Risk-Return Profiles of New Ventures: An Empirical Study

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This study examines how risk evolves in private, venture capital backed companies. It finds that the stochastic Ito processes assumed for public companies probably apply to young, private companies as well. However, the parameters, drift rate and standard deviation, are generally higher. Venture capitalists have viewed companies as evolving through stages, and this study assesses the probabilities of success and failure at each stage. The underlying process of price evolution appears much smoother than the stage model may suggest. The valuation methods developed for public securities, including option pricing, should apply to private companies as well. This study is a step toward measuring the needed parameters.

1. INTRODUCTION

This is an investigation of the evolution of risk in startup companies. It focuses on companies financed with venture capital, companies which aspire to become publicly held at some point. Most will not become public, but those which do presumably will exhibit the relatively stationary risk characteristics typical of public companies—once they have become seasoned public issues. The questions for this paper are:

- How to describe the risk of a startup and how to measure it;
- Whether the new company moves through definable stages, and if so how the transitions affect its risk;
- Measuring risks and associated changes in value of companies which are privately held;
- How to describe the evolution of risk as a company matures and eventually becomes publicly-held, presumably exhibiting the relatively stationary risk properties, which other studies have found for public companies (e.g. Blume, [3]; Fama and MacBeth, [5]).

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Startup companies have received considerable attention in fields aside from finance. The interest stems from findings that new companies are major creators of new jobs in the United States, and of new industries such as work stations, personal computers, and biotechnology. If new corporate ventures, which are less observable but have the same underlying characteristics, are added to independent startups, their combined influence on growth and technological progress is very large indeed. A specialized financial intermediary, venture capital, has emerged in the last thirty years to meet the needs of some startup companies, and has been studied as part of the broader issue of financial intermediation (Amit et. al. [1]; Chan [4]). But the theoretical and empirical work which led to the Capital Asset Pricing Model, to Option Pricing and to their many extensions has not been applied to new companies. That is, we have no idea whether startup companies come close enough to meeting the requirements of existing valuation models that those models may be useful for valuing startups; nor do we have any estimates of the relevant parameters (beta coefficients, variances and the like). Two reasons lie behind the neglect of startup companies by financial researchers interested in security prices:

- Lack of data: the value of startup companies is not easily observed, because they trade infrequently and on private markets.
- Low priority: their aggregate value is small compared to the public market (the venture capital community manages about $30 billion in funds, a little over 1 percent of the value of public equities).

We believe the first problem can be solved, at least partially. Venture capitalists have been investing in over 200 startups per year for at least a decade; so a database of at least a few hundred transactions could be assembled. Although this inevitably falls far short of the detail available in, say, the daily CRSP tapes, it may be enough to make some rough inferences.

The low priority accorded to startups by financial researchers may be misplaced. Many corporate investments in plant and equipment, as well as in research and development, have the characteristics of a startup; namely, the need to make a series of investments before the project becomes a cash generator, high risks associated with a new technology and a new market, and the potential for rapid growth if the project succeeds. In fact, these new venture investments are precisely the ones that U.S. companies have been accused of avoiding. Such investments pose difficulties for traditional discounted cash flow methods using CAPM derived discount rates. Their expected cash flows are hard to assess, because of wide variance. The character of the project changes rapidly over its first few years. And the investment is a form of call option, which requires a series of payments in order to keep

the option alive. Because it is an option, traditional risk adjustments are not sufficient; and because it is a compound option, requiring multiple investments, the simpler option formulae are not suitable either. If the project succeeds, its value will be heavily tied to "growth options" (Pindyck [10]) as well as to its observable cash flow. And, the relevant risk parameters, beta coefficients and variances in value, are even less observable than they are for a typical investment, where an analogous public security often exists.

This study is an exploratory step toward describing the "price process" (i.e. the equation describing the way the price changes over time) of a startup company. Section 2 identifies stages of development through which new companies pass, and estimates the probability of success at each stage. The latter estimates are based on a sample of 203 firms taken from the portfolios of three venture capital firms. Section 3 theorizes about the underlying stochastic process which produces the observed probabilities of success at each stage. Section 4 describes the sample of prices. Section 5 makes some rough estimates of risks and returns at each stage and discusses the implications regarding the underlying stochastic process. Section 6 summarizes the findings.

2. STAGES OF DEVELOPMENT IN A NEW COMPANY

Researchers recognize that a new company changes dramatically as it develops a product, introduces it into the market, and, if successful, builds a self-supporting organization. They have proposed various taxonomies of which we will briefly discuss three. Bell [2] proposes a six-step progression based on his personal exposure to the computer industry over a 30 year period:

- Concept
- Seed
- Product Development
- Market Calibration (Early marketing)
- Market Expansion
- Steady State

Ruhnka and Young [12] survey 73 venture capital investors, asking them to differentiate among stages of development, if appropriate, and to describe the stages as to characteristics, goals, and risks. Most responses identify 5 stages, although the characteristics of the stages vary considerably depending on the respondent. The most common response identifies all of Bell's stages except "Concept," which typically pre-dates a venture capitalist's involvement. Kazanjian [7] develops a four stage model,
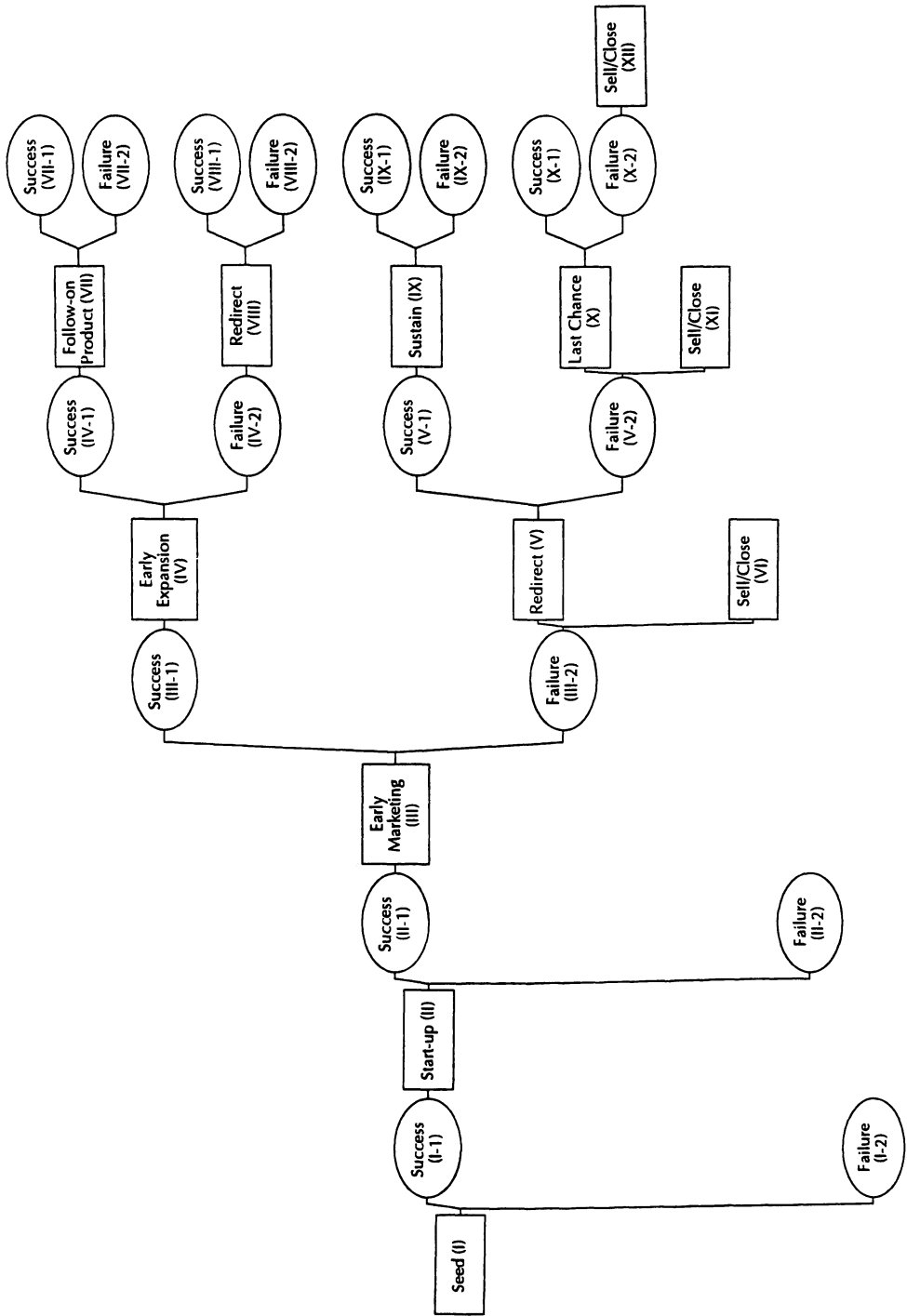
Figure 1.   Stages of Development in a New Company

positing that companies deal with a series of dominant problems: first with product development, then production, then sales and finally with organizational development. His survey of 105 young companies supports the idea that a CEO's priorities shift over time, generally following the stages which he proposes.

Each of the three describes events marking the boundaries of a stage. Ruhnka and Young's boundaries vary depending on the respondent, but generally speaking all three recognize introduction of the first product as a clear transition, and divide the first few years of sales into two parts: establishing a toehold, and then building up to a solid position. They also agree on a final stage in which a company becomes an established competitor. Thus the differences among Bell, Ruhnka and Young, and Kazanjian arise from events prior to introducing the first product. Bell has three stages, Ruhnka and Young have two, and Kazanjian has one (conception and development).

None of the three discusses in detail what happens in the event of failure. Kazanjian views a company as cycling within a stage until it succeeds. Bell also allows cycling, as well as retreat to the previous stage, or possibly going out of business. Ruhnka and Young simply catalog the likely causes of failure.

These three studies, using different sources of data, agree closely enough that we began with their sequence (using the five stage version) for a successful company, and then tested its descriptiveness by asking a few venture capitalists to use it to categorize a random sample of their investments. We also filled out the sequences for failures by asking the venture capitalists to trace the possible paths of several failures. The resulting framework is shown in Figure 1. A new company may begin at either the seed (I) or startup (II) stage, 95 percent in our sample began at II. If successful at developing a product, it then moves to early marketing (III), and, if its success continues, it goes to early expansion (IV). If not successful, it may seek a new direction (V-1 or V-2) or close down (VI). A company which succeeds with early expansion (IV-1) may move on to sustained success (VII-1)—at which point it has typically become a major force in its industry, and can be viewed as equivalent to its older competitors; or, it may have a setback (VII-2) and need to attempt a turnaround. Other branches of Figure 1—VIII through XII—deal with the company's choices when it does not succeed at various points in its history.

Table 1 describes each of the stages of Figure 1 and identifies the event that signals completion of a stage.

Theories and empirical studies of equity price movements have never concerned themselves with stages of development, in part because they concentrate on mature firms. They usually assume a firm's price is in some steady state characterized by a drift rate and a variance (which may be a function of the firm's characteristics and the variance of the market).

Table 1
Description of Stages

Stage	Description	Completion	
		Successful	Unsuccessful
SEED (1)	This is a feasibility testing stage. It may include technology development, market study, business plan preparation, recruiting, or any combination of these	Startup funds are raised	Company closes
STARTUP (11)	The company develops its proposed product	Company begins shipping a working product	Product is not completed or, if introduced, does not work in the field. Company closes
EARLY MARKETING (III)	The company attempts to achieve profitability with its first product, and to prepare for additional product offerings	Company achieves profitability (may not be sustained)	Sales are insufficient to establish profitability
EARLY EXPANSION (IV)	Company attempts to grow rapidly beyond break-even, resist competitive challenges, and introdues follow-on products	Company grows beyond twice its break-even volume, is increasingly profitable, and follow-on products are approaching profitability	Sales never go much beyond break-even, or company suffers losses and market share erosion
FOLLOW-ON SUCCESS (VII)	Company continues to grow, survives any shakeout period, and continues to introduce successful new products	This may continue a long time. Perhaps "maturity" would arrive with slow growth, and cyclical profits, but without a threat to survival	Major reversal in sales, profitability, or market share
REDIRECTION and LAST CHANCE (V, VIII, X)	An effort to change directions when company's strategy/execution is not successful. Often a change of top management signals initiation of this stage	Company achieves consistent profitability (6 months to 1 year)	Turnaround program fails to achieve profitability, and further changes are needed to survive
SUSTAIN (IX)	The turnaround succeeds initially, and the company attempt to achieve longer term profitability	Same as in IV. Company reaches about twice its break-even level of sales	Same as in IV. Company sales never rise much above break-even, or it suffers erosion of its position
SELL/CLOSE (VI, XI, XII)	The investors stop funding the company		

Organization researchers may look at the same firms and see evidence of large changes in structure and management methods, similar to some of the changes undergone by startups (e.g. Miller and Mintzberg, [9]). But such changes will not necessarily affect the underlying equity price process. Thus, our first question is whether a sequence of transitions, as described in Table 1, requires a departure from the common assumption that a company's stock price follows an Ito process with a constant drift and variance.

3. THE PRICE PROCESS FOR A NEW VENTURE

New venture financing differs from a typical transaction in common stock in some notable ways:

Stepwise Investing: A new venture usually requires financial support for its first few years, and investors typically supply that support in a series of steps. With each financing we may observe a value for the venture. In most cases, at least when the venture does well, each new step involves investment by some new investor as well as the old ones.

Financing Steps vs. Stages of Development: The financing steps do not necessarily coincide with the stages of a company's development, described in section 2. However, venture capitalists have stated that they try to finance one stage at a time, and for the purposes of this paper, financings will be treated as occurring at the boundaries between stages. When transactions occur in the middle of a stage (an infrequent event), we will ignore them, using only the ones which occur roughly at the boundaries of stages. When a company moves through a stage without a financing, we will leave out that company, in order to avoid observing a return which clearly combines two stages.

Financing Prices vs. Market Prices: In this paper we will treat the price at each step as a market price, the price which would exist if a large number of well informed buyers and issuers existed and were able to transact at no cost. That view may be reasonable when a new investor participates, but not all of our observed prices stem from such transactions. And, we will often not know whether a new investor participated. We would expect that the price of an "insider only" transaction would not exceed the price which an outsider would pay, and it may be less.

Rates of return: Since calculation of a rate of return requires two price observations, a "market" return requires that a new investor participate in two consecutive financings. Observed returns, which may not have new investors in both transactions, may deviate from market returns, which by

definition require a new investor in both transactions. In addition, a company's first financing may be at a sub-market price, because the company may have imprecise knowledge of market prices. Beyond the first investment its investors will guard against "bargain" purchases by outsiders. In another study (Keeley and Turki [8]) we classified a sample of 186 venture capital transactions as market, inside or unknown, and found that non-market returns differed from market returns in the directions one would expect, but the above-market returns offset the below-market returns. That is, using transactions, some of which do not have new investors, does not bias the data. It introduces extra variance in the returns, however.

Venture Capital Stock Purchases as Options on the Underlying Company: Because a few financing steps will be needed before a company is self sustaining, an early stock purchase is a type of option. It gives the buyer the right to make subsequent investments and eventually to own the self sustaining company. Referring to Figure 1, and assuming that failure at I-2, II-2, III-2, IV-2, or VII-2 all result in a fixed payoff (possibly zero), the value of the company's stock can be modeled using Geske's [6] expression for a compound option . Symbolically,

$V(t)$ = Value of the underlying company; that is, the present value of the company discounted at the time when it needs no further financing—t_{VII-1+}. The "+" means the instant after t_{VII-1}.

$K(i)$ = Investments required at $i = t_I$, t_{II}, t_{III}, t_{IV}, t_{VII}.

$S(t)$ = Value of the company's equity
    = $f\{V(t); K(i), t_{VII} > i > t\}$

If we make the common assumptions that $V(t)$ follows an Ito process, that markets are dynamically complete, that transactions are costless and the interest rate (r) is constant, then $S(t)$ also follows an Ito process.

$dV = \mu_v(V,t) \, dt + \sigma_v(V,t) \, dB$ where B is a Standard Brownian Motion.
$dS = \mu_s \, dt + \sigma_s \, dB$

where

$$\mu_s = \mu_v S_v + \frac{1}{2} \sigma_v^2 S_{vv} + S_t$$

$$\sigma_s = S_v \sigma_v$$

(S_v, S_{vv}, S_t) are respectively the first and second partial derivatives of S with respect to V, and the partial derivative of S with respect to t.

As a redundant security the time path of S will follow the familiar partial differential equation:

$$\frac{1}{2} \sigma_v^2 S_{vv} + rVS_v + S_t - rS = 0$$

If V does not follow an Ito process, then the stock price S will not follow one either. Ito processes are widely assumed for public stocks, and V(t) will be public beyond step VII-1. This suggests that V(t) may be an Ito process prior to going public, although it will not be observable. On the other hand, the tendency of venture capitalists to identify discrete stages seems in keeping with a process that incorporates large jumps in prices. Although not observable, V(t) will be the discounted value of $E[V(t_{VII-1})]$, where $E[]$ refers to an expectation. Young, public companies usually pay no dividends, so $V(t_{VII-1})$ will itself be a discounted value of some later (say at t=T) expected value of the stock. If V(t) after t_{VII-1} is an Ito process, as we observe with public stocks, the updating of $E[V(T)]$, say in the instant following t_{VII-1}, must also be an Ito process.

Prior to t_{VII-1}, when the company is private, the value, V(t), will still be the discounted value of $E[V(T)]$. If the updating of $E[V(T)]$ follows an Ito process after t_{VII-1}, we might expect it to follow the same process before. The act of going public does not change the nature of the business.

On the other hand, one may argue that very early in a company's life, a few events can make or break it. For example, the maker of a new data storage device needs to secure a few large customers early to give it credibility, and to establish its product as a de facto standard. The expected value of its future cash flows, and therefore $E[V(T)]$ as well, might jump discontinuously depending whether it wins or loses a given order early in its life (say soon after t_{III}). That is shortly after t_{III} we may jump $E[V(T)]$, the forecast of value at a much later date, up or down depending on whether the company wins or loses a big, early order.

This study, an early, exploratory examination of the price processes of new ventures, will try to assess whether V(t) may reasonably be assumed to be an Ito process with a constant variance. To do so it will use two primary tests:

- Do the outcomes at a stage (e.g. III-1 and III-2 combined) distribute themselves in a manner consistent with the continuous evolution of value implied by an Ito process?
- Does the variance observed for each stage tend to decline toward the value observed for young, venture capital backed public companies (i.e. companies which have reached stage VII-1)?

The first test implies that combined rates of return for a stage will be roughly normally distributed. III-1 alone will have good returns, and III-2 will have primarily low returns. But combining III-1 and III-2 or IV-1 and IV-2 will produce a distribution of outcomes which follows an approximately normal distribution, if the underlying V(t) follows an Ito process. If it does not, the combined distribution may be bimodal, or show some other deviation from normality. A bimodal distribution seems consistent with the venture capitalist's tendency to identify successes and failures, instead of saying the companies have a continuum of outcomes at any stage.

The second test is consistent with an option that moves increasingly into the money, as would be the case with a progression toward stage VII-1. On the other hand, a small variance at the early stages would imply some other sort of evolution, perhaps one in which uncertainty is resolved later on.

4. DATA

The data sample consists of 203 firms obtained from three venture capital funds that primarily invested in technology-oriented companies. For 142 firms, we had sufficient information to identify both the stages the firms went through, up to the date of data collection, and payoffs at most of those stages. For the remaining 61 firms, we obtained the firm's outcome but were unable to obtain the payoffs.

Most firms, 182, entered the sample at the startup stage (stage II), eleven entered at the seed stage (I), nine at early marketing (III), and one at the early expansion stage (IV). Furthermore, for the firms that were still in existence at the time of data collection, we did not track their evolution beyond the final outcomes of Figure 1.

Along any branch between two adjacent stages, say j and (j-i), read as "j dash i" (e.g. II-1 or II-2), the firms are classified into three categories:

- those firms entering the sample at stage (j-i), their number denoted by n(enter(j-i));
- those firms at stage (j-i), n(j-i);
- those firms beyond stage (j-i), n(beyond(j-i)).

Letting i=1 denote success and i=2 denote failure, the probability of success at stage j is computed as:

$$\text{Prob}(j-1) = \frac{n(j-1) + n(\text{beyond } (j-1)) - n(\text{enter } (j-1))}{n(\text{beyond } j)}$$

where:

$j = I$ to X per Figure 1

The probability of failure at stage j is, therefore, given by:

$$\text{Prob}(j\text{-}2) = 1 - \text{Prob}(j\text{-}1)$$

The counts of companies at each stage are shown in Appendix A.

For the 142 firms on which payoff data were available, we collected 495 stock prices which correspond to the prices at the different stages. These prices were mainly used to estimate the parameters of their generating process.

Assume that stock prices at each stage follow the same Ito Process[2], that is, a diffusion process, of the following simple form:

$$dS = \mu S \, dt + \sigma S \, dB$$

where μ is the instantaneous drift per unit time, σ^2 is the instantaneous variance per unit time, and B denotes a Standard Brownian motion in R. Then, using Ito's Lemma, one can show that the continuously compounded rate of return r:

$$r = \frac{1}{\Delta t} \ln \left(\frac{S_{t2}}{S_{t1}}\right) \sim n \left(\mu - \frac{1}{2} \sigma^2, \frac{\sigma^2}{\Delta t}\right)$$

where $\Delta t = t_2 - t_1$ and n refers to the normal distribution ($\sim$ means distributed as). Then, as shown in Appendix B, the maximum likelihood estimators (MLE) for μ and σ^2 are given, respectively, by:

$$\hat{\mu} = \frac{1}{2} \hat{\sigma}^2 + \alpha$$

$$\hat{\sigma}^2 = \sum_{i=1}^{N} \frac{\Delta t_i \, (r_i - \alpha)^2}{N}$$

where α represents a weighted average of the continuously compounded rate of returns r_i such that:

$$\alpha = \sum_{i=1}^{N} \frac{\Delta t_i \, r_i}{\sum_{i=1}^{N} \Delta t_i} \qquad \text{where N is the sample size}$$

Since the MLE for σ^2 is a biased estimator, an unbiased estimator is constructed as:

$$\hat{\sigma}^2 = \sum_{i=1}^{N} \frac{\Delta t_i (r_i - \alpha)^2}{N - 1}$$

Finally, to check that stock prices follow a stochastic process of the type described above, we constructed histograms from the z-scores of the continuously compounded returns and checked if the latter are normally distributed as suggested. The z-score for a given return was obtained using the following equation:

$$\text{z-score} = \frac{(r_j - \alpha)}{\hat{\sigma}/\sqrt{\Delta t_i}}$$

5.   RESULTS

Figure 2 presents the estimated probabilities at each transition between stages. For example, a company that begins at a seed stage (stage I) has an 85 percent likelihood of successfully moving on to stage II, startup. The likelihood of successfully moving from stage II to stage III is 97 percent, which implies that very few companies fail to develop their initial product—only 3 percent. The odds of success during initial marketing, stage III, fall considerably to 60 percent. They improve to 77 percent for stage IV, early expansion. That is, a venture capital backed company that reaches break-even, the test for exiting stage III, has a 77 percent chance of doubling its sales soon thereafter. The last stage, stage VII of our model, when a company becomes a major participant in its industry if it succeeds at that stage, has a 64 percent chance of success.

Multiplying the above probabilities gives the likelihood that a company, starting at a seed stage, will become a major force in its industry. That figure is (0.85) (0.97) (0.60) (0.77) (0.64) = 0.24. Thus, a seed stage company, based on the experience of our sample, has a 24 percent chance of having uninterrupted success during its early years. Of the 203 companies in the sample, only 11 began with seed financings. The rest commenced with a larger startup financing, and their implied likelihood of reaching VII-1 is 29 percent.

Considering events following a failure, V, VIII, IX and X, the probabilities of a success generally lie below 0.40 (Following III-2, only 24 of 60 companies successfully completed the next stage; 18 closed without
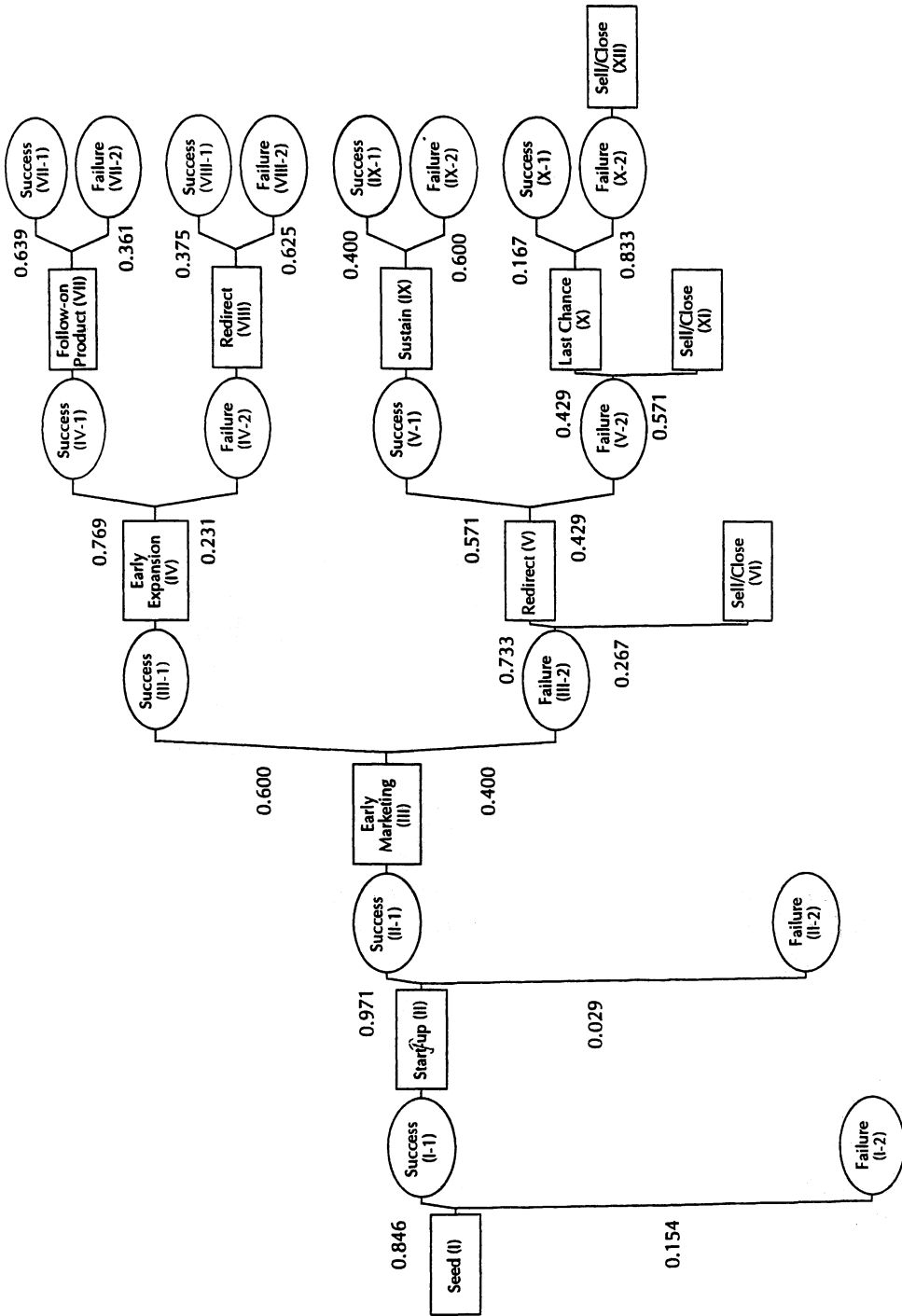
Figure 2. Estimated Probabilities at Transition Between Stages

attempting a turnaround, and 18 turnaround efforts failed.) Any setback in the first several stages, even when the company has achieved profitability, apparently precludes a "fresh start," in which the chance of success is as good as ever.

A failure at a later stage, for example at VI, does not necessarily imply that an early investment will lose money. That depends on the respective gains and losses of each stage. Figure 3 shows those payoffs using the average multiple of a hypothetical investment made at the beginning of a given stage. For example, if a company fails at early marketing (III-2), but remains in operation (V) the average multiple of an investment made at the start of early marketing (III) is 0.562, a loss in value of 43.8 percent. The average time, over which that multiple is earned, is 1.92 years.

From Figure 3 one can easily determine that only three outcomes lead to an average multiplier greater than 1.0 for someone who invests at startup (II). They are:

- VII-1 with an average multiple of 24.16 which is realized after 6.48 years and has a likelihood of 0.286.
- VII-2 with an average multiple of 5.08 which is realized after 7.84 years and has a likelihood of 0.162.
- VIII-1 with an average multiple of 1.32 which is realized after 8.25 years and has a likelihood of 0.052.

By tracing all branches an overall expected multiple and rate of return can be determined for a portfolio of investments made at a given stage. Similar returns can be determined for other investment points such as early expansion (IV) or redirect (V). Table 2 summarizes the results of investing at stages II, III, IV, V, or VII. They show that startups (II) had the highest rate of return followed by early expansion stages (IV). When a company has failed at a given stage, investments in a turnaround effort lead to negative returns on the average for stages V, VIII, IX, and X (Table 2 shows results for V only). Of course, some turnarounds have positive returns, but on the average they do not.

Figure 3 shows that startup financings have a high multiple and a very low failure rate (The same may be said of seed financings, but we will ignore them because only 5 percent of our sample began with seed financings). Although it may appear that investors earn high returns for assuming minimal risks, success refers only to completion of design. Quite possibly investors are assessing the potential market and the ability of the managers during this stage. That is, they may be resolving risks beyond mere technical
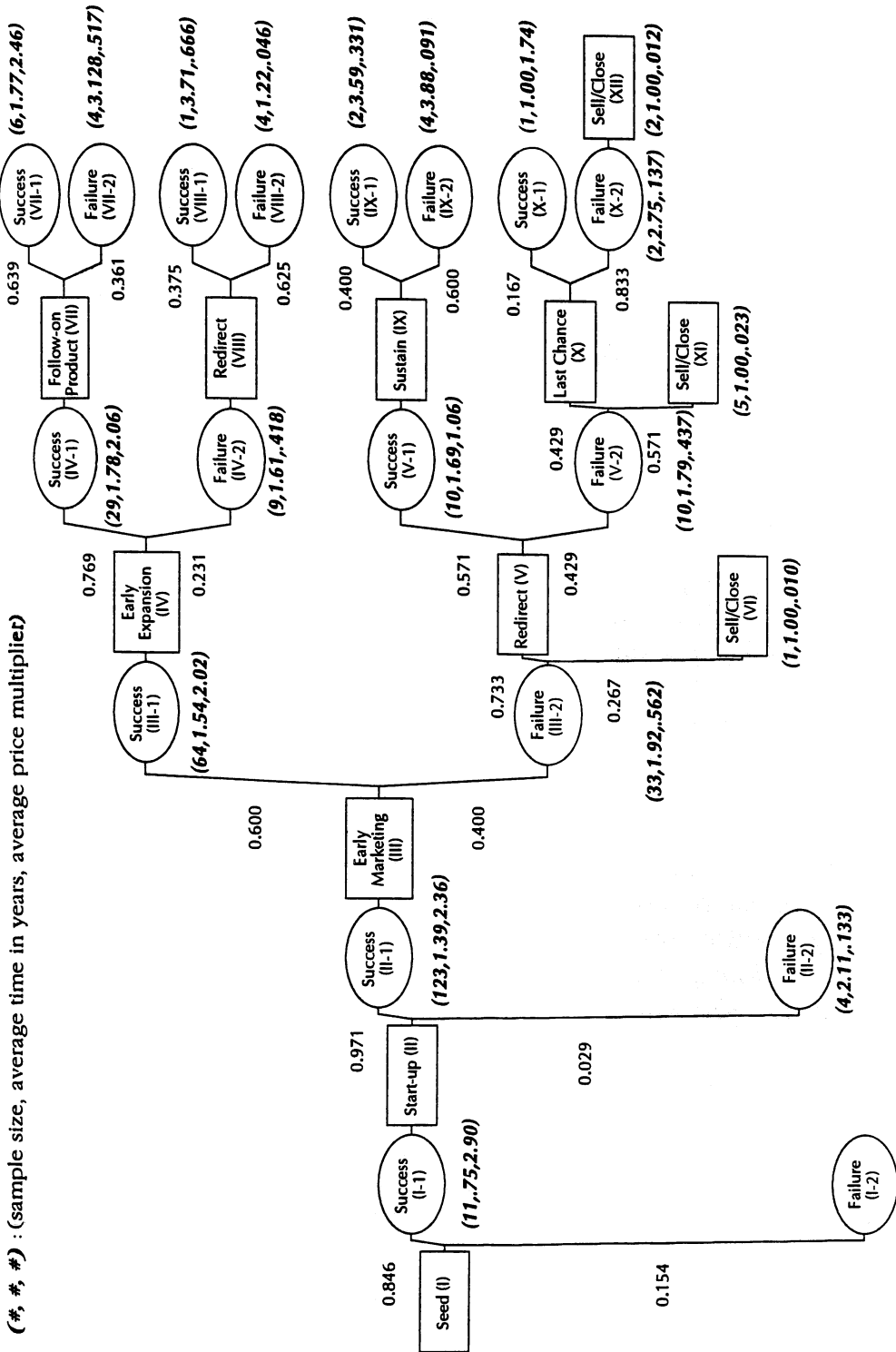
(#, #, #) : (sample size, average time in years, average price multiplier)

Figure 3. Payoffs at Each Stage

Table 2
Investment Performance vs. Stage of Investment

Investment Stage	Number in Sample	Expected Multiple[1]	Annualized Rate of Return[2]	Average Holding Time
Startup (II)	171	7.89	38.1%	6.4 years
Early Marketing (III)	165	3.44	26.8%	5.2 years
Early Expansion (IV)	78	2.82	29.6%	4.0 years
Follow-On (VII)	36	1.76	29.3%	2.2 years
Redirect (V)	42	0.12	−38.2%	4.4 years

Notes: [1] = Prob (success @ i) × EM (stage i+) + Prob (failure @ i) × EM (stage i-), where EM denotes expected multiple. That is, the expected multiples are computed by rolling back the tree in Figure 3.

[2] = (Expected Multiple)$^{(1/\text{Average Holding Period})}$ − 1

issues. More generally, dividing each stage into successes and failures creates an appearance of a binary process, where one may not exist.

Instead of a binary separation, we may examine returns for all companies at each stage. In particular, if private companies experience the same processes as public companies, rates of return from stage II to III, or from III to IV should be normally distributed, and distributions looking only at successes (e.g. III-1) or failures (e.g. III-2) should be non-normal, because they will be decidedly nonrandom samples of the underlying distribution. Figure 4 displays histograms for the stages having reasonably large samples, II, III, IV, and V, showing success/failure splits. The combined stage looks decidedly more normal than the splits. A Kolmogorov-Smirnov test fails to reject normality in all four cases even at significance levels of 0.20. Thus, the evidence fits the hypothesis of an underlying Brownian motion.

Some evidence exists for isolated jumps in value. Four cases fall beyond the 0.001 significance level, considerably more than would be expected for our sample of 325 returns. Two of those apply to one company, that first jumped upward and then downward. Possibly that case resulted from mispricing. Even so, the remaining two cases, both negative, suggest that large changes occur occasionally.

The results do not imply a Brownian motion with constant variance necessarily. Conceivably, the variation becomes large near the end of a stage. That is, variance may change with time. Additionally, the option-like nature of an investment in a new company means the variance will change depending on the movement of the company's value. However, the initial evidence suggests that a stage represents a continuous unfolding of information about the company's prospects, not a bifurcation into a successful and an unsuccessful path. The evidence also fits the view that a
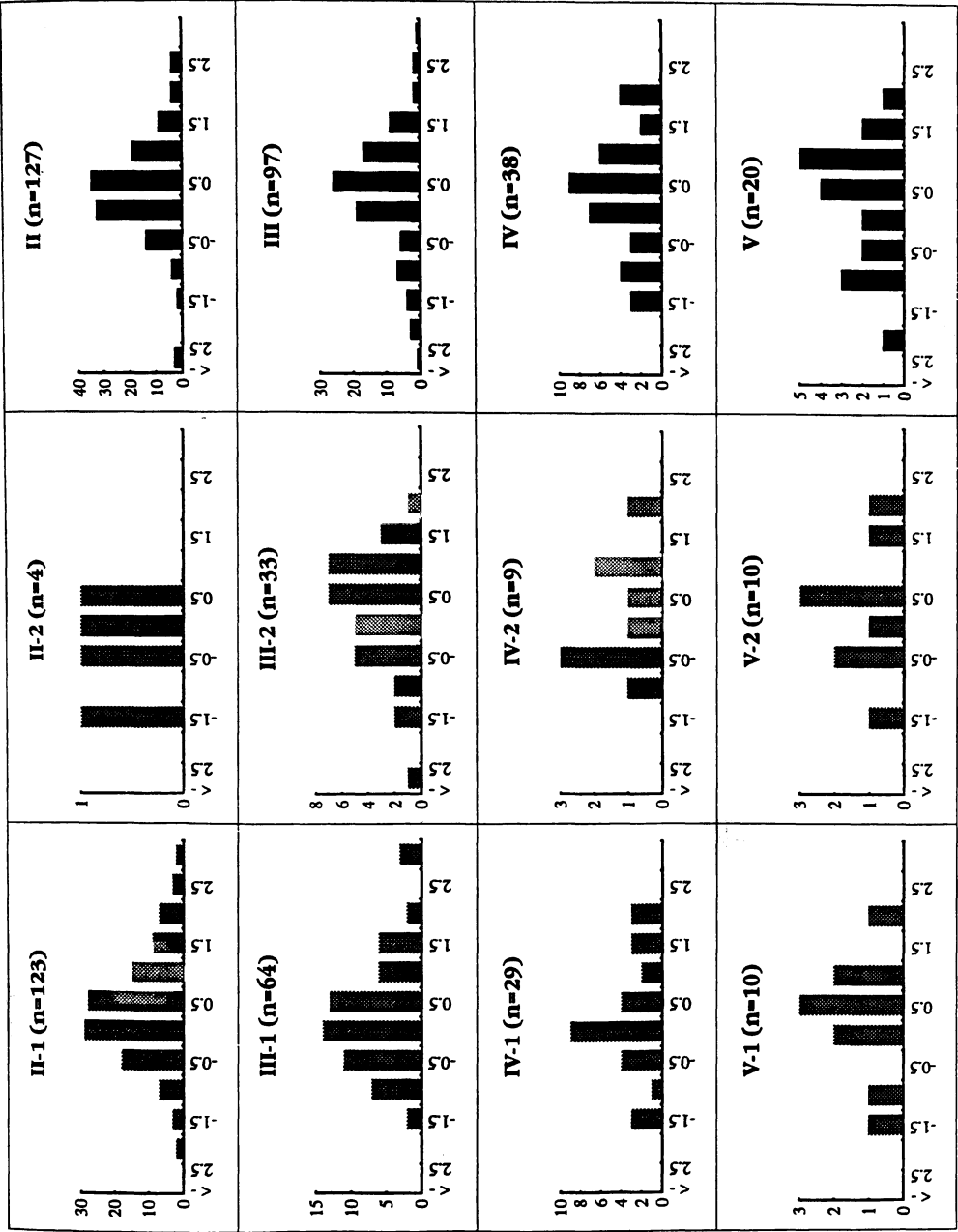
**Figure 4.** Histograms of the z-scores

young private company and an established public company differ mainly in the observability of their values, not in the underlying events which determine how those values evolve.

Figure 5 estimates the parameters for the assumed Ito process at stages II, III, IV, and V, for which the sample size is large enough to obtain estimates. Two returns are shown: the drift of the process $(\hat{\mu})$ and the mean of the implied normal distribution of returns $(\alpha = \hat{\mu} \quad 0.5\hat{\sigma}^2)$, as well as the standard deviation of the process $(\hat{\sigma})$. These estimates use continuous compounding at all stages. Drift rates and volatilities are higher than are typical in public markets.

We view the data in Figure 5, particularly the standard deviations, as valuable because they provide data which may allow the extension of option pricing approaches to new ventures. The similarity of price processes for public and private companies also suggests that our parameters for startups may represent reasonable standards for new ventures within established companies as well.

The standard deviations of the process do not appear to evolve steadily. They drop after the startup stage (II) but do not trend downward. The high variation at the initial stage, 95 percent of our sample started at stage II, and the high returns may reflect varying degrees of underpricing at the initial transaction. At that point a company often has limited knowledge about valuation; whereas, at all later points it has its own venture capitalist experts as members of the board of directors. Additionally, in the absence of an investor group a company often has little staying power, which hurts its bargaining position. An appearance of underpricing may also result if a low initial price serves to compensate investors for services that they subsequently provide (e.g. expert advice, introductions to customers).

The standard deviations of these private early stage companies are above those of venture capital backed startups, that have become public. Using weekly data Punjabi [11] found standard deviations averaging about 55 percent per year for a sample of 48 such companies. Although higher, they seem to be in a reasonable range, between 76 and 99 percent per year. The higher variations for private companies, not yet mature enough for public markets, may reflect the optionlike nature of early stage investments. They may also stem from the inclusion of transactions in which no outside investors participated, a process which we believe increases variation, although it does not bias the averages (Keeley and Turki [8]). On the other hand, the absence of trading diminishes any volume based volatility, which would tend to raise the standard deviations of public companies vis-à-vis their private counterparts.
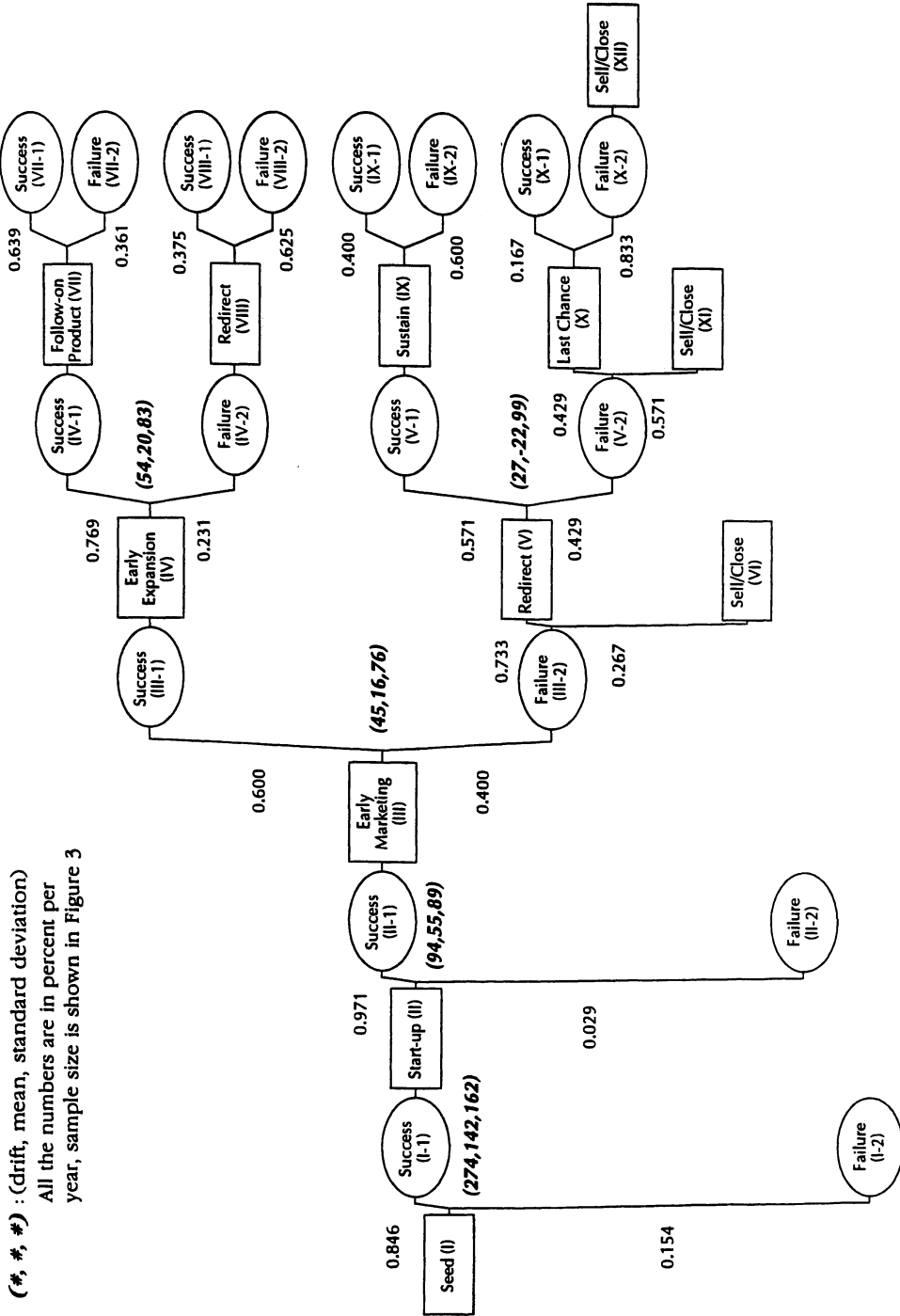
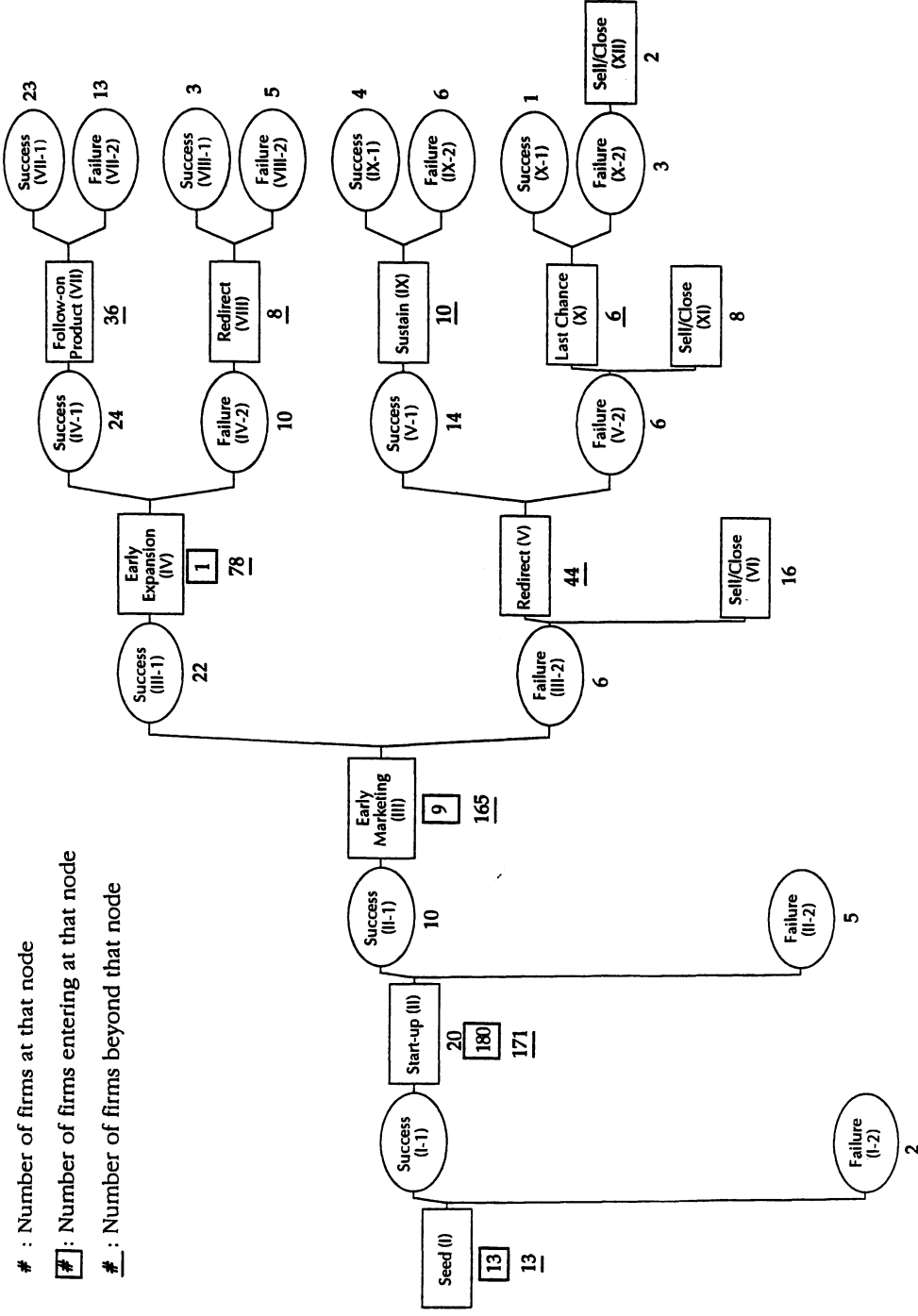**Figure 5.**   Estimates of the Generating Process Parameters

6. CONCLUSIONS

This study explores the nature of financial risks and returns in young, private companies. Its primary objective is to compare the evolution of value in such companies with the evolution found in public companies. Logic suggests that the processes should be similar, regardless of the age of the company, and this database of 203 venture capital backed start-ups provides empirical support for that logic.

The stages of development, which venture capitalists readily identify, give an appearance of a binary process, characterized by large jumps up or down in value at infrequent intervals. However, this database shows the continuous variation of prices within a stage, supporting the view that their evolution follows an Ito process, similar to that for public stocks.

The estimated standard deviations of the process lie above those of slightly more mature, but otherwise similar, public companies, a result which seems reasonable. The standard deviations do not drift steadily downward to meet the values of public companies, as one might expect.

The data also provides evidence on the returns on venture capital investments separated by stages. Previous data has generally reported on venture capital portfolios, which are mixtures by stage, holding period, and investment amount. The information from this database more closely matches the nature of data on public securities. Returns, assuming the investment is held until the final stage of the development "tree" outlined in Figure 1, range from 38.1 percent per year for investments at stage II to 26.8 percent per year for investments at stage III. Investments after a company had suffered a setback show negative expected returns.

Appendix A. Number of Firms at Each Node

\# : Number of firms at that node

[\#] : Number of firms entering at that node

<u>\#</u> : Number of firms beyond that node

APPENDIX B

Given that r_i is normally distributed with mean $(\mu - 0.5\sigma^2)$ and variance $\sigma^2/\Delta t_i$, then one can construct a likelihood function for an N-size sample as:

$$L(\mu, \sigma^2, r_i) = (2\pi\sigma^2)^{-N/2} \prod_{i=1}^{N} \sqrt{\Delta t_i} \exp \left\{ - \frac{\Delta t_i (r_i - \mu + 0.5\sigma^2)^2}{2\sigma^2} \right\}$$

The corresponding log likelihood function is:

$$\log L(\mu, \sigma^2, r_i) =$$

$$- \frac{N}{2} \log(2\pi) - \frac{N}{2} \log(\sigma^2) + \frac{1}{2} \sum_{i=1}^{N} \log(\Delta t_i) - \frac{1}{2\sigma^2} \sum_{i=1}^{N} \Delta t_i (r_i - \mu + 0.5\sigma^2)^2$$

The MLE for μ and σ^2 are the solutions to:

$$\frac{\partial}{\partial \mu} \log L(\hat{\mu}, \hat{\sigma}^2, r_i) = 0$$

$$\frac{\partial}{\partial \mu} \log L(\hat{\mu}, \hat{\sigma}^2, r_i) = 0$$

That is,

$$- \frac{1}{2\hat{\sigma}^2} \sum_{i=1}^{N} -2 \Delta t_i (r_i - \hat{\mu} + 0.5\hat{\sigma}^2) = 0$$

$$- \frac{N}{2\hat{\sigma}^2} - \frac{1}{2(\hat{\sigma}^2)^2} \sum_{i=1}^{N} \Delta t_i (r_i - \hat{\mu} + 0.5\hat{\sigma}^2)^2 - \frac{1}{2\hat{\sigma}^2} \sum_{i=1}^{N} \Delta t_i (r_i - \hat{\mu} + 0.5\hat{\sigma}^2) = 0$$

Rearranging and solving for $\hat{\mu}$ and $\hat{\sigma}^2$ yields the desired results.

It is straightforward to show that the second order conditions are satisfied by $\hat{\mu}$ and $\hat{\sigma}^2$. Mainly,

$$\frac{\partial^2 \log L}{\partial \mu^2} \bigg| = - \frac{1}{\hat{\sigma}^2} \sum_{i=1}^{N} \Delta t_i < 0$$

$$\frac{\partial^2 \log L}{\partial (\sigma^2)^2} \bigg|_{\hat{\sigma}^2} = - \frac{N}{2\hat{\sigma}^4} < 0$$

$$\frac{\partial^2 \log L}{\partial \mu \partial (\sigma^2)^2} \bigg|_{\hat{\mu}\hat{\sigma}^2} = 0$$

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