Value of Commercial Software Development under Technology Risk

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Abstract

Risk, or exposure to uncertainty, is an inherent part of software development. It is therefore an important factor in software investment decisions. This paper presents a disciplined approach to treating technology risk—an approach that links software development decisions to be linked to the financial markets. The approach relies on the premise that uncertainty creates value when managed properly. The paper demonstrates the utility of securities in estimating the risk underlying an investment in software development. It accomplishes this objective by means of a familiar development scenario that is subject to the uncertainty of a particular software technology: Java. The estimate of the underlying risk helps determine the value of the scenario. The valuation is performed through *real options analysis*, a financial technique well suited to deal with investment decisions under uncertainty. This kind of analysis is likewise applicable when Java is substituted by another software technology, such as the Extensible Markup Language (XML).

Keywords—*Software economics, decision-making, real options, real options analysis, uncertainty, investment analysis, financial valuation, risk, Java, XML*

1. Introduction

Software development is a highly uncertain activity. Even when software projects are on schedule and within budget, failure in the market is not uncommon for commercial products. Given the low chances of success and the high-level of private risk, many software endeavors probably would look unattractive on an expected net present value basis. On the other hand, some of these endeavors become significant sources of wealth generation for those who undertake them. The current level of activity in commercial software development is difficult to reconcile with the low chances of success. One explanation is that the software economy is driven not by the expectation of a steady stream of cash flows, but rather, by the uncertain prospect of high returns. In general, the higher the level of uncertainty, the more opportunities there are to create value.

To see how managed uncertainty creates value, consider the following scenarios.

1. A large software system was designed to easily accept components. In the midst of development, an off-the-shelf product becomes available. Suddenly the opportunity to use this product for a major subsystem at a fraction of the cost of developing that subsystem from scratch arises The opportunity eliminates the technical risk associated with the subsystem development. Management takes advantage of this opportunity, and thus reduces both

the development cost and private risk significantly.

2. A software startup decides to make its product XML-compatible to allow it to easily exchange information with external applications. XML was an evolving, unstable standard when development began. Before the product is completed, XML becomes an industry standard. As a result, not only demand for the product exceeds the company's initial expectations, but also its prior experience with that technology provides it with the opportunity to become a major market player.

These two examples demonstrate that, when managed properly, uncertainty can be very valuable. In both cases, the value results from the flexibility to adapt to changing conditions.

This paper will show how to capture such value in the development of commercial software. Its approach is based on a state-of-the-art financial valuation technique: *real options analysis*. The highlighted feature of the technique is its ability to use objective information from the financial markets. The paper will explain how to harvest this information in the context of a familiar software development scenario that is subject to the uncertainty of a relevant software technology, Java [15]. The generality of the approach is illustrated by an additional case study based on the Extensible Markup Language (XML) [23].

The rest of the paper is organized as follows. Section 2 explains some basic corporate finance concepts, such as risk and present value, and describes a methodology for risk estimation using information from financial markets information. Section 3 gives an overview of option concepts, real options analysis, and a widely known option valuation model. Section 4 presents a software development scenario based on Java and shows how it can be framed as an option valuation problem. Section 5 deals with the estimation of the underlying risk of this scenario with the methodology described in Section 2. This is followed in Section 6 by the valuation and analysis of the scenario using the model described in Section 3. Section 7 applies the risk estimation methodology to XML, and Section 8 provides some final remarks.

2. Basic Concepts

Risk refers to exposure to uncertainty. While uncertainty is inherent, risk can often be managed. Risk has two components: *private* and *systematic*.

An *asset* is something that has a currency value, which can change over time. A *certain*, or *riskless*, asset is one whose value at any point over a given time horizon is known. A short-term government bond is a riskless asset. An *uncertain*, or *risky*, asset is one whose value over a given time horizon is stochastic. Stocks and derivative securities such as stock options are risky assets. An asset can be *real* or *financial*. A project with a stream of cash flows is a real asset. Stocks, stock options, and business contracts are financial assets.

A *portfolio* is a bundle of assets. The value of a portfolio is a weighted average of the values of the assets in the portfolio.

Given a portfolio, *private risk* refers to risk that is unique to individual assets in the portfolio. *Systematic risk* is risk that applies equally to each asset in the portfolio.

The *growth rate*, or *return rate*, of an asset is the percentage change in the value of an asset over a given time unit. The *instantaneous*, or *continuous* growth rate of an asset is the logarithmic change in the value of an asset over a given time unit. The growth rate of a riskless asset is called the *risk-free rate*. The risk-free rate is the same for all riskless assets, and is given by the interest rate on short-term government bonds.

Volatility is a quantitative expression of risk. It is usually measured by the standard deviation of the growth rate. The volatility of an individual asset in a portfolio is an expression of that asset's total risk with respect to the other assets in the portfolio. Provided that the portfolio is sufficiently diversified, the volatility of the portfolio itself can be thought of as an expression of the systematic risk of every asset *with respect to* that portfolio. Volatility is usually measured by standard deviation of the growth rate of an asset.

2.1. Private Risk

In any technology-based investment, high levels of *private risk*, or risk that is project-specific, are common. This is risk that shareholders of a company can theoretically eliminate by maintaining a sufficiently diversified portfolio of similar assets. Private risk is due to unique internal factors such as experience, development process, management style, and unforeseen technical problems.

2.2. Systematic Risk

Even with low internal uncertainty, a software development venture can fail to generate value due to several other reasons. For example, interest rates may jump, slowing the economy down. The market may not be ready for the end product. A major competitor may move in, or the standard on which the end product is based may fail to achieve widespread acceptance. These examples constitute *systematic risks*—risks that are due to factors often external to a project. Such risks are equally applicable to projects that have similar features and targets. On the downside, investors *cannot* eliminate systematic risk simply through diversification. On the upside, at the project level, management can sometimes control it. As we will see, systematic risk can be accounted for more easily than private risk.

2.3. Estimation of Risk

The focus of this paper is on uncertainty that gives rise to systematic risk. Financial markets are valuable sources of information for estimating this kind of risk. If the financial markets contain a sufficient number of traded assets whose values are somewhat dependent on a given source of uncertainty, then a portfolio composed of those assets would also be subject to the same source of uncertainty. As a consequence, the volatility of the portfolio can provide a reasonable, objective estimate of the risk.

Such a portfolio is called a *tracking portfolio*, since it tracks systematic risk.

The foundation of this argument is a widely accepted financial model: the *Capital Asset Pricing Model*. An overview of the CAPM can be found in any introductory corporate finance text; for example, see Ross et al. [19]. Although a detailed discussion of this model is beyond the scope of this paper, a brief intuitive explanation is given. At the heart of the CAPM is the diversification principle: in a sufficiently diversified portfolio, risk that is unique to individual assets, or private risk, will be negligible. Fluctuations in the growth rate of the portfolio caused by such risk will appear to be random, and thus tend to cancel each other out. What is left is the risk that applies to all the assets in the portfolio—or systematic risk.

Section 6 will illustrate the application of the diversification principle to estimate the systematic risk of two software technologies, Java and XML, within the context of a typical development scenario. For each case, a tracking portfolio is formed by a custom stock index of publicly traded software companies. Each company offers at least one major product or service based on the tracked technology, and therefore, it can be assumed that its market capitalization is at least partially correlated with the technology's success. For Java, only those companies with Java-based products and services that are targeted at the e-business sector are included.

The market capitalizations of the companies in the tracking portfolios are inevitably affected by several other factors besides the intended source of uncertainty. The CAPM states that the net effect of those factors will be small in a diversified portfolio—a condition that we hope to have satisfied by including a sufficient number of companies in the portfolios. With this approach, it is also highly probable to incidentally capture other, unanticipated sources of uncertainty. This effect does not pose a major problem since the resulting systematic risk would also be likely to apply to the situation at hand.

2.4. Present Value

The *present value* of a future asset is the amount the asset would be worth today. Consider an asset whose expected value at a future time T is V_T. Let the expected growth rate of this asset over this time period be r. The present value of the asset is computed by *discounting* the future value back to the present time using the expected growth rate as an interest rate applied in reverse. If r is a discrete growth rate, the present value of the asset is given by:

$$V_0 = V_T / (1 + r)^T \ .$$

If r is a continuous growth rate, the present value of the asset is given by:

$$V_0 = V_T \exp(-rT) \ .$$

In present value calculations, the expected growth rate r is often referred to as a *discount rate*.

2.5. Net Present Value (NPV)

The *net present value* of a project is the sum of the present value of its positive cash flows, minus the sum of the present value of its costs. Costs are usually discounted using the risk-free rate since they are often only subject to private risk. The NPV rule states that only positive-NPV projects should be undertaken.

3. Real Options

The high valuation of technology stocks has recently been explained in the popular press through a concept called *real option* value [18]. An active area of corporate finance research, this concept focuses on the economic quantification of managerial flexibility in the face of uncertainty.

3.1. Real Options Analysis

Real options analysis [2, 10, 16] is used primarily in the valuation of strategic investments. Its suitability depends on the presence of two properties: (1) *one or more sources of uncertainty* and (2) *irreversible future decisions* that depend on the uncertain outcomes. The technique is particularly appropriate in cases where classical financial valuation techniques, such as *discounted cash flow analysis* and static *net present value* [19], fail to deal with the dynamic aspects of decision making under uncertainty in a satisfactory manner [17].

Real options analysis techniques are increasingly applied in such sectors as natural resources (exploration and development), pharmaceutical (drug development), real estate (leasing decisions) manufacturing systems (convertible plants), aerospace (aircraft development and acquisition), and information technology (R&D, technology valuation). For examples, see Trigeorgis [22] and Amram and Kulatalika [1]. Applications to IT investments in general, and software development decisions in particular, are more recent, but are quickly gaining popularity [3, 5, 7, 12-14, 20, 21]. Boehm and Sullivan [5] point out to role of the real options approach in the evaluation of software development investments. Here are a few examples:

- Flexibility projects: designing a system to easily accept COTS components [12];
- Learning projects: development of a software prototype to resolve technical or market uncertainty [20];
- Infrastructure projects: development of an application framework for a future product line [13, 14]; and
- Risk management [7]: simultaneous support of competing software standards in a product.

3.2. Options

Central to the real options approach is the concept of an *option*. In general terms, an option refers to a projected discretionary action whose execution is contingent on the realization of certain future conditions. More specifically, an option is the opportunity, *without the obligation*, to exchange two possibly uncertain assets on or before a future date. Both of these definitions stress three fundamental characteristics: the presence of uncertainty, the presence of a future opportunity, and the discretionary nature of the action associated with the future opportunity.

The last characteristic is of paramount importance, and as such, deserves further elaboration. Since an option represents a discretionary action ("an opportunity without the obligation"), it should be exercised only when the net payoff of exercise is positive. This behavior, called rational exercise, has a central implication: the value of an option is always positive since a loss can be avoided by refusing to exercise the option. In addition, while losses can be avoided, no such limitation is placed on the gains. When the underlying uncertainty is high, the potential for gains is also proportionately high. Therefore the value of an option in general increases with the level of uncertainty. This intuition is one of the cornerstones of option valuation.

Financial options refer to options contracts written on financial assets, such as stocks, commodities, or exchange rates. A stock option is the best known form of a financial option. Real options refer to options that are implicit in an investment decision, or that are deliberately designed into a project. They are defined on real assets, typically on a stream of uncertain future cash flows. They focus on the ability of management to respond to changing conditions. Real options analysis is concerned with the identification of such options, their framing as option pricing problems, their valuation, and the interpretation of the results [1].

3.3. Black-Scholes Call Option Model

The theory of option valuation, both financial and real, has its roots in the Nobel prize winning work of three financial economists—Black, Scholes, and Merton—on the pricing of derivative securities and corporate liabilities [4]. In their seminal work, Black and Scholes derive an analytic solution for the value of a call option. Their solution is based on no-arbitrage arguments and a particular stochastic model of the underlying risky asset value.

A call option is the right to acquire a risky asset (called the *underlying asset*) for a preset price (called the *exercise price*) on or before a future date (called the *maturity date*). A call option is exercised only when the payoff is positive, that is when the strike price is inferior to the value of the underlying asset at maturity. Let V represent the value of the underlying asset. V is assumed to follow a lognormal diffusion process[1], specified by the stochastic differential equation:

$$\frac{dV}{V} = \alpha_V dt + \sigma_V dZ_V ,$$

where α_V is the expected continuous growth rate of V, σ_V is the standard deviation of this growth rate, and dZ_V is the increment of the standard Wiener process. Roughly, this equation states that percentage changes in the asset's value over small intervals exhibit random fluctuations around a mean. In other words, the logarithm of the asset's value follows arithmetic Brownian motion, the continuous-time version of random walk. Based on this model, Black and Scholes arrive at an analytic solution for the value of the call option by constructing a continuously updated portfolio that consists of a long position in the underlying asset, levered by a short position in a riskless asset (such as a short-term government bond). The portfolio is constructed and updated such that it replicates exactly the payoffs of the option at all possible states of the future. The value of the call option must then equal the value of this portfolio to avoid any arbitrage opportunities. If S is the agreed upon strike price, τ is the maturity date of the option, r is the short-term risk-free interest rate, $D_0 = S\exp(-r\cdot\tau)$ is the present value of S, and V_0 is the present value of the underlying asset, then the (present) value of the call option is given by the formula:

$$C(V_0, D_0, \tau, \sigma_V) = V_0 N(d_1(P, \tau, \sigma_V)) - D_0 N(d_2(P, \tau, \sigma_V)),$$

where

$$P = \frac{V_0}{D_0},$$

$$d_1(x, \tau, \sigma) = \frac{\ln x + \frac{1}{2}\sigma^2\tau}{\sigma\sqrt{\tau}},$$

$$d_2(x, \tau, \sigma) = d_1(x, \tau, \sigma) - \sigma\sqrt{\tau},$$

and N denotes the cumulative standardized normal distribution function. Most remarkable here is that the solution does not depend on α_V, the expected growth rate of the underlying asset. The derivation elegantly eliminates this variable, thanks to the replication and no-arbitrage assumptions. For a simplified, alternative derivation of the Black-Scholes model, see Cox et al. [8]

The parameter σ_V is the *volatility* of the underlying asset. The value of a call option increases when the value of this parameter increases.

The suitability of the Black-Scholes model for non-traded assets is not free of pitfalls. The model makes a number of strong assumptions, the diffusion model being the least problematic. Thus it must be kept in mind that the option value calculated by the Black-Sholes is an *idealized* value—the value the option would have if the underlying asset could be traded without transaction costs and with unlimited shortselling such that the replicating portfolio could be maintained in a continuous manner without giving rise to arbitrage opportunities.

4. A Software Platform Investment with Technology Risk

As an example, consider the investment decision faced by a fictitious company. For ease of illustration, the investment decision is limited to a single source of uncertainty. Favaro et al. [14] and

[1] Lognormal diffusion, or *geometric Brownian motion*, is a popular model of stock prices [6].

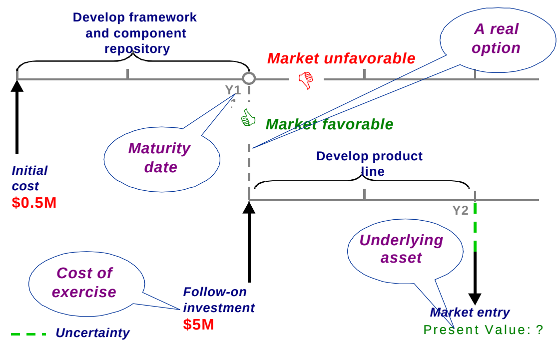

Figure 1. The development strategy of JSystems and the underlying option.

others [3, 11, 21] have treated similar software and IT investment scenarios within the real options framework, however they did not address the estimation of the underlying risk. This section will set the context and frame the investment problem. Sections 5 and 7 will focus on the estimation problem and valuation.

4.1. Context

JSystems, a Java[2] startup, is considering developing a new software platform—dubbed Enterprise JFrames (EJF)—for a future product line of e-business applications. EJF will consist of an application framework and a component repository to complement the framework. Once developed, EJF will enable JSystems to efficiently produce new, customized e-business applications.

4.2. Forces

JSystems is taking a risk by investing in a still evolving, unstable technology such as Java. On the one hand, the return on investment from the project depends on the market for Java-based e-business applications. On the other hand, the future of the e-business market looks promising. JSystems should structure its investment with these considerations in mind.

4.3. Development Strategy

JSystems will first develop the application framework and a core component repository at a relatively low estimated cost of $0.5M. This first-stage development will take one year. At the end of the first year, JSystems will make a decision depending on the outlook of the e-business market and the success of Java in that market. If the market in Java-based e-business applications is unfavorable, it will abandon the project, and its first-stage cost will be sunk. If the market is favorable, it will follow up with a more substantial second-stage investment of $5M. The second-stage investment will involve extending the component repository and developing the initial product line. The launch of the initial product line will take place at the end of year two.

4.4. The Investment Problem

What should the present value of the complete project be to make this project worthwhile? The complete project consists of the fully developed platform, EJF, and the initial product line. Its value is thus the post-development value of the second-stage investment. Note that this value is created only if the second-stage investment is fully undertaken. To avoid having to choose a discount rate, we require the present value of this investment rather than its future value at the end of year two.

[2] Java is a trademark of Sun Microsystems, Inc.

4.5. Problem Framing

Figure 1 depicts the formulation of this strategy as a call option on the value of the complete project. The option can be exercised at the end of year 1, at the end of the first-stage investment. The exercise price of this option is the cost of the second-stage investment, or $5M. The exercise of the option is dependent on the year-one value of the initial product line exceeding the second-stage cost. This value is uncertain because the success of the base technology, Java, of the final product is uncertain.

5. The Risk of Java in E-Business

At first sight, the risk borne by JSystems seems private, and intangible. How is it possible to quantify the risk of an evolving software technology in a given application domain? A closer look at the financial markets provides an elegant solution to this problem.

Software ventures are special. It requires relatively little capital to start and run a small software firm. Virtually no regulatory or other barriers exist, save fierce competition. These characteristics create an environment where many specialized innovative firms are free to explore specific, promising technologies. Having demonstrated their potential, some of these firms will endeavor to raise capital through initial public offerings. Once they become public, their market capitalization will reflect the value assigned to their future growth potential by investors. If this value is based on a specific technology, then the dynamics of their stock price will presumably, at least partly, reflect the risk of that technology.

5.1. The Case of Java

Such is the case for Java. Java is indeed quite special. In 1996, having realized the potential of Java as a "de facto standard for open, multi-platform, secure networked computing", the Silicon Valley venture capital firm Kleiner Perkins Caufield & Byers created a $100 million fund to invest in startup companies working with Java.

Technology companies that have contributed to the KPCB Java Fund include Sun Microsystems Inc., Cisco Systems Inc., IBM Corp., Netscape Communications Corp. and Oracle Corp. The mission of the fund, which continues to be in existence, is "to encourage and invest in new ventures using Java technology to develop tools and applications." The establishment of the KPCB fund fuelled increased interest in Java. In 1997, more than a dozen Java startups were in existence. The financing of a new programming language in this way was unprecedented in the software industry.

Some of the companies KPCB investee companies have held public offerings since their inception. Others that did not get funded, nevertheless, remained in existence, and a few of those eventually went public as well. Of those public companies, a significant number have since been acquired by Sun. Hence their value has been integrated with that of a much larger corporation.

5.2. The Tracking Portfolio

A recent study by the authors has identified 18 public companies with at least one major e-business product or service based on Java. All self-identify as a player in the e-business market. The companies include two blue-chip companies, Sun, the developer of Java, and IBM, the developer of Visual-Age-for-Java and an e-business solution provider. The

Table 1. Java : The tracking portfolio.

Name	Stock Symbol	Weight	Average Weighted Market Cap ($M)
Allaire Corp.	ALLR	1	1297
Applix Inc.	APLX	1	139
Art Technology Group	ARTG	1	2850
Active Software	ASWX	1	1526
BEA Systems	BEAS	1	8187
Bluestone Software	BLSW	1	1163
Calico Commerce	CLIC	1	1386
CyberCash	CYCH	1	244
Elcom International	ELCO	1	321
IBM	IBM	0.05	10119
Informix Corp.	IFMX	1	2924
Marimba Inc.	MRBA	1	850
RSA Security	RSAS	1	1666
Segue Software	SEGU	1	112
Sun Microsystems, Inc.	SUNW	0.15	14950
Sybase Inc.	SYBS	0.05	73
Unify Corporation	UNFY	1	273
Versant Corp.	VSNT	1	70

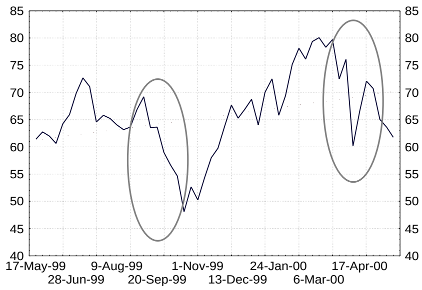

Figure 2. Java: Performance of the tracking portfolio.

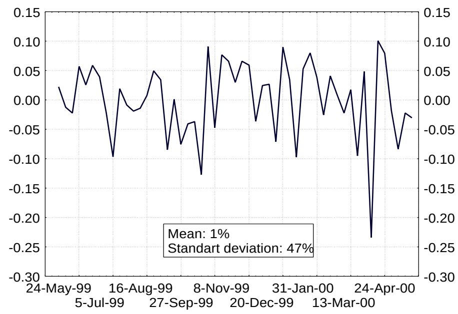

Figure 3. Java: Continuous growth rates for the tracking portfolio.

remainder largely consists of Java startups and former startups, including three KPCB-funded companies. The companies are diversified within the e-business sector in that their products and services span a wide spectrum from core technology, web servers, and network security, to component integration, and business-to-business solutions. Thanks to the selection criteria, part of the market capitalization of each firm can be attributed to value derived from Java. Table 1 shows the list of the companies.

The list is used to estimate the systematic risk of Java within the targeted e-business sector as follows. The list of companies is composed into a portfolio that tracks the systematic risk. The portfolio is treated as a custom index. Weekly stock prices for the twelve-month period ending in March, 2000 constitute the historical data. The index is dynamic in that a company's stock is included in the index only for those periods during which the company was in existence and offered Java-based products or services. The data is adjusted to account for stock splits. The value of the index for each data point is calculated as a weighted average from the individual observations using two different weights.

The first weight is common practice, and is based on market capitalization: for a given observation, each stock contributes to the value of the index in the same proportion as its market capitalization contributes to the total market capitalization of the portfolio for that observation.

The second weight determines the proportion of a company's market capitalization attributed to Java. This is a subjective estimate. The Java weight is set to unity for Java startups. For larger and more diversified companies, a number smaller than unity is chosen. The Java weights were estimated based on information about the companies' products and services and relevant press releases. The third column of Table 1 shows these weights. The last column shows the average weighted market capitalization for each stock over the twelve-month period considered. Figure 2 plots the calculated portfolio values over this period. The ellipses mark the two market corrections that have virtually eliminated the exponential trend in the portfolio. (The exponential trend was prominent in an earlier study.) The nearly straight horizontal line is the fitted exponential trend.

5.3. The Volatility of the Portfolio

The continuous growth rates of the tracking portfolio are plotted in Figure 3. Over the analyzed period, the portfolio exhibited an annual mean growth rate of less than 1%. The volatility, estimated by the standard deviation of the growth rate [6], was 47% per year. Note that although the growth rate was negligible, the standard deviation was high. In contrast, the annual growth rate for the twelve-month period ending in February, 2000 was a whopping 150%, while the volatility was only slightly lower than the replicated study, at 43% per year. The fact that the volatility figure did not significantly change suggests that the two market corrections did not affect the systematic risk to a sufficient degree. The volatility figure is essentially a compact expression of the way the financial markets have priced the risk that systematically applies to all the assets in the portfolio as the software technology in question (Java) and the target sector (e-business) evolved over time.

5.4. Pre-Valuation Analysis

The continuous growth rates of the tracking portfolio appear to exhibit random fluctuations around a mean value, strong indication that the underlying time series follows a lognormal diffusion process. A closer investigation confirms this suspicion. The bell-shaped outline of the probability histogram (Figure 4) and the absence of major outliers outside the extremities of the normal probability plot (Figure 5) suggest a normal distribution of the growth rates. The autocorrelations (Figure 6) and the partial autocorrelations (Figure 7) further suggest that the growth rates are serially independent. The vertical lines mark the boundaries outside which the autocorrelations and the partial autocorrelations are, respectively, statistically significant at an alpha level of 5% and above their standard errors. All autocorrelations remain within the boundaries. In addition, application of Dickey-Fuller regression [9] on the logarithm of the original time series does not allow the the random walk hypothesis to be rejected at an alpha level of 5%. Again, this last result is suggestive of the prominence of lognormal diffusion.

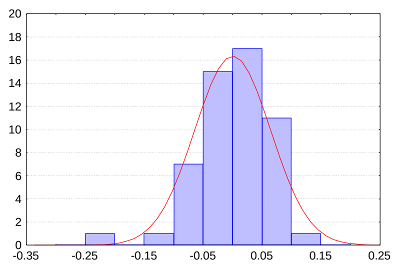

Figure 4. Java: Probability histogram of growth rates.

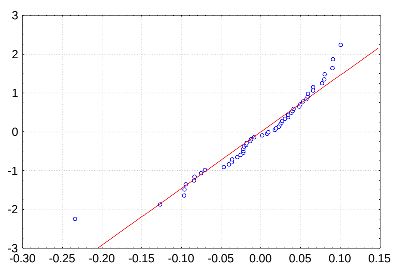

Figure 5. Java: Normal probability plot of growth rates.

5.5. Valuation

Having established the prominence of lognormal diffusion in the underlying asset, the Black-Scholes call option formula is applied to determine the value of the second-stage investment. The formula requires five inputs:

- *The present value of the underlying asset* is the present value of the complete project. This amount is unknown, and will be treated as a sensitivity variable.
- *The exercise price of the option* is the cost of the second-stage investment, the $5M required to

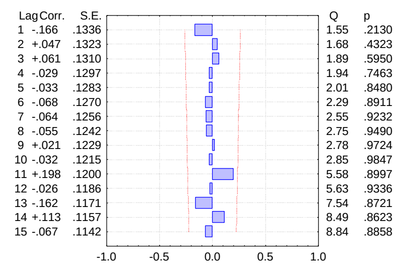

Figure 6. Java: Autocorrelogram for growth rates.

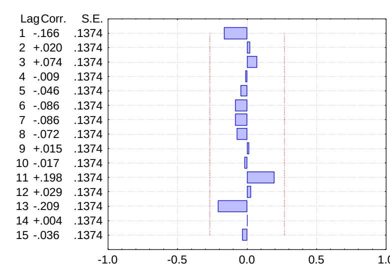

Figure 7. Java: Partial autocorrelogram for growth rates.

- extend the component repository and develop the initial product line.
- *The maturity date* is the time to develop the core EJF, or one year.
- *The risk-free rate* is assumed to be 6% per year, continuously compounded.
- *The volatility of the underlying asset* is estimated by the volatility of tracking portfolio, 47% per year.

The top curve in Figure 8 depicts the option value of the second-stage investment as a function of the present value of the underlying asset, or of the value of the complete project.

5.6. Post-Valuation Analysis

Were the second-stage investment not discretionary (that is if it were not an option), the net present value of the overall project would be given by:

$NPV_{STATIC} = -$ (Cost of initial investment)
$-$ (Present value of cost of second stage investment)
$+$ (Present value of complete project)

The net present value calculated in this way is a static NPV since it treats the project as a linear sequence of investments rather than a sequence of options. In Figure 8, the static NPV is represented by the dashed line.

The net present value should account for the discretionary nature of the second-stage investment. To acquire the option to make the second-stage investment (extend repository and develop the initial product line), JSystems must first complete the first-stage investment (development of the framework and the core repository). Hence, the net present value of the overall project is more accurately given by:

$$NPV_{\text{option}} = -(\text{Cost of initial investment}) + (\text{Option value of second stage investment})$$

The middle curve of Figure 8 is this NPV, that is the NPV of the overall project with the option. This value is positive when the present value of the complete project exceeds approximately $4M. Therefore, JSystems should not consider the project unless it is able to project a value above this threshold. The static NPV threshold, on the other hand, stands at approximately $5.25M—30% higher

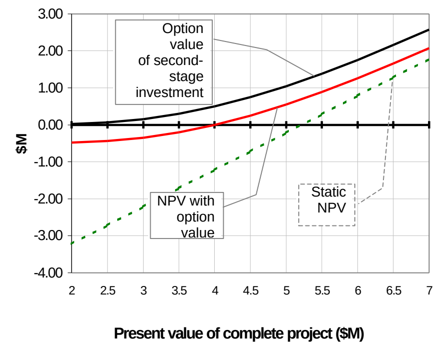

Figure 8. EJF: Option value and static NPV.

than the NPV with the option. Therefore, the static NPV makes the overall project look much less attractive.

Remarkably, the $4M threshold is smaller than the cost of the second-stage investment. How can this be? The effect is due to the high volatility of the underlying asset (the risk of Java in e-business) combined with the discretionary nature of the second-stage investment. The $4M figure represents a statistical expectation[3]. Since the volatility of the tracking portfolio is substantial, at the maturity of the option, the realized value of the complete project may very well exceed the cost of the second-stage investment, or the exercise price of the option. In this case, the option will be exercised with a positive net payoff. *However, if the value falls below the cost, the option will not be exercised, avoiding further losses*. In this case, the only loss will be the relatively small cost of the initial investment.

6. The CASE of XML

The application of the same risk estimation methodology to a second software technology, the Extensible Markup Language [23], yielded similar results. The study has identified 37 public companies with major products or services based on the XML standard. Table 2 shows the list of the companies and their weights in the tracking portfolio. Figure 9 shows the value of the tracking

[3] This is sometimes called an *unbiased estimate*[14].

portfolio over the twelve-month period ending in May (based on weekly observations) together with the exponential trend line. The continuous growth rates are plotted in Figure 10. The portfolio exhibits an annual mean growth rate of 48% and an annual volatility of 48% around this growth rate.

As with the Java case study, an analysis of the resulting time series points to lognormal diffusion. The probability histogram (Figure 11) is close to a bell shape. The normal probability plot (Figure 12) has a single outlier at one extremity. The autocorrelograms (Figures 13 and 14) do not show any statistically significant serial correlation, with the exception of a single lag. As before, Dickey-Fuller test on the logarithm of the original time. series cannot reject the random walk hypothesis at a statistical significance of 5%. As a consequence, had XML been substituted for Java in the example development scenario, the Black-Scholes model could still be applied to determine the idealized value of the underlying option

Table 2. XML : The tracking portfolio.

Name	Stock Symbol	Weight	Average Weighted Market Cap ($M)
ActionPoint	ACTP	0.75	31
Adobe Systems	ADBE	0.05	446
Agile Software Corp.	AGIL	0.75	2026
Ariba, Inc.	ARBA	0.25	3881
Active Software	ASWX	0.25	382
Bitstream, Inc.	BITS	0.25	14
Bluestone Software	BLSW	0.25	279
Clarus Corp.	CLRS	0.25	209
Commerce One, Inc	CMRC	0.75	6091
Entrust Technologies	ENTU	0.25	671
Jetform, Inc.	FORM	0.75	77
GA Express	GAUM.OB	0.25	7
Harbinger Corp.	HRBC	0.1	231
Information Architects	IARC	1	4049
IBM	IBM	0.02	735
Informix Corp.	IFMX	0.25	125
Intranet Solutions	INRS	0.25	31239
Intel Corp.	INTC	0.1	1262
Interwoven, Inc.	IWOV	0.5	318
Macromedia, Inc.	MACR	0.1	996
Mercator Software Ltd	MCTR	0.75	70
Merant PLC	MRNT	0.1	23881
Microsoft Corp.	MSFT	0.05	794
Novell, Inc.	NOVL	0.1	1276
OnDisplay, Inc.	ONDS	0.75	32692
Oracle Corp.	ORCL	0.25	334
Progress Software	PRGS	0.5	496
PeopleSoft, Inc.	PSFT	0.1	19
Rogue Wave Software	RWAV	0.25	654
SilverStream Software	SSSW	0.5	5247
SUN	SUNW	0.05	151
Sybase, Inc.	SYBS	0.1	28
Unify Corp.	UNFY	0.1	28
Vignette Corp.	VIGN	0.5	3711
Vitria Technology	VITR	0.5	2832
Webmethods, Inc.	WEBM	1	4708
Xcare.net, Inc.	XCAR	1	173

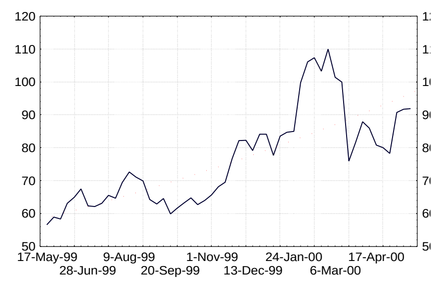

Figure 9. XML: The performance of the tracking portfolio.

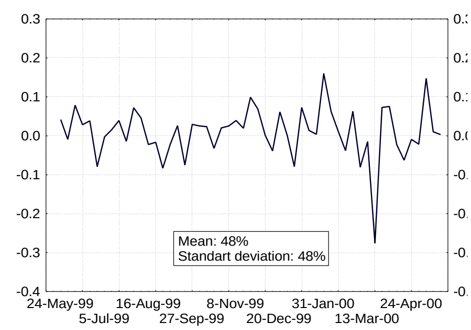

Figure 10. XML: Continuous growth rates of the tracking portfolio.

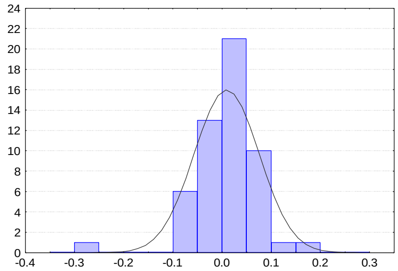

Figure 11. XML: Probability histogram of growth rates.

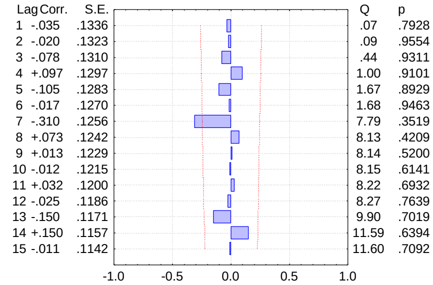

Figure 13. XML: Autocorrelogram for growth rates

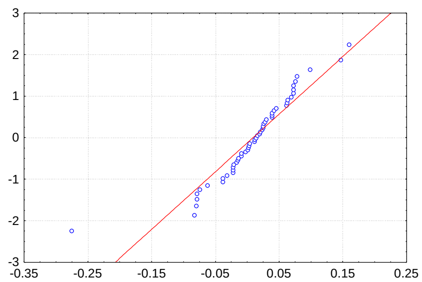

Figure 12. XML: Normal probability plot of growth rates.

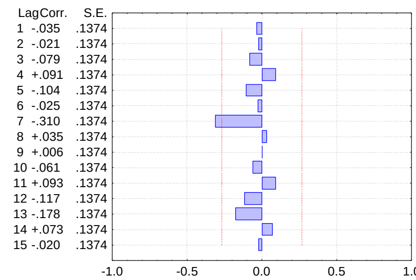

Figure 14. XML: Partial autocorrelogram for growth rates.

7. CONCLUSION

Software development is rich in strategic opportunities, but it is subject to multiple sources and high levels of uncertainty. Since development costs are irrecoverable, it is important to manage the risks.

Software projects can be structured better and development decisions can be taken in a more rigorous manner when the value-generating potential of managed uncertainty is recognized. In addition, the explicit identification and optimal management of the alternatives help rationalize the *gut-feel* of value that is otherwise intangible.

The real options approach not only provides a framework with which to address these considerations, but also allows decision makers to make the elusive connection with the financial markets. Indeed, software development involves many types of real options, including growth, flexibility, reuse, timing, exit, platform, and learning options [12, 14, 20]. With the proliferation of related securities, the financial markets are becoming increasingly useful sources of information to assess and estimate the various types of technological uncertainty that generate these potentially valuable options.

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