Valuation of Venture Capital Investments: Empirical Evidence

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ABSTRACT

Using the valuation data of 429 U.S. venture capital transactions and 178 initial public offerings, we test a risk-neutral binomial valuation model in modelling the risk-return profiles of venture capital investments. We find that the model behaves consistently with the previous knowledge on the risk-return profile of venture capital investments. With two independent random samples, we also analyse the predictive power of the risk-neutral binomial valuation model. We construct one-step ex post valuation forecasts for the sample ventures and compare the results to the actually realised step-ups in value. The findings indicate that the model has explanatory power over the actually realised step-ups in value of the sample ventures. The forecasts are fairly unbiased estimates of the actual valuations, but the standard deviation of the forecast errors is comparatively large. However, we find that the fit of the risk-neutral model is significantly better than the fit of traditional discounted cash flow models.

Consider a firm that has a unique business concept, significant growth opportunities, and no real positive cash flow to show the profit potential of the venture. Valuing such high-growth, high-uncertainty firms is a major challenge faced by most venture capital firms. A typical venture capital valuation procedure culminates to an analysis of potential future cash flows, an analysis of comparative firms' stock prices or IPO performance, and an analysis of the price-to-earnings ratio or the price-to-sales ratio of the venture. Yet, the resulting valuations of these growth firms seem to defy all the common wisdom on growth firm valuation.

The option value of uncertainty has been studied extensively in the theory of investment already for two decades (e.g. Dixit and Pindyck, 1994; Trigeorgis, 1996; Brennan and Trigeorgis, 1999). Even the uncertainty inherent in venture capital investments has been conceptually shown to be decomposable into a set of options. Sahlman (1993) identifies in his pioneering work three major options inherent in venture capital investments: the option to abandon investment, the option to re-value a project, and the option to increase capital commitment. In general, the theory of investment has made significant advances and already enables elaborate analyses of real options and option interactions. Yet, the lack of empirical evidence to show the practical applicability would seem to effectively inhibit adoption in practice.

This paper sets out to test a risk-neutral option valuation model with a large sample of venture capital investments. The results contribute both to theory and to practice in at least two ways. Firstly, despite the wide variety of option-pricing applications, there has not been any empirical testing of the applicability of option-pricing theory in venture capital investment decision making. Secondly, real option valuation, in general, has been tested empirically in only few published papers. These papers include the papers of Paddock et al. (1988); Quigg (1993); and Berger, Ofek, and Swary (1996). More empirical evidence is clearly needed to further validate the option-pricing analogy to real investment opportunities in general.

This paper contributes to the existing venture capital valuation methodology by providing the first empirical study where the applicability of an options-based valuation methodology is tested. Using the ex-post valuation data from 429 U.S. venture capital transactions and 178 initial public offerings, it is possible to test a risk-neutral binomial valuation model in modelling the risk-return profiles of venture capital investments. Knowing the ex post values of the target firm at each stage of the venture capital investment process enables us to determine the implicit risk-neutral probabilities that the venture capitalists would have needed to determine to correctly price the investment option. Similar risk-return profiles of venture capital investments have been examined previously in surveys and small-sample studies, but there are no previous established structures or structured approaches for analysing the risk-return profiles of venture capital investments.

The rest of the paper is organised as follows. The first section develops the risk-neutral valuation model for venture capital investments and the testable hypotheses on the validity of the model. The second section describes the data and methodology used in the study. The third section examines the validity of the model empirically. The fourth section analyses the ex post predictive power of the model by comparing valuations forecasted one step forward to the realised valuations. Finally, conclusions are presented in section five.

I. Hypothesis Development

A. Previous Evidence on the Valuation and the Risk-Return Profile of Venture Capital Backed Companies

The risk-return profile of venture capital investments has been studied previously with survey and interview methods (Ruhnka & Young 1991, Chiampou & Kallett 1989, Ruhnka & Young 1987, Wetzel 1981). Psychological risk theory has been applied to explain the profiles found (Ruhnka & Young 1991). The existing research shows that the risk of loss associated with venture capital investment decreases steadily as the venture reaches higher stages of development. Also, the venture capitalists' rate of return requirement has been found to decline.

Due to the lack of data available, large-scale empirical studies on the returns and valuations of venture capital transactions did not appear until the late 1990s. Earlier studies were based on much smaller samples. Bygrave and Timmons (1992) report evidence of venture capital returns and transaction valuations from two surveys with samples less than 100 each, whereas Houlihan Valuation Advisors (1998) examine the pricing of 1,247 private U.S. venture capital investments made into ventures that went public between January 1993 and June 1997[1].

Bygrave and Timmons (1992) report the results of Bygrave and Stein (1989) and Bygrave and Stein (1990). They found that the return on the venture capital investment at the IPO was 22.5 times for the first round, 10.0 times for the second round, and 3.7 times for the third round. The results imply a diminishing risk as the venture reaches higher stages of development.

Also, Houlihan Valuation Advisors (1998) conclude that the number of the financing round is a very significant factor in determining the value increase from the previous round to the next. Later rounds are associated with higher valuations, even independent of the company's stage of development. Additionally, it was found that the step-ups in value[2] decreased with the development of the company's business and with increases in amounts raised at any particular round. Company

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[1] Houlihan Valuation Advisors used the VentureOne database to access the transaction data.

[2] Houlihan Valuation Advisors (1998) define step-up in value as the increase in a company's pre-money valuation between two financing rounds. It is calculated as the pre-money valuation at a round divided by the pre-money valuation at a prior round.

location and industry type had also predictive power in company valuations. However, Houlihan Valuation Advisors (1998) did not find evidence on time variation of the step-ups in value, as no specific years appeared significant in determining the differences of the step-ups in value.

B. *Model Structure*

Motivated by Jägle's (1999) model for pharmaceutical R&D, we use a simple binomial valuation framework for analysing the valuation histories of the ventures in our sample. The model is based on the principles of risk-neutral option valuation originally put forward by Black and Scholes (1973) and later expanded by Cox, Ross, and Rubinstein (1979).

Consider first an asset, the current value of which is denoted as *S*, and construct a one-period binomial tree so that the asset's value can be either S^+ or S^- at the end of the period. Let the actual probabilities of these states be *p* and 1-*p*, accordingly.

The traditional present value framework suggests that the value of the asset, *S*, is equal to its probability weighted expected value at the end of the period, discounted by the risk-adjusted rate of return *R*. In other words, for a period length *t*,

$$S = \frac{pS^+ + (1-p)S^-}{(1+R)^t}. \tag{1}$$

On the other hand, we define the risk-neutral probability *q* so that the value of *S* is, in an arbitrage-free world, equal to

$$S = \frac{qS^+ + (1-q)S^-}{(1+r_f)^t} \tag{2}$$

where we denote the risk-free rate of one period with r_f.

We model each stage of venture capital investment as one-step binomial trees discussed above. Each stage has thus two outcomes: 'good' and 'bad'. We assume that the good outcome results in an increase in value by factor *k*, and that the bad outcome results in a decrease in value by factor $1/k$. The final outcome is the net exit value of the firm. In the model, the outcome of each previous stage would be obtained by backward iterative recursion from the final outcome.

We also note that in the risk-neutral model, each stage of development where venture capital financing occurs represents in effect an option to abandon the venture, as explained by Sahlman (1993). The venture capitalists will not invest if the venture's future does not look bright enough. Not investing may result in a bankruptcy of the venture. Thus, each stage may result in abandonment and a zero outcome for the equityholders. In addition, if the venture never reaches the exit stage, the equity investments made into the company become 'living dead', i.e. they may have some value but they are not liquid. Practically, the investments made may be worthless if the exit never occurs.

The problem in applying the traditional present value framework to venture capital situations is that we would have to know the appropriate risk-adjusted rate of return for each stage. In addition, we should be able to separate between the risk included in the success probabilities and the risk included in the risk-adjusted rate of return. Capital asset pricing model suggests that the non-diversifiable or private part of risk should be reflected by the success probabilities and the diversifiable or market-priced part of risk should be included in the risk-adjusted rate of return. Jägle (1999) argues that this view is incomplete because the amount of systematic risk varies every step, and because the commercial part of the private risk is not independent of economic conditions. As a consequence, also venture capitalists may not be able to recognise the difference between the two components of risk, and using the required rates of return and the actual success probabilities indicated in previous surveys and research may produce biased results.

We argue that the risk-neutral framework offers improvement to some of these problems. It is possible to use the risk-free rate of return throughout the analysis, and the risk-neutral success probabilities are not more difficult to estimate from a data set than the actual success probabilities needed in the traditional framework.

To establish the risk-neutral binomial model of venture capital investments, we define our notation as follows. For each stage *i*, the risk-neutral probability of success is $q(i)$, the duration of the stage is $t(i)$ and the applicable risk-free discount rate for the stage is $r_f(i)$. The model will then result in the tree structure shown in Figure 1.

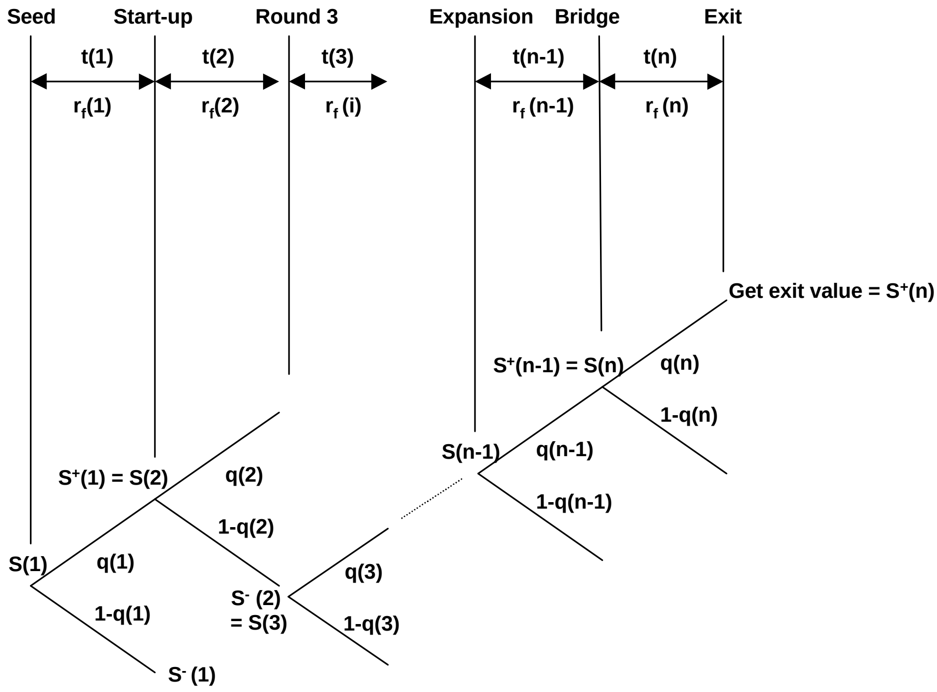

Figure 1 Venture capital investments as risk-neutral success / failure binomial trees

We now derive the necessary equations for applying the risk-neutral valuation framework. From (2), we can now solve the one-period risk-neutral probability *q* for stage *i* as follows:

$$q_i = \frac{S_i\left(1 + r_{f_i}\right)^{t_i} - S_i^-}{S_i^+ - S_i^-} \tag{3}$$

We set $S^+ = kS$ and $S^- = \frac{1}{k}S$ in (3) as suggested above. With two consecutive valuations, we have an estimate for *k* if the value developed favourably and for $1/k$ if the value developed unfavourably. Thus, an estimate for *q* can be obtained each period.

To forecast the step-up in value, *k*, when the one-period *q* is known, we solve *k* as follows.

$$S = \frac{qkS + (1-q)\frac{1}{k}S}{\left(1+r_f\right)^t} \tag{4}$$

$$Sqk^2 - S\left(1+r_f\right)^t k + (1-q)S = 0 \tag{5}$$

$$k = \frac{S\left(1+r_f\right)^t \pm \sqrt{S^2\left(1+r_f\right)^{2t} - 4S^2 q(1-q)}}{2Sq} \tag{6}$$

In case we can set $S^- = 0$, the step-up in value from round *j* to round *n* can be estimated from the value of round *j* ($j < n$). Using backward iterative recursion and (2), we find that

$$\frac{S_n^+}{S_j} = \frac{1}{\prod_{i=j}^{n} \frac{q_i}{\left(1+r_{f_i}\right)^{t_i}}} \tag{7}$$

as can be easily verified by induction. For example, an estimate of the exit value of the firm could be obtained in this way, using the latest observed valuation as S_j and appropriate risk-neutral probabilities as q_i:s. This identity shows that the risk-neutral success probabilities reflect the inverse step-up in the venture's value between two valuation observations if we assume $S^- = 0$.

For further use, we note that the corresponding discounted cash flow model would yield the actual probability of the good state of nature as

$$p_i = \frac{S_i\left(1+R_i\right)^{t_i} - S_i^-}{S_i^+ - S_i^-} \tag{8}$$

and the forecasted step-up in value as

$$k = \frac{S(1+R)^t \pm \sqrt{S^2(1+R)^{2t} - 4S^2 p(1-p)}}{2Sp}. \tag{9}$$

C. *Hypotheses for Model Validity*

To assess the validity of the risk-neutral valuation model, we construct four testable hypotheses. We base the hypotheses on previous findings on the risk-return profile of venture capital investments, which indicate that the risk of loss associated with these investments decreases as the venture reaches higher stages of development. The model should, thus, behave accordingly.

In all argumentation and analysis that follows, we use the classification of venture capital financing stages used by Venture Economics, Inc. We code these stages with numbers indicating the order of the stages. Buyouts are classified to represent the same level of development as bridge financing, since MBOs and LBOs occur typically in later-stage companies. The classification and ordinal numbering are shown in Appendix I. Since our data does not include the complete valuation histories of the companies, but rather consists of occasional observations on the venture's value, we call the period between two successive observations on the venture's value the "observation period".

According to the survey of Ruhnka and Young (1987), venture capitalists expect that the risk of loss associated with venture capital investments decreases steadily as a venture reaches higher stages of development. Their results indicate that the aggregate risk of loss is as high as 66% for seed investments, and around 20% for bridge financings. Wetzel (1981) reports results in line with Ruhnka and Young (1987). Both report also that the venture capitalists' required rate of return declines as the venture reaches higher stages of development. Plummer (1987) supports this observation. All these studies also indicate that it is more probable for a venture to fail in the early stages of development rather than in the later stages of development. Therefore, as the venture advances from the first stage of development to the second stage, the risk of loss decreases more than if the venture advances from stage four to stage five. As a consequence, step-ups in value are typically larger in the early stages of the venture's development.

The risk-neutral success probabilities of our model reflect the probability of reaching the better state of nature next round. The central determinant of the risk-neutral probabilities is the inverse step-up in the venture's value as indicated in (7). Thus, we first hypothesise that the risk-neutral probability of reaching a successive financing round should increase as the venture's current stage of development increases:

> *H1: The risk-neutral success probability for achieving the next financing round is positively related to the level of the stage where the observation period started.*

We note that it is possible that a venture develops rapidly and "jumps" over certain development stages to receive additional venture capital financing at a higher level. To take the differing length of these "jumps" into account, we define the variable STEP as the difference between the level of the venture's development at the time of the first valuation observation and the level of the venture's development at the time of the second valuation observation. Since the stages are defined on an ordinal scale, STEP represents the number of development stages that the venture advances. This definition is shown in Figure 2.

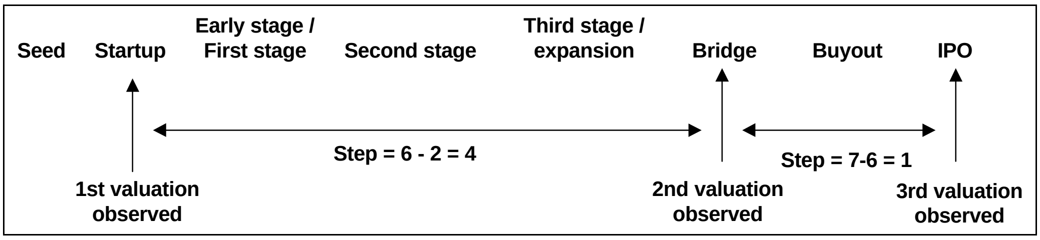

Figure 2 Illustration of the definition of the variable STEP. Horizontal arrows illustrate the observation period.

Consider now two observations of the valuation of the same venture, which are not from consecutive stages of development. Let the later observation be from a higher stage of development than the first one. In this case, the variable STEP is greater than two. Consider then two similar observations that are from consecutive stages of development, implying that STEP is equal to one. Previous findings implicitly indicate that in the first case, the aggregate risk of loss is reduced more than in the second case because the venture has advanced through more stages of development in the first case (Ruhnka and Young 1987, Wetzel 1981). Similarly, the step-up in value should typically be larger in the first case than in the second case. We hypothesise that the risk-neutral success probabilities of the model should be negatively related to the variable STEP:

H2: The risk-neutral success probability for achieving the next financing round is negatively related to the length of the observation period.

Previous argumentation showed that the step-ups in value are large when a lot of the aggregate risk of loss is reduced by reaching a certain stage of development and small when the risk of loss is reduced only little. If a venture has already received a lot of venture capital financing rounds, the risk of loss should have decreased substantially. Combining these arguments, we note that step-ups in value should be smaller for those companies, which have received many rounds of venture capital financing. As a consequence, we hypothesise that the more the venture has already received venture capital financing rounds, the larger should be the risk-neutral probability of reaching the next financing round:

H3: The risk-neutral success probability for achieving the next financing round is positively related to the number of financing rounds that the venture has received prior to the current stage of development.

Ruhnka and Young (1991) report that ventures in different industries may have different risk characteristics. Discussions with practitioners indicate strong support for this claim. Therefore, we hypothesise that the risk-neutral probabilities should differ from each other in different industries:

H4: The risk-neutral success probability for achieving the next financing round is dependent on the industry in which the venture operates.

II. Data

A. Venture Capital Investment Data

The empirical sample consists of 608 investment rounds made into 178 U.S. venture capital backed companies that were listed on a U.S. stock exchange between January 2, 1998 and December 31, 1999. Of these rounds, 429 represent venture capital financings and 178 IPOs. The sample includes all companies which went public during that period and for which valuation data for at least one venture capital financing round and the IPO were available.

We obtain the valuation data from Venture Economics, Inc. This extensive source of venture capital investment data has been used also in previous venture capital research (see e.g. Bygrave 1989, Gompers 1995 or Gompers and Lerner 1998), but previous studies have not had the possibility to analyse the company valuations. The sample of this study consists of the disclosed post-money valuations that were available in the Venture Economics' Venture Expert database in January 2000. This source includes valuation data on only part of the venture capital financing rounds that the ventures have received. However, limiting the sample to those ventures that made an IPO provides an additional data point for each venture. As a result, we can obtain at least one risk-neutral probability estimate for each venture of our sample.

In addition to the valuations, we use the Venture Expert data to determine the amount of financing each round, the number of venture capital rounds that each company has received, the dates of the financing rounds, the venture's stage of development each round, and the venture's industry classification according to Venture Economics.

B. Other Data

The data on the initial public offerings sample is obtained from Venture Economics' Venture Expert IPO database. We use the data on the offer price and the amount of shares outstanding after IPO to calculate the venture's market capitalisation at IPO. This figure is used as the net exit value of the venture. The IPO date is taken from the same database.

The risk-free interest rate data is obtained from the U.S. Federal Reserve Bank of Chicago files. Daily closing yields of the 30-year U.S. Treasury bill are used in all calculations. If the date of a financing round, as disclosed in the Venture Economics database, appears to be a holiday, no risk-free rate for this date exists. In these cases, we use the closing yield of the nearest possible date.

C. Limitations of the Sample

The valuation data on the venture capital investment rounds is limited in several respects. Firstly, the observations include only successful ventures, which were able to proceed to the initial public offering. This fact may bias the data so that steadily rising valuations may occur more often than if the sample contained also the less successful ventures. Secondly, it may be that the valuations are disclosed only when they have developed positively as compared to the previous financing round. Disclosing lower valuations than before might cause negative publicity for the venture and perhaps make it more difficult to attract investors in the future. Thirdly, it seems that valuations associated with the seed and start-up stages are less frequently disclosed than later-stage valuations. It may be that venture capitalists want to disclose company valuations only at later stages when the uncertainty about the actual quality of the deal is smaller. Fourth, the short time frame may bias the results because of the very bullish market conditions during the latter part of the sample period.

D. Summary Information and Descriptive Statistics

The ventures in the sample operate mainly in the high-technology industries, as is typical for venture capital backed companies in general. Venture Economics classifies 165 of the total 178 ventures as information technology companies, 6 as medical, health, and life sciences companies, and 7 as non-high-technology companies. 78 of the information technology ventures operate in an Internet specific industry. Almost all the medical, health, and life sciences ventures operate in the biotechnology industry. Non-high-technology ventures included companies from several industries. Table I lists the industry classification and industry subgroups of the sample.

Table I

Venture Economics industry classification of the sample companies

Industry class and industry subgroup (*italic*)	**Ventures**
Information technology	165
Internet specific	*78*
Computer software	*43*
Communications	*35*
Semiconductors / other electronics	*5*
Computer hardware	*4*
Medical / Health / Life sciences	6
Biotechnology	*5*
Medical / Health	*1*
Non-high-technology	7
Total	**178**

The data contains altogether 607 financings and the corresponding valuations. From these financings 178 represent IPOs and 429 represent venture capital investment rounds. We have, on average, 3.42 observations per firm. There are on average 2.42 observations at venture capital financing rounds and one at the IPO. Most of the observations on venture capital investment are from third stage or expansion rounds, but there is a representative sample of valuations from all the stages (*n* for each stage appears in Figure 3).

Figure 3 presents the average and median step-ups in value from each round to the IPO[3]. We note that the valuations increase rapidly at the early stages of development and increase also at later stages, but less rapidly. The step-up from the buyout stage to IPO is between the step-up from the third stage and the bridge stage; this is as expected since buyouts are likely to occur somewhere between expansionary stages and the bridge stage. Fried & Hisrich (1994) note that gross return rates may, however, be biased due to the venture capitalists' investment in due diligence in the earlier financing rounds. The step-ups in value may thus seem huge from the early rounds to IPO but may yet not yield as much return to the investors in practice.

3 Step-up in value is here the post-money valuation at IPO divided by the post-money value at a financing round.

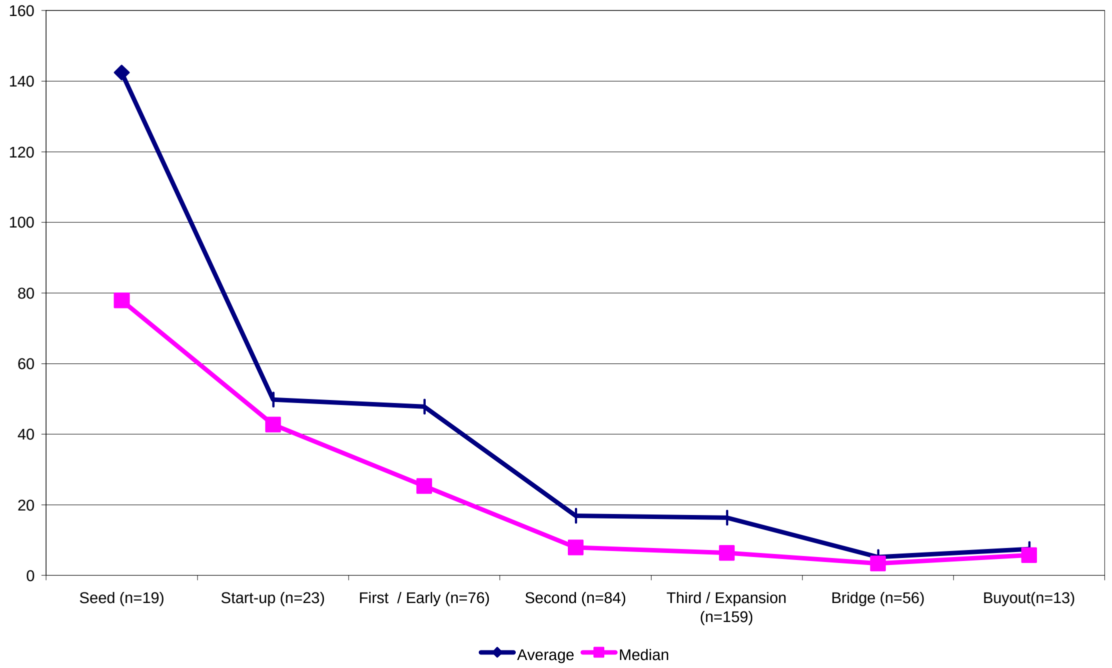

Figure 3 Average and median step-ups in value from each round to IPO

Appendix II shows the monthly number of IPOs by the sample companies. There is a significant concentration of the IPOs in the second half of 1999, which corresponds to the bullish market conditions in that period. The companies raised on average 73.5M USD in the offering (median 60.0M USD) and offered on average 19.8% of the post-IPO amount of shares to the public. The average market capitalisation at the IPO was 476M USD (median 330M USD).

III. Results on the Validity of the Model

We calculate the risk-neutral success probabilities from the data using equation (3). Since the sample is selected so that there is at least two valuation observations for each venture, we get at least one observation per venture from the risk-neutral probability for succeeding from a particular stage to another. With this data set, we test hypotheses 1 – 4.

A. *Operationalisation and Correlation Structure of Variables*

We define the necessary variables in Table II. In addition to the variables needed to test hypotheses 1 – 4, we control for the time passed from the previous valuation observation with TPREV, for the total amount of venture capital financing received in the round with RNDTOT, and for the return from the Nasdaq Composite index between the previous valuation observation and the current observation with CH_NAS. These control variables are necessary to eliminate the potential bias from the time length and the market return of the observation period. Additionally, controlling for the total amount of venture capital financing each round mitigates the potential bias in post-money valuations caused by the typical increase in the amount capital provided in later rounds. The industry dummies INFO, BIO, and NONHT classify the ventures into information technology, medical, health, and life sciences, and non-high-technology companies. In unreported analysis, finer industry divisions had no qualitative effect on the results.

Table II

Operationalisation of variables

Dependent variables	**Name**	**Explanation**
Risk-neutral success probability	RNPROB	Defined by equation (3)
Independent variables	**Name**	**Explanation**
Number of prior financing rounds	RND	Number of venture capital financing rounds in the company prior to the valuation observation
Length of the observation period	STEP	Number of development stages that the venture advanced during the observation period
Development stage at start of the observation period	START	Coding in Appendix I
Industry class was information technology?	INFO	Dummy variable. = 1, if the venture operates in information technology. = 0 otherwise.
Industry class was biotechnology / medical?	BIO	Dummy variable. = 1, if the venture operates in biotechnology / medical. = 0 otherwise.
Industry class was non-high-technology?	NONHT	Dummy variable. = 1, if the venture operates in the non-high-technology area. = 0 otherwise.

Control variables	Name	Explanation
Total amount of venture capital financing received at the round	RNDTOT	Total investments in thousands of nominal U.S. dollars
Return from the Nasdaq composite index between two consecutive financing rounds	CH_NAS	Absolute return from the index I. Return = $(I_1 - I_0)/I_0$ where 0 = previous round and 1 = this round
Time from the previous valuation observation	TPREV	Years between the start and the end of the observation period

We first analyse the Spearman's Rho correlation coefficients between the risk-neutral probabilities and the anticipated determinants of them presented in hypotheses 1–4 (Table III). Non-parametric correlations are used since the variables are not from a normal distribution.

We note that the length of the step that the venture made in the series of development stages (STEP) is negatively and significantly correlated with the risk-neutral probability. Also the number of prior financing rounds, the information technology industry dummy, the total amount of venture capital financing, and the return from the Nasdaq Composite index are negatively and significantly correlated with RNPROB. The number of prior financing rounds (RND) and the non-high-tech industry dummy (NONHT) have a positive and significant correlation with the risk-neutral probability. The development stage at the start of the step (START) does not correlate significantly with the risk-neutral probabilities, but correlates highly with the number of prior financing rounds, the step length, the total amount of venture capital financing, and the market return. This indicates that a lot of the information contained in the START variable is already contained in the other explanatory variables. Also the STEP variable correlates significantly with the other explanatory and control variables. This may cause multicollinearity problems that should be taken into account in further analysis.

Table III

Spearman's Rho correlation coefficients for the hypothesised determinants of the risk-neutral probabilities

This table provides the non-parametric correlation matrix for the hypothesised determinants of the risk-neutral success probabilities and the control variables. The two-tailed p-values of the correlation coefficients are in parentheses. Statistically significant values are in bold. N = 429.

	RNPRB	RND	STEP	START	INFO	BIO	NONHT	RNDTOT	CH_NAS	TPREV
RNPRB	1.000	**0.160**	**-0.302**	0.005	**-0.111**	0.034	**0.113**	**-0.384**	**-0.277**	-.082
		(.001)	**(.000)**	(.910)	**(.021)**	(.479)	**(.019)**	**(.000)**	**(.000)**	(.089)
RND		1.000	-0.053	**0.446**	0.014	0.057	-0.064	**0.270**	**0.156**	-0.006
			(.270)	**(.000)**	(0.777)	(.235)	(.187)	**(.000)**	**(.001)**	(.896)
STEP			1.000	**-0.350**	-0.002	0.006	-0.002	**0.393**	**0.445**	**0.195**
				(.000)	(.966)	(.895)	(.959)	**(.000)**	**(.000)**	**(.000)**
START				1.000	-0.064	0.066	0.027	**0.463**	**0.168**	**-0.212**
					(.187)	(.170)	(0.577)	**(0.000)**	**(.000)**	**(.000)**
INFO					1.000	**-0.614**	**-0.769**	-0.028	-0.029	-0.006
						(.000)	**(.000)**	(.568)	(.555)	(.899)
BIO						1.000	-0.033	0.027	0.081	0.062
							(0.496)	(.578)	(.094)	(.199)
NONHT							1.000	0.013	-0.029	-0.042
								(.786)	(.544)	(.380)
RNDTOT								1.000	**0.508**	-0.020
									(.000)	(.686)
CH_NAS									1.000	**0.590**
										(.000)
TPREV										1.000

B. *Regression Analysis*

To directly test hypotheses 1 – 4, we perform an ordinary linear regression analysis (Table V), controlling for the time passed, for the market return and for the total amount of venture capital financing. We use the risk-neutral probability as the dependent variable and check that it fulfils the normality assumptions. The other independent variables are as in Table II.

We estimate altogether four models. The first three are OLS regressions where all the explanatory variables and control variables are inserted into the equation, except that only one industry dummy is used at a time. The fourth regression represents a stepwise OLS model[4] where only the significant explanatory and control variables are included.

The results support hypotheses 2 – 4, whereas hypothesis 1 is not supported. The risk-neutral probabilities are indeed negatively related to the step length and positively related to the number of prior financing rounds. Additionally, they are dependent on the information technology and non-high-technology industry dummies. However, the coefficient of the START variable was not statistically significant. This results most likely from the high correlation with the other explanatory variables, although no significant collinearity problems could be found.

The control variables indicate that the total amount of venture capital financing injected into the company in the financing round is a significant determinant of the risk-neutral success probabilities. Additionally, the market return represents a weakly significant control variable. The actual time passed from the previous financing does not, however, indicate any significant relationship to the risk-neutral success probabilities.

Table V

Regression results for the determinants of the risk-neutral success probabilities, controlling for the time passed from the previous observation, for the total amount of venture capital financing and for the market return

Columns (1)-(3) provide the OLS regression results when the dependent variable = risk-neutral success probability and independent variables are RND, STEP, START, and the industry dummies. Column (4) provides the results of a stepwise OLS regression. Control variables were RNDTOT, CH_NAS, and TPREV in each regression. The hypothesised signs of the regression coefficients are included in the table. Significant values (95%) are in bold. *t*-statistics are in parentheses.

			Dependent variable: risk-neutral success probability			
Independent variables		**Exp. sign**	**(1)**	**(2)**	**(3)**	**(4)**
Constant			**0.376** **(7.27)**	**0.299** **(7.03)**	**0.293** **(6.91)**	**0.360** **(10.6)**
# of prior financing rounds	RND	+	**0.0179** **(4.70)**	**0.0173** **(4.53)**	**0.0183** **(4.78)**	**0.0173** **(4.93)**
Length of the observation period	STEP	-	**-0.0233** **(-2.52)**	**-0.0232** **(-2.50)**	**-0.0233** **(-2.51)**	**-0.0202** **(-2.84)**
Development stage at start of the observation period	START	+	-0.00553 (-0.617)	-0.00490 (-0.544)	-0.00501 (-0.558)	
Industry class was information technology?	INFO	≠ 0	**-0.0800** **(-2.67)**			**-0.0791** **(-2.64)**
Industry class was biotechnology / medical?	BIO	≠ 0		0.0661 (1.37)		
Industry class was non-high-technology?	NONHT	≠ 0			**-0.0860** **(2.27)**	
Control variables						
Total amount of venture capital financing of the round	RNDTOT		**-6.63xE-07** **(-3.29)**	**-6.59xE-07** **(-3.25)**	**-6.83xE-07** **(-3.38)**	**-7.87xE-07** **(-4.55)**
Return from the Nasdaq index between two consecutive financings	CH_NAS		-4.16xE-04 (-1.78)	-4.15xE-04 (-1.77)	-3.92xE-04 (-1.68)	**-2.81xE-04** **(-2.36)**
Time from the previous valuation observation	TPREV		0.0128 (0.815)	0.0126 (0.800)	0.0140 (0.891)	
R^2			0.176	0.166	0.172	0.173

[4] We used the following criteria: probability-of-F-to-enter 0.05, probability-of-F-to-remove 0.10.

Table VI presents the mean risk-neutral success probabilities for different step lengths. Consistent with Hypothesis 2, the probabilities follow an almost consistent downward trend as the step length increases. It is also interesting to see that the sample companies imply risk-neutral success probabilities of less than 0.4 for almost every step length, implying that the risk-neutral success probabilities are relatively low especially for longer steps.

Table VI

Mean risk-neutral success probabilities for each step size

Step	N	Mean	Lower 95% c. i.	Upper 95% c. i.
-2	1	-	-	-
-1	14	0.352	0.280	0.423
0	79	0.349	0.305	0.393
1	137	0.299	0.274	0.325
2	136	0.250	0.224	0.275
3	46	0.243	0.185	0.301
4	11	0.259	0.139	0.380
5	2	0.115	-	-
6	3	0.024	-	-

C. *Summary of the Hypotheses and Tests*

The binomial risk-neutral model seems to behave consistently with prior knowledge on venture capital investments. Table VII summarises the results of the validity tests and supports this conclusion. The fact that hypothesis 1 is not supported does not weaken the validity of the model. The correlation matrix of the explanatory variables shows that most of the information contained in START may already be contained in the other independent variables.

Table VII

Summary of the hypotheses and the results of the validity tests

Hypothesis	Support?
H1: The risk-neutral success probability for achieving the next financing round is *positively* related to the level of the stage where the observation period started.	No support
H2: The risk-neutral success probability for achieving the next financing round is *negatively* related to the length of the observation period.	Support
H3: The risk-neutral success probability for achieving the next financing round is *positively* related to the number of financing rounds that the venture has received prior to the current stage of development.	Support
H4: The risk-neutral success probability for achieving the next financing round is *dependent* on the industry in which the venture operates.	Support

IV. Results on the Explanatory Power and Comparative Fit of the Model

We analyse the explanatory power and comparative fit of the risk-neutral binomial valuation model by constructing one-step ex post forecasts for the venture's step-up in value[5] and by comparing them to the actually realised step-ups and to the step-ups predicted by a corresponding discounted cash flow model. Step-ups are used instead of actual valuations since they represent a relative measure of the development of the venture's value and avoid the bias from the difference in the actual size of the businesses.

A. Estimation and Control Samples

We divide the data into two random samples, both of which are designed to contain approximately 50% of the data[6]. The first sample, referred to as the estimation sample, is used to estimate the model for the appropriate risk-neutral probabilities. The second sample, referred to as the control sample, is used to generate forecasts of the venture's step-up in value in the good state of nature with these risk-neutral probability estimates.

The descriptive statistics and the average risk-neutral probabilities for the two random samples are compared in Table IX. There does not seem to be significant differences between the samples. This suggests that it is feasible to use a data set to estimate the risk-neutral probabilities and use these estimates in modelling the valuations of observations from an independent sample.

[5] Step-up in value is here the post-money valuation at the next financing round divided by the post-money value at the previous financing round.

[6] The random samples were generated as follows. Each case was assigned a random number between 0 and 1 on a spreadsheet. Following that, the cases that received a random number less than 0.5 were selected to the estimation sample. The control sample consisted of the rest of the cases.

Table IX

Means for the estimation and control samples and t-test for equality of means

The table presents the descriptive statistics for the significant determinants of the risk-neutral probabilities and the results of the t-test for equality of means when variances are assumed to be equal. Results do not change if unequal variances are assumed.

PANEL A

	Estimation sample (n=212)	Control sample (n=217)	t-test for equality
Variable	**Mean**	**Mean**	**t**
RNPROB	0.282	0.287	-0.313
RND	4.14	4.27	-0.623
STEP	1.39	1.42	-0.325
START	4.25	4.23	0.233
INFO	0.93	0.94	-0.454
BIO	0.028	0.023	0.344
NONHT	0.043	0.037	0.296
RNDTOT	40 731	39 891	0.189
CH_NAS	57.2	51.5	0.838
TPREV	0.940	0.937	0.034

B. *Stepwise Regression Analysis for the Risk-Neutral Probability Estimates*

Using stepwise regression, we attempt to estimate the parameters of the regression model that best determines the risk-neutral success probabilities in the estimation sample. We use the natural logarithm of the risk-neutral probabilities as the dependent variable and the same independent and control variables as in Table V.

The results are presented in Table X. They indicate that the risk-neutral probabilities may be approximated with the equation

$$q = 0.414 + 0.0129RND - 0.0396STEP - 0.116INFO - 6.31\text{E} - 07RNDTOT \qquad (10)$$

We also note that the length of the step explains almost 60% of the total variation explained by the both independent variables, making the step length by far the most important explanatory variable.

Table X

Stepwise regression results for the parameter estimates used in the forecasts

This table provides the stepwise OLS regression results for the hypothesised determinants of the risk-neutral success probabilities and the control variables, when the sample is the estimation sample. The dependent variable = risk-neutral success probability and independent variables are as in Table V. Some of the independent variables do not appear in the final stepwise solution, since their coefficients were not statistically significant. The regression is significant on a 99% confidence level. F[4,210] = 15.0, R^2 = 0.225.

Variable	Coefficient	t	Contribution to R^2
Constant	0.414	9.66	
STEP	-0.0396	-4.48	0.129
INFO	-0.116	-3.19	0.044
RNDNO	0.0129	2.76	0.029
RNDTOT	-6.31E-07	-2.99	0.023

We perform a similar stepwise regression analysis for the DCF model, where the determinants for the actual probabilities *p* are estimated from the estimation sample using (8). The dependent variable is the natural logarithm of *p* and the independent variables as above. The logarithmic transformation improves the normality of the distribution of the actual success probabilities. We obtain the necessary risk-adjusted rates of return from previous survey studies by Ruhnka and Young (1987, 1991) and Wetzel (1981). The rates of return are listed in Appendix III. These estimates can be regarded as the best available estimates of the venture capitalists' required rate of return at different stages of the venture's development.

For Wetzel's risk-adjusted rates of return, the actual success probabilities may be approximated with the equation

$$p = 0.643 + 0.104 TPREV - 0.0576 STEP - 0.189 INFO - 7.22\mathrm{E}-07 RNDTOT \qquad (11)$$

and for the risk-adjusted rates of return of Ruhnka and Young (1987, 1991) with the equation

$$p = 0.601 + 0.89 TPREV - 0.0593 STEP - 0.156 INFO - 7.81\mathrm{E}-07 RNDTOT \qquad (12)$$

We next use these estimates to generate forecasts in the independent control sample.

C. *Regression Analysis for Explanatory Power and Comparative Fit*

Using the control sample, we attempt to forecast the venture's step-up in value in one observation period using equation (6) for the risk-neutral forecasts and equation (9) for the DCF forecasts. We also compare the fit of the risk-neutral model to the fit of the DCF model. The risk-neutral probabilities are estimated using the linear regression parameters from the estimation sample (Table X). Similarly, the actual probabilities needed in the DCF model are estimated using (11) and (12). The risk-free rate is the 30-year bond yield at each stage, and the length of the observation period is the actually realised length.

We analyse the explanatory power and comparative fit of the risk-neutral and the DCF models by ordinary least squares regression. Using the actual step-up in value as the dependent variable and the step-up forecast as the independent variable, we note that there is a significant linear relationship between the forecasted step-ups and the actual step-ups for both of the models.

Table XI presents the results of the regressions where the actual step-up in value is explained with the forecasted step-up in value. Panel A includes the results for the risk-neutral model, Panel B for the DCF model with Wetzel's (1981) risk-adjusted rates of return, and Panel C for the DCF model with Ruhnka and Young (1987, 1991) risk-adjusted rates of return. Two regressions are presented for each model: 1) the dependent variable is the pure actual step-up in value and 2) the dependent variable and the independent variables are transformed using a logarithmic transformation. This procedure is necessary to better fulfil the normality assumptions of the regression model.

Table XI shows that all the models have at least some predictive power. They are well posed, since the regression coefficients are statistically different from zero. However, the comparative fit of the models differs a lot. Panel A shows that the risk-neutral forecasts explain 39.3% of the variation in the actual step-ups in value and 23.6% of the variation in the transformed step-ups. The DCF models do not exceed 19% in explanatory power in any of the cases.

Table XI

Explanatory power and comparative fit of the valuation forecasts

This table provides the results of the regression where the actual step-up in value is explained with the forecasted step-up in value (FCAST). The forecasts are calculated using the parameter estimates presented in Table X. All regressions: Actual step-up in value = $a + b$ * model value or ln(Actual step-up in value) = $a + b$ * ln(model value). A model is well specified if the coefficient is not statistically different from zero. Panel A presents the results for the risk-neutral model and Panels B and C for the DCF tree model when different risk-adjusted rates of return are used. *Note: the regressions on non-transformed actual step-ups do not fulfil all normality assumptions.*

Panel A: Risk-neutral model						
	Dependent : actual step-up			Logarithmic transformation		
Variable	**Coefficient**	**t**	**R^2**	**Coefficient**	**t**	**R^2**
Constant	0.195	0.69		0.260	3.13	
FCAST	1.160	16.1	0.393	0.805	11.2	0.236

Panel B: DCF model Risk-adjusted rates of return reported by Wetzel (1981) are used						
	Dependent : actual step-up			Logarithmic transformation		
Variable	**Coefficient**	**t**	**R^2**	**Coefficient**	**t**	**R^2**
Constant	0.605	1.53		0.364	4.07	
FCAST	1.137	9.61	0.186	0.761	9.16	0.172

Panel C: DCF model Risk-adjusted rates of return reported by Ruhnka & Young (1987, 1991) are used						
	Dependent : actual step-up			Logarithmic transformation		
Variable	**Coefficient**	**t**	**R^2**	**Coefficient**	**t**	**R^2**
Constant	-0.569	-0.95		0.417	4.34	
FCAST	1.862	8.03	0.138	0.846	7.90	0.134

We conclude that the risk-neutral binomial valuation model seems, indeed, to have explanatory power in one-step valuation forecasts, although the regression R-squared indicates that actual deviations from the correct value may occasionally be large. In addition, the comparative fit of the risk-neutral model is much better than the fit of the DCF models. This may result from the fact that the correct risk-adjusted rates of return are unobservable, whereas the risk-free rate of return is observable.

D. Analysis of Bias and Efficiency

The risk-neutral valuation forecasts appear to be relatively unbiased estimates of the actual step-ups in value. Table XII presents the mean and median forecast errors and standard deviations for the whole control sample and the subsets of different step lengths. On average, the forecast error is -9% (median 7.4%), indicating that the model may produce slightly biased valuations. Some very large errors forced the average downwards, and the median may represent a more reliable measure of forecast error.

The standard deviation of the forecast error is large for longer steps. On the other hand, in cases where the venture stayed at the same level of development, mean forecast error is nearly zero and standard deviation somewhat smaller than for longer step lengths.

The overall standard deviation of the forecast error is large, 84%. This implies that although the forecasts seem to be fairly right on average, errors are large in both directions when they occur. The result is not a surprise, since previous research on venture capital has shown that the outcomes of venture capital investments include both extreme returns and total losses – these investments result in anything but the average.

Table XII

Forecast error statistics for different step lengths for the risk-neutral model

The table presents the mean and median forecast errors and standard deviations of the error for different step lengths in the control sample. The forecast errors are calculated as follows: forecast error = (forecast – actual value) / (actual value).

Step	Mean forecast error	Median	Std dev. of the forecast error
-2	-	-	-
-1	10%	3.3%	39%
0	5.0%	12%	48%
1	-9.8%	9.8%	50%
2	-14%	7.1%	140%
3	-34%	15%	114%
4	-10%	-6.7%	150%
5	-	-	-
6	-	-	-
Whole control sample	-9.0%	7.4%	84%

V. Conclusion

During the last two decades, real option-pricing models have been applied to many areas. However, venture capital has remained almost untouched, although it has been identified that these investments include several option-like characteristics. Few serious attempts have been made to model the investments based on option-pricing theory, excluding e.g. Willner's (1995) model of start-up venture growth options. Neither has anybody carried out empirical testing of the applicability of option-pricing theory to venture capital settings. Finally, and most importantly, the current knowledge on venture capital lacks efficient methodologies for analysing the risk-return structure of these investments.

We introduce a risk-neutral binomial valuation model for the analysis of venture capital investments. We also provide empirical evidence that this risk-neutral model is consistent with previous knowledge on the risk-return profile of venture capital investments. Furthermore, we find that the model has predictive power on the actual future valuations. We also find that the predictive power of the model is better than that of traditional discounted cash flow models. The risk-neutral valuation estimates seem to be fairly unbiased, since the median forecast error is found to be small. Nevertheless, the variance of the forecast error is large, which is consistent with the common observation that venture capital investments often result in extreme outcomes.

This paper has both theoretical and practical implications. The main theoretical implication is that option-pricing theory seems to have relevance in venture capital applications. The risk-neutral model provides a much-needed methodology for analysing the risk-return structure of these investments. Practical implications arise from the fact that the model is relatively simple. We argue that it is understandable and feasible also in practice. Venture capital practitioners may thus benefit from the model in decision-making and company analysis settings.

The main limitations of this paper arise from the empirical sample. The observations consist of only successful ventures, which were able to proceed to the initial public offering. If we could construct a sample that contained observations also from ventures that did not succeed, the reliability of the results would increase.

However, such a sample is hard to construct, since the Venture Economics database used in this study and other corresponding data sets may not yet include enough such observations. Alternative sources, such as large-scale surveys, could be potentially useful. These methods could also alleviate the possible bias associated with the publicly disclosed valuations that Venture Economics reports. Additionally, selecting a longer time frame for the sample could be useful and feasible to implement.

Further research should examine the validity of more advanced option-pricing models in venture capital applications. We have shown that risk-neutral pricing is consistent with empirical observations. However, option-pricing models based on an underlying stochastic process that attempts to capture the venture's value have not been empirically validated. Furthermore, it would be interesting to examine the exercise policy of the venture capitalist's series of options to abandon. When do the venture capitalists decide to invest and when do they decide not to? The risk-neutral approach may offer a basis for the analysis. Finally, analysing further the risk-return structure of staged venture capital investments using a theoretically sound model, such as the risk-neutral approach, would contribute to the current knowledge significantly.

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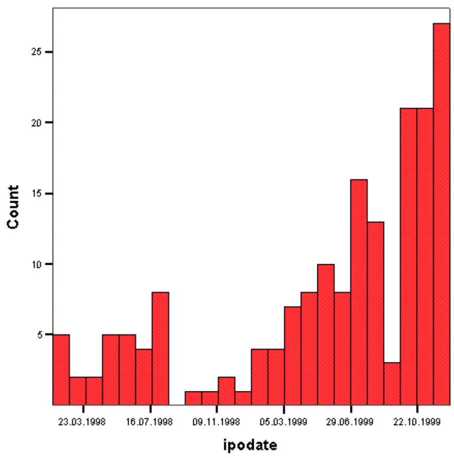
Appendix I

The coding of the development stages

Stage of development	Ordinal code
Seed	1
Start-up	2
First stage / Early stage	3
Second stage	4
Third stage / Expansion	5
Bridge	6
Buyout	6
IPO	7

Appendix II



Monthly number of IPOs in the sample

Appendix III

Venture capitalists' risk-adjusted rates of return for different stages of development as reported in earlier research

		Rate of return demanded	
Stage reported in the paper	Coded as stage #	Wetzel (1981)	Ruhnka & Young (1987, 1991)
Seed	1	73.0%	50.0%
Start-up	2, 3	54.8%	50.0%
Third stage	4	42.2%	37.5%
Fourth stage	5	35.0%	30.0%
Exit stage	6	35.0%	22.5%