and analyzing the event histories of funding opportunities for these firms. An "event" is an observation on each firm in the sample in each quarter year. In particular, we observe whether a firm has been funded, the type of funding, and, sometimes the revelation of value. These event histories are analyzed by estimating an ordered probit model using the seven outcomes possible in each quarter. They are: 1) revelation of value through shutdown; 2) funding through acquisition, without revelation of value; 3) no funding at all; 4) private equity funding without revelation of value; 5) private equity funding with revelation of value; 6) funding through acquisition with revelation of value; 7) funding and revelation of value through an IPO.

The observations on individual firms yield 293,927 observations on the occurrence or non-occurrence of one of these events in each quarter. We use this information to construct event histories, recording the occurrence of each of these distinct events in each quarter from 1987 through 2003. Event histories are used to estimate the probability of funding and the probability that valuation is revealed by any firm in any quarter. The seven possible events observable in any quarter are rather clearly ordered from the least desirable for any firm, revelation of value through bankruptcy, through the most desirable, revelation through an IPO. We estimate event probabilities using an ordered probit model.

We estimate the probability of contemporaneous funding of any firm as a function of its development status, recorded at its most recent round of funding, of its industry group and geographical location, the stock market capitalization at the time and calendar time in quarters. We also hypothesize that the probability of funding is inversely related to the elapsed time since its last injection of capital, and that the importance of elapsed time varies with the type of round of previous financing.

The estimates of the ordered probit model are presented in Table 3, based upon the 293,927 observations on funding events. It is widely observed that private equity firms which do not receive regular injections of capital through funding events are less likely to survive and prosper. The results in Table 3 confirm this intuition. They clearly establish that firms whose last round of finding is further in the past are less likely to receive funding in the current period. In particular, a longer elapsed time since the seed (the original) round or the mezzanine (the presumed penultimate) round is inversely related to funding in the current period. Longer elapsed times since funding rounds described as "early" and "late" are also associated with lower probabilities of funding in the current period. Firms which have not been funded "recently" are less likely to be funded "today."

There are also systematic differences in the probabilities of funding and revelation for broad industry groups. Similarly, the kinds of firms located in different geographical regions are associated with differing propensities to receive funding, *ceteris paribus*. Firms in the beta testing stage of development are systematically less likely to receive funding, while firms that are already profitable are much more likely to obtain new funding.

The return on the S&P500 is included to measure the impact of public equity investment opportunities. This impact can come from two different sources. Higher values of the variable are associated with greater availability of investment funds. However, for a given level of funding available, the variable also reflects the degree of competition with public equity investments.

Table 3.
Ordered Probit Model of New Private Equity Finance and Revelation of Value by Quarter, 1987:I through 2003:II

Variables	Coefficient	t-ratio
Days elapsed x Type of Last Funding Round		
Elapsed Days $\left(\times 10^3\right)$	7.7241	151.820
Elapsed Days x Previous Round (Seed) $\left(\times 10^3\right)$	-7.9292	-151.100
Elapsed Days x Previous Round (First) $\left(\times 10^3\right)$	-8.0226	-159.284
Elapsed Days x Previous Round (Early) $\left(\times 10^3\right)$	-8.0290	-159.208
Elapsed Days x Previous Round (Later) $\left(\times 10^3\right)$	-8.0478	-158.877
Elapsed Days x Previous Round (Mezzanine) $\left(\times 10^3\right)$	-8.0271	-118.767

Table 3. (continued)
Ordered Probit Model of New Private Equity Finance and Revelation of Value by Quarter, 1987:I through 2003:II

Variables	Coefficient	t-ratio
Development Status		
Product Development	0.4247	22.426
Beta Testing	0.2077	6.551
Clinical Trials	0.4565	13.896
Shipping Product	0.5246	30.736
Profitable	0.6401	31.249
Geographical Location		
Northern California	0.0770	8.111
Southern California	0.0411	3.202
Massachusetts	0.0912	12.793
Texas	0.0306	3.049
Northern Virginia	0.0319	2.365
NY-NJ	-0.0051	-0.455

Table 3. (continued)
Ordered Probit Model of New Private Equity Finance and Revelation of Value by Quarter, 1987:I through 2003:II

Variables	Coefficient	t-ratio
Technology Group		
Health Care	0.1392	6.445
Information Technology	0.0666	3.158
Retail and Services	0.0166	0.743
Other		
S&P 500	-0.9153	-15.666
Cutoff Points		
Acquisition without Valuation	0.0000	-----
No Funding	0.2486	36.053
Private Equity Financing without Valuation	4.0459	363.809
Private Equity Financing with Valuation	4.7772	409.487
Acquisition with Valuation	5.5106	426.395
IPO	5.7488	414.622

Note: The ordered probit model also contains 65 indicator variables for time in quarters, from 1987:II through 2003:II. The estimation is derived from 293,927 observations on one of 7 funding events observed each quarter for each firm from 1987:I (or when the firm enters the data set) through 2003:II (or when the firm exits the data set).

The table also reports the estimated value of the shift in the probit plane (the "cutoff points") associated with each of the potential events.[6] The magnitudes of the shifts are ordered with the desirability of the outcome. The estimated probit model also includes 65 indicator variables representing time in quarter years beginning with 1987:II. These coefficients are not reported in the table.

We use this ordered probit model to estimate the probability that each firm will experience one of these funding and valuation events in each period. For each observation on firm value, we include the inverse Mill's ratio calculated from this probability as a variable, correcting the estimation for selection bias.[7]

4.2 Estimation of Venture firm valuation and Index

Table 4 reports the coefficient estimates for the valuation models. For comparison, the simple repeat valuation model, equation (3), is presented as well as the hybrid model, equations (5) through (8), estimated by maximum likelihood. Results are reported both with and without the bias correction factor. Since the dependent variable is expressed in logarithms, the coefficients are interpreted as the percentage change in firm valuation associated with a one-unit change in each independent variable.

These models have been estimated in two variants: including a set of 197 indicator variables representing months, beginning with February 1987, and also including a set of 65 indicator variables representing quarter years, beginning with 1987:II. There are only very small differences in the coefficient estimates of the other variables when calendar time is represented in these two variants. Table 4 reports the coefficients when time is measured in quarter years.

As the table indicates, later rounds of financing are generally associated with higher firm valuations. In particular, late rounds of private finance, acquisitions, and IPOs are all associated with higher valuations. Firms reporting profits are valued substantially higher, by about twenty five percent, than other firms at the same round in the same line of business.

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[6] There is not uniform agreement about the appropriate ordering of events in the ordered probit model. In particular, one reviewer questioned the ordering of events 2 ("funding through acquisition, without revelation of value") and 3 ("no funding at all") and events 5 ("private equity funding with revalation of value") and 6 ("funding through acquisition with revalation of value"). To test the sensitivity of our results to the ordering of events, we re-estimated the probit models with several variants on ordering. When outcomes 2 and 3 are re-ordered, the log likelihood is reduced from -159703 to -180840, and the scaled R^2 (See Estrella, 1998) drops from 0.172 to 0.031. When outcomes 5 and 6 are re-ordered, the log likelihood and scaled R^2 statistics are reduced only marginally to -159890 and 0.170, respectively. (See also note 17 below.)

[7] The details of calculating the Mills ratio in the context of ordered probit are reported in Appendix A.

Table 4.
Valuation of Private Equity Firms
1987:I through 2003:II
(t-ratios in parentheses)

	Uncorrected Models		Selection Corrected Models	
	Repeat	Hybrid	Repeat	Hybrid
Current Financing Round				
Seed	11.5970 (162.39)	11.0924 (199.23)	11.1620 (102.32)	10.6693 (128.44)
First	12.1368 (217.98)	11.7485 (293.71)	11.6529 (109.62)	11.2870 (144.52)
Early	12.6423 (247.94)	12.4099 (320.42)	12.0665 (101.62)	11.8502 (130.86)
Late	12.8114 (233.90)	12.7010 (284.00)	12.2509 (103.91)	12.1509 (131.79)
Mezzanine	13.0562 (199.11)	12.9718 (222.46)	12.4875 (100.30)	12.4172 (124.17)
IPO	13.4495 (241.56)	13.5011 (309.74)	12.7682 (92.63)	12.8317 (119.66)
Acquisition	12.7671 (225.69)	12.7556 (292.63)	12.1368 (92.81)	12.1300 (118.94)
Development Status				
Product Development	0.0746 (2.25)	0.0462 (1.54)	0.0704 (2.12)	0.0348 (1.16)
Beta Testing	0.1659 (2.76)	0.1523 (2.74)	0.1341 (2.23)	0.1148 (2.06)
Clinical Trials	-0.0117 (0.1622)	-0.0417 (0.61)	-0.0077 (0.11)	-0.0483 (0.70)

Table 4. (continued)
Valuation of Private Equity Firms
1987:I through 2003:II
(t-ratios in parentheses)

	Uncorrected Models		Selection Corrected Models	
	Repeat	Hybrid	Repeat	Hybrid
Shipping Product	0.2329 (6.22)	0.1886 (6.67)	0.2402 (6.20)	0.1849 (6.54)
Profitable	0.3341 (4.930)	0.2397 (5.11)	0.3381 (4.98)	0.2348 (5.01)
Geographical Location				
Northern California		0.1406 (3.07)		0.1464 (3.19)
Southern California		0.0735 (1.16)		0.0756 (1.20)
Massachusetts		0.0677 (1.11)		0.0725 (1.19)
Texas		0.1882 (2.41)		0.1884 (2.41)
Northern Virginia		-0.0417 (0.51)		-0.0356 (0.43)
NY-NJ		0.0181 (0.28)		0.0151 (0.23)
Technology Group				
Health Care		0.1488 (1.11)		0.1662 (1.24)
Information Technology		0.2673 (2.04)		0.2878 (2.20)

Table 4. (continued)
Valuation of Private Equity Firms
1987:I through 2003:II
(t-ratios in parentheses)

	Uncorrected Models		Selection Corrected Models	
	Repeat	Hybrid	Repeat	Hybrid
Retail and Services		0.1932 (1.41)		0.2025 (1.48)
Mills ratio			0.1092 (5.46)	0.1088 (6.28)
Constant	0.0997 (7.05)	-10.1928 (54.96)	0.0969 (6.85)	-9.6739 (48.37)
λ	0.9447 (167)	0.9587 (7855)	0.9487 (165)	0.9593 (4935)
σ_{μ}^{2}	0.1007 (19.91)	0.0931 (53.09)	0.1007 (19.79)	0.0915 (52.42)
σ_{η}^{2}	0.2108 (24.49)	0.2352 (36.64)	0.2115 (24.48)	0.2364 (36.64)
R^2	0.9265	0.9255	0.9267	0.9257
Number of Firms	4,412	9,092	4,412	9,092
Number of Observations	8,797	13,477	8,797	13,477
Number of Rounds	14,528	19,208	14,528	19,208

Note: The estimated model also contains 65 indicator variables for time in quarters, from 1987:II through 2003:II. (Results from comparable models containing 197 indicator variables for time in months beginning in February 1987 are available on request.) The coefficients of both sets of these variables representing time are reported in Figure 1.

The importance of sample selection bias in the statistical models is quite large indeed. Value of a firm that has a twenty five percent probability of having a pricing event revealing value in the sample ($\varpi = \phi\left(\Phi^{-1}(0.75)\right)/0.75 = 0.4237$) is about ten percent lower than the value of a firm with a 75 percent probability ($\varpi = \phi\left(\Phi^{-1}(0.25)\right)/0.25 = 1.2712$) of experiencing a pricing event which reveals value. Correcting for selection bias influences both the level and precision of the measurement of the value of the stock of private equity which we impute from the sample of firms receiving funding in any period. The coefficients of the selection-bias-corrected models are more precisely estimated, and the coefficients of the more-efficiently-estimated hybrid model differ from those of the uncorrected model.[8]

As noted, each valuation model also includes a set of variables representing calendar time. Figure 1 graphs the nominal price index derived from these variables as well as the 90 percent confidence interval of that index. The figure is based upon the preferred specification: the bias-corrected hybrid model of valuation reported in Table 4, column 4. Figure 1A presents the results based upon the dummy variables representing each quarter. Figure 1B presents the results using the dummy variables designating each quarter. The time pattern of the estimated substantially more volatile, but of course this also reflects the increased sampling error with a highly disaggregated representation of time. The index in Figure 1 tracks the valuation of a "standardized" venture firm (where firms are standardized by the characteristics reported in Table 4). The figure reports that this index of venture company prices falls during the early days of the sample, starts to rise in the mid-1990s, reaching its peak at the first quarter of 2000 (the index value of 238.31). Since then, the index falls dramatically, ending up at less than 50 in the second quarter of 2003.

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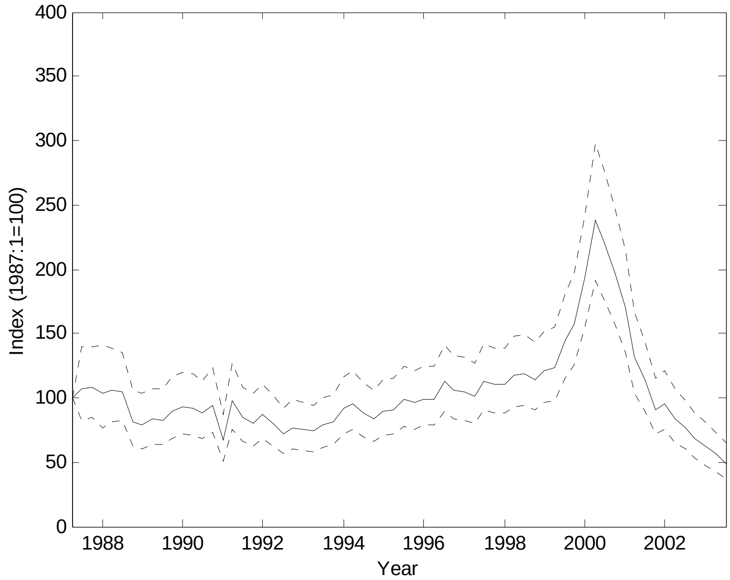
[8] It is, of course, possible that the specific variables which appear in the selection equation do not fully identify that equation. For example, the elapsed time variables which are highly significant in the selection equation might independently affect firm valuation, given selection. In this case, the selection and valuation equations would only be identified by the functional form of the equations and the joint normality assumed in the error terms. We can provide some evidence on this by relaxing the parametric restrictions on the relationship imposed by the functional form (See Ahn and Powell, 1993). To do this, we re-estimated the results reported in Table 4 using the inverse Mills ratio, its square, and its cube as right hand side variables. In this reformulated model, the higher order terms were statistically significant in the valuation equation, but the estimated index was insensitive to this variation in functional form. Of course, this does not insure that the results are insensitive to *other* variations in functional form which depart from joint normality. As with many others who have applied the "Heckit" technique, we would have preferred to rely upon theoretically unambiguous variables to identify the selection mechanism.

Figure 1.

A. Quarterly Valuation Index of Private Equity Firms, 1987-2003
(90 percent confidence interval in dashed lines)



B. Monthly Valuation Index of Private Equity Firms, 1987-2003
(90 percent confidence interval in dashed lines)

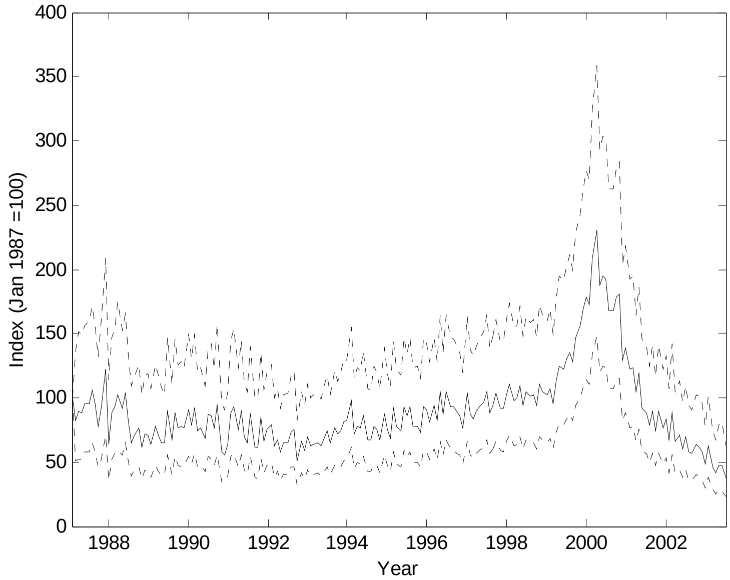


Figure 2.
Hybrid Quarterly Valuation Index of Private Equity Firms:
Selectivity Corrected and Uncorrected Price Indexes

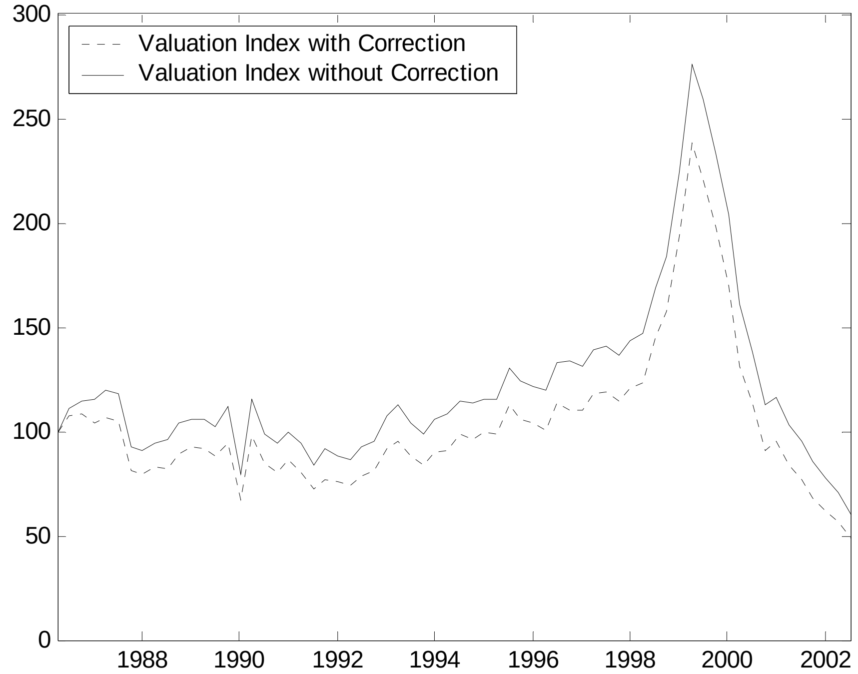


Figure 2 compares the selectivity-corrected index of private equity with the uncorrected index. It plots the quarterly index estimated from column 2 and 4 of Table 4. The selectivity corrected index is lower than the uncorrected index, reflecting the fact that the firms which reveal value at any time are not a random sample from the population. The uncorrected index is also much higher than the corrected index at the peak of private equity values in 2000.[9]

[9] As reported above, we experimented with alternative orderings of outcomes in the probit model, finding little change in the probit results when outcomes 5 and 6 were re-ordered, and significantly worse results when outcomes 2 and 3 were re-ordered. When Mills ratios computed from these alternative probit models are included in the valuation equation, they lead to only small changes in valuation estimates. When outcomes 5 and 6 are reordered, the R^2 in the valuation equation is unchanged, the average log return of index is identical and the standard deviation of log returns is the same. When outcomes 2 and 3 are reordered, the R^2 in the valuation equation is marginally reduced, the mean log index of returns declines from -0.011 to -0.009 and the standard deviation is marginally reduced as well. The estimated indexes are virtually identical to those reported in Figure 1A.

V. An Application

The price index derived in the previous section facilitates some suggestive *ex post* comparisons between investment in venture capital and investment in other financial instruments such as common stocks. Of course, with current institutional arrangements, it is quite easy to invest in a pool of common stocks, for example in a mutual fund or derivative of the S&P500. While venture capital was growing in importance during the 1990s (measured by the amounts outstanding), it is directly accessible as an investment for individuals only if they are "accredited" investors, while indirect investments for individuals are possible through pension funds. In this section, we illustrate the potential role for private equity funds in investment portfolios and assess the possible improvements in the efficient mean-variance frontier made possible by including venture capital in a portfolio. Specifically, we consider a fund or a portfolio which consists of all the firms in the Sand Hill database with valuation information during the period 1987-2000 and 1987-2003. As noted above, this database is the nearest thing to a comprehensive inventory of the venture capital sector. The initial portfolio consists of the venture firms that have valuation events in the first quarter of 1987.

When a new firm has a valuation event, it enters the portfolio in that quarter, and when a firm exits by shutdown, acquisition or IPO, it is removed from the portfolio. Therefore, a firm will remain in the portfolio as long as there is no exit event. When a firm exits successfully by acquisition or IPO, its proceeds are reinvested in the private equity portfolio. For a firm in the portfolio, its value can be affected by changes in the index or by changes in firm attributes, according to (5e), in a valuation event. Valuation events can be intermediate rounds or exit rounds. Intermediate funding events can affect the hypothetical private equity portfolio value, but portfolio returns due to intermediate events do not represent actual returns for the investor since it is quite difficult to realize capital gains (or losses) prior to exit rounds.

Table 5 reports the performance of private equity investments when the investment is based solely on the index, on the index and exit rounds, and on the index and all the funding rounds. There are substantial differences in the investment returns by index only and the investment returns by index and exit rounds. For the whole sample period, the difference is 2.8 percent per quarter, and for the period of 1987 through 2000, the difference is 3.2 percent. In contrast, the difference between the investment returns based on exit rounds and the investment returns based on all funding rounds is relatively small, 0.2 percent for the whole sample period and 0.4 percent for the period of 1987 through 2000. This shows that most of investment performance comes from exit rounds, not from intermediate rounds. In the following analysis, we use the investment performance based on the index and exit rounds.[10]

Table 5. Private Equity Investment Performance
(Nominal Quartetly Returns)

A. Whole Sample Period (1987:I through 2003:II)

	Index Only	*Index and exit rounds*	*Index, exit rounds and intermediate rounds*
Average Return	0.9907	1.0190	1.0212
Standard Deviation	0.1230	0.1376	0.1370

B. Early Sample Period (1987:I through 2000:II)

	Index Only	*Index and exit rounds*	*Index, exit rounds and intermediate rounds*
Average Return	1.0168	1.0492	1.0527
Standard Deviation	0.1074	0.1307	0.1284

We now consider the allocation of an investment portfolio among six types of assets whose prices are indexed by: the S&P500; the NADAQ index; the long term Government Bond index; the Corporate Bond index; Treasury Bill; and the private equity index (PEI) derived in the previous section. We ignore holdings of human capital and owner-occupied housing. We consider these two periods since aggregate returns certainly behaved differently after the second

[10] Note that The private equity returns are not adjusted for the expenses or carry of the venture general partners.

quarter of 2000.[11] Figure 3 indicates the courses of indices based on real returns to investments in the S&P500, the NASDAQ Index, long-term government bonds, corporate bonds and T-Bills during the period 1987-2003. All asset returns are measured quarterly.

Figure 3. Asset Price Development

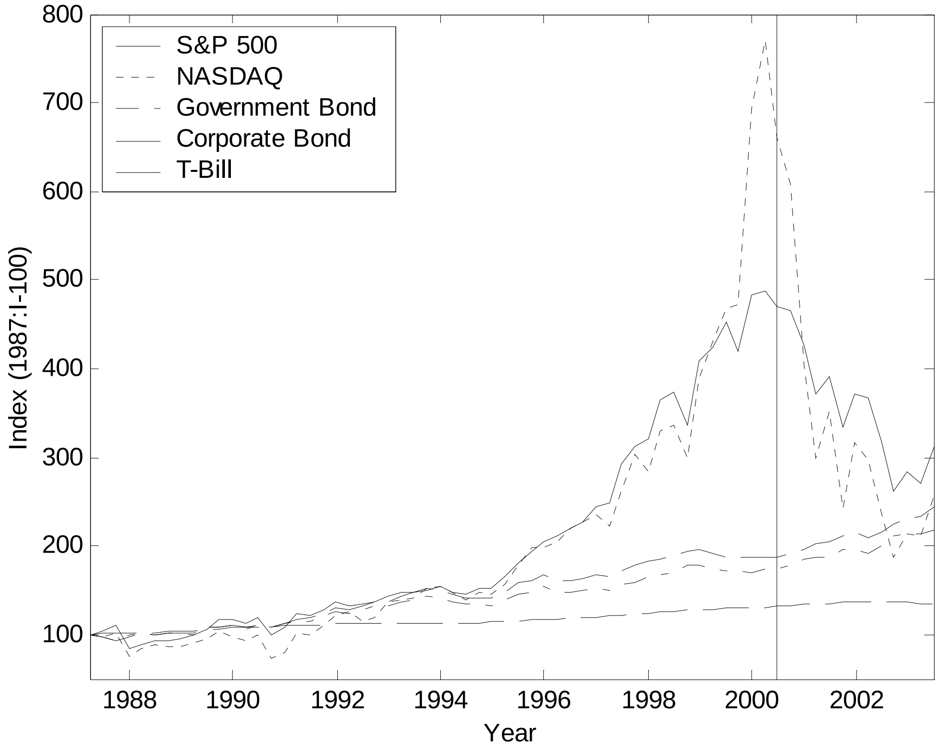


Table 6 reports the means, standard deviations, and the correlations among real returns during the periods of 1987 to 2000 and 1987 to 2003. Real returns on private equity averaged more than five percent for the earlier period, substantially higher than both S&P500 and NASDAQ. For the whole sample period, private equity investment performance comes between S&P and NASDAQ. In both

[11] The NASDAQ reached its historical peak on March 10, 2000 at 5048.62, then dropped to 1622.80 on June 30, 2003, the last day of our sample. Similarly, S&P 500 reached its peak of 1527.46 on March 24, 2000, and dropped to 974.50 on June 30, 2003.

sample periods, standard deviations of private equity returns are comparable to those of the NASDAQ returns. Note that the estimated standard deviations are smaller than those previously reported. For example, Cochrane reports that the standard deviation of quarterly returns to private equity investment is about 54 percent. The lower volatility of private equity returns reported in Table 6 arises only because idiosyncratic error terms are excluded when individual venture firms are valued in the hypothetical private equity portfolio. Volatilities of idiosyncratic errors of private equity investment returns in our data are substantial. Using equation 8(b) and the estimates for variance components (reported in Table 4), the standard deviation of idiosyncratic errors in log returns is 75 percent. However, those idiosyncratic errors are uncorrelated with other asset returns, and thus do not affect optimal portfolio allocation.

Table 6.
Summary Statistics of Asset Returns (Real Quarterly Returns)

A. Entire Sample (1987:I through 2003:II)

	Mean / Standard Deviation	Simple Correlation				
		NASDAQ	*Gov Bond Index*	*Corp. Bond Index*	*T-bill*	*PE Hybrid Index*
S&P	1.0213 0.0840	0.8796	-0.1364	0.0409	0.3025	0.3856
NASDAQ	1.0254 0.1466		-0.1870	0.0002	0.1871	0.4710
Gov. Bond Index	1.0124 0.027			0.9274	0.3334	-0.1365
Corp. Bond Index	1.0142 0.0266				0.3473	-0.1474
T-bill	1.0046 0.0051					0.2170
PE Hybrid Index	1.0234 0.1322					

Table 6. (continued)
Summary Statistics of Asset Returns (Real Quarterly Returns)

B. Early Sample (1987:I through 2000:II)

	Mean / Standard Deviation	Simple Correlation				
		NASDAQ	*Gov. Bond Index*	*Corp. Bond Index*	*T-bill*	*PE Hybrid Index*
S&P	1.0323 0.0736	0.8486	0.0549	0.1572	0.3053	0.2908
NASDAQ	1.0431 0.1207		0.0094	0.1229	0.1955	0.4250
Gov. Bond Index	1.0109 0.0269			0.9619	0.4159	-0.0793
Corp. Bond Index	1.0122 0.0277				0.4198	-0.0667
T-bill	1.0052 0.0046					0.1380
PE Hybrid Index	1.0531 0.1245					

All the equity returns have substantially lower average returns after the year 2000. In contrast, bond returns are comparable across the different sample periods. The average return on T-bills is 0.46 percent per quarter while, for long term bonds, it is over one percent.

Note that returns on the assets in the bond group (T-bill, long term government and corporate bonds) and returns on the assets in the equity group (private equity, S&P500 and NASDAQ) are only weakly correlated while assets within each group are highly correlated. For example, returns on the S&P500 index and returns on the NASDAQ index have a correlation coefficients of 0.88 for the entire period and 0.85 for the early period. Similarly, the correlation between corporate bond and long term government bond is 0.96 for the early period, and 0.93 for the entire sample period. The correlation of returns from T-

Bills with long terms government bonds is 0.33 for the whole sample period and 0.42 for the early period. The correlation coefficient of private equity return with the NASDAQ is 0.47 for the whole sample period. The correlation with S&P500 is lower than that of NASDAQ as expected, but is still as high as 0.29. On the other hand, private equity returns are negatively correlated with long term bonds for the entire sample period, and almost uncorrelated with them for the early period. These correlations suggest that there is at least some role for private equity investment in the portfolios of qualified investors.

Results of market regressions are reported in Table 7. For the entire sample, the estimated beta between the venture deals and the S&P500 is 0.6, and between the venture deals and the NASDAQ it is about 0.4. Even though beta with the S&P500 is somewhat higher than NASDAQ in individual regressions, a regression with both index returns presents a somewhat different picture. The beta with NASDAQ is higher than the beta from the regression with NASDAQ returns alone. About a twenty percent of the variance in the Private Equity Index is "explained" by the NASDAQ. Estimates of alpha in all three regressions are about one percent, but the estimates are insignificantly different from zero. For the early sample period, the findings for the betas are similar. But in the early period, the estimated alphas are much higher, about three percent, and are significant. These values are substantially smaller in magnitude than those reported by Cochrane, but they are nevertheless quite large for quarterly returns. The explained variance is lower for the early sample period, suggesting that private and public equity returns are more correlated in troughs than in peaks.

Appendix Table B1 compares the weights on these five asset classes in optimal portfolios with varying risk and return characteristics. The portfolios, derived by standard Markowitz techniques, represent the weights on a portfolio of these six assets that minimize the variance in the total return at a given level of the expected return. Portfolio allocations are presented for the entire sample period and also for the early period ending in the second quarter of 2000. A dominant portfolio strategy seems to take long positions on S&P and private equity funds while taking short positions on NASDAQ, and to take long positions on corporate bonds while taking short positions on government bonds. A consequence of the high correlations within asset groups is that the standard deviations of portfolios are much lower than those of individual assets. For example, a portfolio of 5 percent expected return comes with a standard deviation of 0.90 percent for the whole sample period, and with a standard deviation of 0.65 percent for the early period. Note that the optimal weights on private equity are relatively smaller than are weights on other assets on long positions, such as the S&P500 or long term corporate bond for the whole sample period.[12] In general, private equity appears to be attractive enough to be considered as a part of an optimal portfolio, but its importance is smaller than that of public equity.

Table 7.
Market Regressions of Private Equity Returns
(t-statistics in parentheses)

A. Entire Sample (1987:I through 2003:II)

	Market Regression 1	*Market Regression 2*	*Market Regression 3*
Alpha	0.0090 (0.5780)	0.0102 (0.6915)	0.0117 (0.7863)
S&P 500	0.5910 (3.1807)	0.4175 (4.1547)	-0.2525 (-0.6743)
NASDAQ			0.5433 (2.5608)
$\overline{R}^2$	0.1247	0.2026	0.1956

[12] Note that the optimal portfolios are computed from a "qualified" investor's point of view. For other investors, such as non-institutional and small investors, there are large transaction costs and high entry barriers for private equity investment, and optimal portfolio weights on private equities for them may be much smaller once those costs are considered.

Table 7. (continued)
Market Regressions of Private Equity Returns
(t-statistics in parentheses)

B. Early Sample (1987:I through 2000:II)

	Market Regression 1	*Market Regression 2*	*Market Regression 3*
Alpha	0.0349 (1.9786)	0.0315 (1.9233)	0.0351 (2.1067)
S&P 500	0.4787 (2.0773)	0.4328 (3.2921)	-0.4586 (-1.1201)
NASDAQ			0.6673 (2.7016)
$\overline{R}^2$	0.0599	0.1591	0.1633

Table 8 presents spanning tests for the optimal portfolios reported in Appendix C. We present six tests, four based on regressions as suggested by Kan and Zhou (2003), and two based on stochastic discount factors (SDF), as suggested by Bekaert and Urias (1996) and DeSantis (1993). The overall results for the entire sample period suggest that the inclusion of private equity investment does not change the optimal portfolio frontier significantly. With sample moments computed only from the early sample, the results are mixed. Three tests do reject the null hypothesis, indicating that a portfolio containing private equity performs significantly better. The other two tests do not reject the null, but the p-values are quite small, around six percent. Figure 4 illustrates the shifts of efficient frontier arising from private equity investment. There is a large shift in the efficient frontier for the early sample period, probably due to the higher alpha of private equity returns reported in the Table 8. When post-2000 observations are included, the alpha becomes insignificant, and the shift of the efficient frontier is only significant at about the 0.14 level of confidence.

Table 8. Spanning Tests on Inclusion of Private Equity in Investor Portfolios

A. Entire Sample (1987:I through 2003:II)

Tests	*Statistics*	*p-value*
Regression based tests: Kan and Zhou (2003)		
LM	3.9192	0.1409
LR	4.0423	0.1325
W	4.1706	0.1243
Wa (small sample adjusted)	4.1917	0.1230
SDF based tests		
Bekaert and Urias (1996)	3.4670	0.1767
DeSantis (1993)	6.2259	0.0445

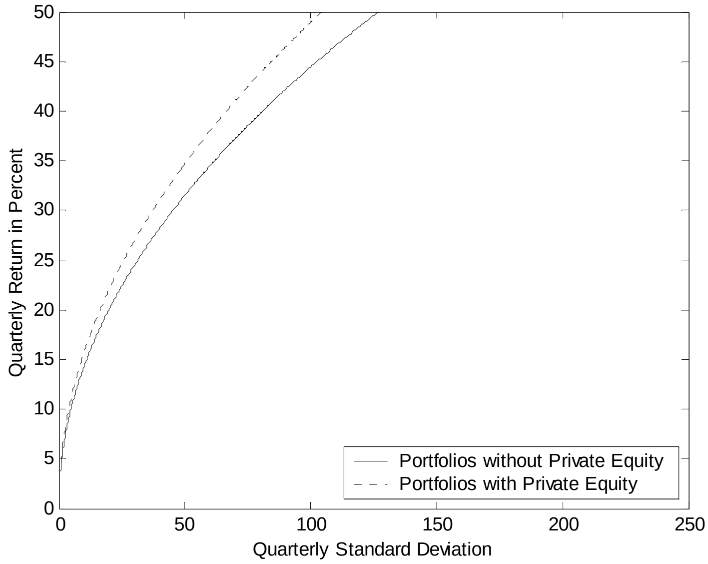
B. Early Sample (1987:I through 2000:II)

Tests	*Statistics*	*p-value*
Regression based tests: Kan and Zhou (2003)		
LM	5.6673	0.0588
LR	5.9938	0.0499
W	6.3459	0.0419
Wa (small sample adjusted)	8.9250	0.0115
SDF based tests		
Bekaert and Urias (1996)	5.4605	0.0652
DeSantis (1993)	7.1420	0.0281

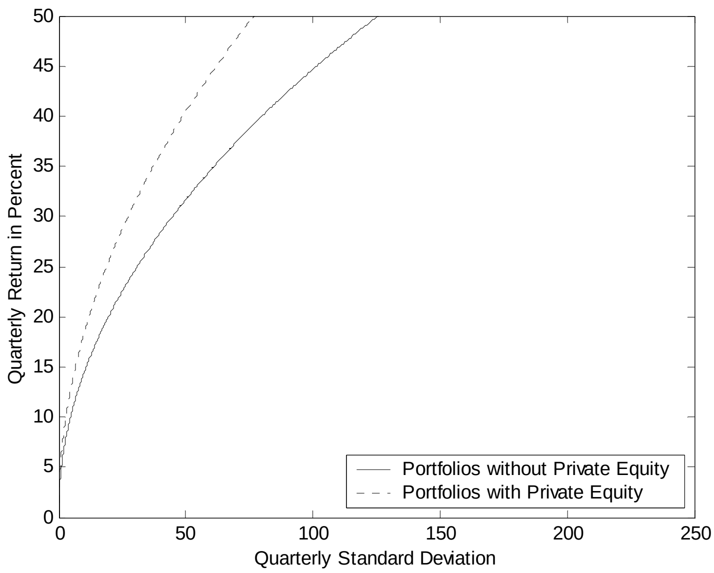
Note: Each row reports the test statistics and the p-value for the hypothesis that the inclusion of private equity in the optimal investment portfolios significantly affects the mean-variance frontier.

Figure 4. Efficient Frontiers for Asset Portfolios

A. Mean Variance Efficient Frontiers: 1987:I - 2003:II



B. Mean Variance Efficient Frontiers: 1987:I - 2000:II



VI. Conclusion

This paper reports a method for building an index of venture capital that can be used in much the same manner that the NASDAQ and the S&P500 are used as indices of the prices of common stocks. Because venture capital is traded infrequently in thin markets, the technique uses a hybrid repeat-valuations approach and employs a correction for the selection bias present in the observations on value for private equities.

The approach is used to estimate an index for venture capital using the Sand Hill database, a comprehensive database of pricing events for venture companies' private rounds of funding and ultimate disposition. The index is precisely estimated, and the results indicate the importance of selection bias in the funding events which do report firm valuation. The estimated price index for private equity falls in nominal terms between 1987 and the mid 1990s, after which it rises steadily until 1998, and then abruptly through early 2000. It then falls sharply through the second quarter of 2003, the end of our sample period.

The price index does permit systematic investigations of the role of private equity in diversified portfolios. We present an approach to calculate private equity returns, taking not only common market-wide valuation of venture firms but also firm-specific exits, into account. An analysis of the optimal allocation among T-bills, common stocks, long term bonds, and private equity indicates a limited role for private equity investment in increasing returns during the 1987-2003 period. Optimal portfolios with higher expected returns do include private equity investment, and we can be confident of this at the .14 level. However, the weight on private equity in diversified portfolios is substantially less than the weight on public equity investment.

Appendix A. Sample Selection and Inverse Mills Ratios with Ordered Probit Models

Let $v_t = z_t'\gamma + u_t$ and $y_t = x_t'\beta + \sigma\varepsilon_t$ where the former is a selection equation and the latter a valuation equation. Assume also that u_t and ε_t are normally distributed with zero mean and unit variance with correlation coefficient ρ. We recall two attributes of the normal distribution;

$$\varepsilon \mid u \sim N\left(\rho u, 1-\rho^2\right) \text{ and } \phi'(\varepsilon) = -\varepsilon\phi(\varepsilon).$$

Case I: we observe y_t only when $v_t > a$.

$$E(y_t \mid x_t, z_t, v_t > a) = x_t'\beta + \sigma E(\varepsilon_t \mid u_t > a - z'\gamma_t)$$
$$= x_t'\beta + \sigma\int_{-\infty}^{\infty} \varepsilon_t f(\varepsilon_t \mid u_t > a - z_t'\gamma) d\varepsilon_t = x_t'\beta + \sigma\int_{-\infty}^{\infty} \varepsilon_t \frac{f(\varepsilon_t, u_t > a - z_t'\gamma)}{\Phi(-(a - z_t'\gamma))} d\varepsilon_t$$
$$= x_t'\beta + \frac{\sigma}{\Phi(-k(a))}\int_{-\infty}^{\infty} \varepsilon_t \int_{k(a)}^{\infty} f(\varepsilon_t, u_t)\, du\, d\varepsilon \text{, where } k(a) = a - z_t'\gamma$$
$$= x_t'\beta + \frac{\sigma}{\Phi(-k(a))}\int_{-\infty}^{\infty} \varepsilon_t \int_{k(a)}^{\infty} f(\varepsilon_t \mid u_t)\phi(u_t)\, du_t\, d\varepsilon_t$$
$$= x_t'\beta + \frac{\sigma}{\Phi(-k(a))}\int_{k(a)}^{\infty} \phi(u_t) \int_{-\infty}^{\infty} \varepsilon_t f(\varepsilon_t \mid u_t)\, d\varepsilon_t du_t$$
$$= x_t'\beta + \frac{\rho\sigma}{\Phi(-k(a))}\int_{k(a)}^{\infty} u_u \phi(u_t)\, du_t = x_t'\beta + \rho\sigma\frac{\phi(a - z_t'\gamma)}{\Phi(-(a - z_t'\gamma))}$$

Mill's ratio when $v_t > a$: $\dfrac{\phi(a - z_t'\gamma)}{\Phi(-(a - z_t'\gamma))}$

Case II: we observe y_t only when $v_t < a$.

$$E(y_t \mid x_t, z_t, v_t < a) = x_t'\beta + \sigma E(\varepsilon_t \mid u_t < a - z'\gamma_t)$$
$$= x_t'\beta + \sigma\int_{-\infty}^{\infty} \varepsilon_t f(\varepsilon_t \mid u_t < a - z_t'\gamma) d\varepsilon_t = x_t'\beta + \sigma\int_{-\infty}^{\infty} \varepsilon_t \frac{f(\varepsilon_t, u_t < a - z_t'\gamma)}{\Phi(a - z_t'\gamma)} d\varepsilon_t$$

$$= x_t'\beta + \frac{\sigma}{\Phi(k(a))}\int_{-\infty}^{\infty}\varepsilon_t \int_{-\infty}^{k(a)} f(\varepsilon_t, u_t) du\, d\varepsilon \text{, where } k(a) = a - z_t'\gamma$$

$$= x_t'\beta + \frac{\sigma}{\Phi(k(a))}\int_{-\infty}^{\infty}\varepsilon_t \int_{-\infty}^{k(a)} f(\varepsilon_t \mid u_t)\phi(u_t)\, du_t\, d\varepsilon_t$$

$$= x_t'\beta + \frac{\sigma}{\Phi(k(a))}\int_{-\infty}^{k(a)} \phi(u_t)\int_{-\infty}^{\infty}\varepsilon_t f(\varepsilon_t \mid u_t)\, d\varepsilon_t du_t$$

$$= x_t'\beta + \frac{\rho\sigma}{\Phi(k(a))}\int_{-\infty}^{k(a)} u_u \phi(u_t)\, du_t = x_t'\beta - \rho\sigma\frac{\phi(a - z_t'\gamma)}{\Phi(a - z_t'\gamma)}$$

Mill's ratio when $v_t < a$: $-\frac{\phi(a - z_t'\gamma)}{\Phi(a - z_t'\gamma)}$

Case III: we observe y_t only when $a < v_t < b$

$$E(y_t \mid x_t, z_t, a < v_t < b) = x_t'\beta + \sigma E(\varepsilon_t \mid a - z'\gamma_t < u_t < b - z'\gamma_t)$$

$$= x_t'\beta + \sigma\int_{-\infty}^{\infty}\varepsilon_t f(\varepsilon_t \mid a - z'\gamma_t < u_t < b - z'\gamma_t) d\varepsilon_t$$

$$= x_t'\beta + \sigma\int_{-\infty}^{\infty}\varepsilon_t \frac{f(\varepsilon_t, a - z_t'\gamma < u_t < b - z_t'\gamma)}{\Phi(b - z_t'\gamma) - \Phi(a - z_t'\gamma)} d\varepsilon_t$$

$$= x_t'\beta + \frac{\sigma}{\Phi(k(b)) - \Phi(k(a))}\int_{-\infty}^{\infty}\varepsilon_t \int_{k(a)}^{k(b)} f(\varepsilon_t, u_t)\, du\, d\varepsilon \text{,}$$

where $k(a) = a - z_t'\gamma$ and $k(b) = b - z_t'\gamma$,

$$= x_t'\beta + \frac{\sigma}{\Phi(k(b)) - \Phi(k(a))}\int_{-\infty}^{\infty}\varepsilon_t \int_{k(a)}^{k(b)} f(\varepsilon_t \mid u_t)\phi(u_t)\, du_t\, d\varepsilon_t$$

$$= x_t'\beta + \frac{\sigma}{\Phi(k(b)) - \Phi(k(a))}\int_{k(a)}^{k(b)} \phi(u_t)\int_{-\infty}^{\infty}\varepsilon_t f(\varepsilon_t \mid u_t)\, d\varepsilon_t du_t$$

$$= x_t'\beta + \frac{\rho\sigma}{\Phi(k(b)) - \Phi(k(a))}\int_{k(a)}^{k(b)} u_u \phi(u_t)\, du_t$$

$$= x_t'\beta + \rho\sigma\frac{\phi(a - z_t'\gamma) - \phi(b - z_t'\gamma)}{\Phi(b - z_t'\gamma) - \Phi(a - z_t'\gamma)}$$

Mill's ratio when $a < v_t < b$: $\frac{\phi(a - z_t'\gamma) - \phi(b - z_t'\gamma)}{\Phi(b - z_t'\gamma) - \Phi(a - z_t'\gamma)}$

Appendix Table B1.

Optimal Portfolio Weights

A. Entire Sample (1987:I through 2003:II)

Expected Returns	*Standard Deviations*	*S&P 500*	*NASDAQ*	*Long Term Gov't Bonds*	*Long Term Corp. Bonds*	*T-bills*	*Private Equity*
1%	0.02%	0.0745	-0.0434	-0.3332	0.7113	0.5488	0.0420
2%	0.11%	0.2492	-0.1341	-0.8085	1.8746	-0.3036	0.1224
3%	0.29%	0.4240	-0.2247	-1.2838	3.0379	-1.1560	0.2027
4%	0.56%	0.5988	-0.3154	-1.7592	4.2012	-2.0085	0.2831
5%	0.90%	0.7735	-0.4061	-2.2345	5.3644	-2.8609	0.3635
6%	1.34%	0.9483	-0.4967	-2.7098	6.5277	-3.7134	0.4439
7%	1.86%	1.1231	-0.5874	-3.1852	7.6910	-4.5658	0.5243
8%	2.46%	1.2978	-0.6780	-3.6605	8.8542	-5.4182	0.6047
9%	3.15%	1.4726	-0.7687	-4.1358	10.018	-6.2707	0.6851
10%	3.92%	1.6474	-0.8593	-4.6112	11.181	-7.1231	0.7655
11%	4.78%	1.8221	-0.9500	-5.0865	12.344	-7.9756	0.8459
12%	5.72%	1.9969	-1.0406	-5.5618	13.507	-8.8280	0.9262

Appendix Table B1. (continued)

Optimal Portfolio Weights

B. Early Sample (1987:I through 2000:II)

Expected Returns	*Standard Deviations*	*S&P 500*	*NASDAQ*	*Long Term Gov't Bonds*	*Long Term Corp. Bonds*	*T-bills*	*Private Equity*
1%	0.01%	0.0870	-0.0318	-0.0863	0.2291	0.7487	0.0532
2%	0.08%	0.2867	-0.1036	-0.1578	0.6387	0.1814	0.1545
3%	0.21%	0.4863	-0.1754	-0.2293	1.0484	-0.3859	0.2559
4%	0.40%	0.6859	-0.2471	-0.3009	1.4581	-0.9532	0.3572
5%	0.65%	0.8855	-0.3189	-0.3724	1.8678	-1.5205	0.4585
6%	0.97%	1.0852	-0.3907	-0.4440	2.2775	-2.0878	0.5598
7%	1.35%	1.2848	-0.4625	-0.5155	2.6872	-2.6551	0.6611
8%	1.79%	1.4844	-0.5342	-0.5870	3.0969	-3.2224	0.7624
9%	2.29%	1.6840	-0.6060	-0.6586	3.5065	-3.7897	0.8637
10%	2.86%	1.8837	-0.6778	-0.7301	3.9162	-4.3570	0.9650
11%	3.49%	2.0833	-0.7496	-0.8017	4.3259	-4.9243	1.0664
12%	4.18%	2.2829	-0.8214	-0.8732	4.7356	-5.4916	1.1677

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