Real Options in Information Systems – a Revised Framework

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ABSTRACT

We propose a new performance metric by which to evaluate capital budgeting proposals. Our metric is derived from a decision theoretic view of the firm’s problem in deciding whether to invest in a risky project. Our approach contrasts considerably from the Black-Scholes method, specifically by not making the same assumptions regarding the properties of the underlying asset on which the option may be exercised, such as its tradability in a public financial market. By not making these stringent assumptions, we allow for greater flexibility and accuracy in calculating the business value of a real option. In numerical exercises, we show that, on average, the Black-Scholes model overestimates the option value by more than 10 times. Furthermore, our model is robust to distributional assumptions about the returns on underlying assets, suggesting that the consequences of choosing an incorrect distribution are not severe.

Keywords: real options; capital budgeting.
1. Introduction

Option theory is commonly used to evaluate capital budgeting proposals, in particular when a large component of the project’s business value is derived from a real option. Several studies have attempted to use the real options framework to study information systems projects (Kambil et al., 1993, Benaroch and Kauffman, 1999; Fichman, 2004). Real options confer the right to an entity to enter into a transaction at a specified date in the future by making an upfront small payment (payment is relatively small compared to the value of the transaction). Information systems projects have certain properties such as riskiness and uncertainty which lend them amenable to analysis using the real options framework. Typical examples of real options in IT projects include the following scenarios (Kambil et al., 1993): (i) when investing in one project such as IT infrastructure enables a firm to make a follow-on investment in other projects, (ii) when a firm decides to defer an investment to obtain additional information and reduce risks, (iii) when a firm decides to abandon a project and put the investments to alternate use. However, most prior work evaluates real options using the Black-Scholes model, which has been borrowed from the literature in finance and deals with options traded publicly in financial markets. Whether such a model applies to all kinds of real options is an open question, and in this paper we show that the restrictive assumptions of the Black-Scholes model can indeed result in a significant overvaluation of the true option value in IT projects.

The term ‘real options’ derives its meaning from financial markets where an option refers to a contract which gives an individual the right to buy a security (e.g., stocks or commodities) at a future date and a certain price (Dixit and Pindyck, 1994). The individual pays a certain fee for entering into this contract. If the price of the security on the future date is less than the agreed
upon price, the individual will decide not to buy the security at the agreed upon price (since
 doing so will certainly lead to loss). On the other hand, if the price of the security is higher than
 the agreed price at the future date, the individual will buy the security at the agreed price and
 make a profit. Therefore, the losses of the individual have an upper bound which is the cost of
 buying the option, but the profits do not have any upper bound.

 Several scholars have advocated using the options framework for evaluating managerial
decision making under uncertainty (Dixit and Pindyck, 1994). Real options have been studied in
the context of several strategic decisions of a firm, such as firm capabilities (Kogut and
Kulatilaka, 2001), research and development investments (Weeds, 2000), and marketing
(Haenlein et al., 2006). Benaroch and Kauffman (1999) estimated the value of an IT project
using the real options framework. Fichman (2004) used the real options framework in the case of
innovative IT platforms. Schwartz and Zoyaya-Gorostize (2004) modeled the valuation of two
types of information systems projects – IT acquisition and IT development, by considering the
underlying uncertainties in the underlying costs and benefits over time. Li and Johnson (2002)
used the real options framework to evaluate strategic IT investments in the presence of switching
costs and market competition. Bardhan et al. (2004) used the real options framework to select the
optimal portfolio of projects.

 Prior studies on real options have used traditional financial frameworks such as the
Black-Scholes (B&S) to analyze managerial decisions on when to invest in IT projects. However,
the Black-Scholes model has been designed for financial assets that are traded in a
competitive market and may not apply when the underlying asset is an information technology
(IT) project. For example, the Black-Scholes model makes the following assumptions: (i) The
underlying asset and the options thereon are freely tradable in the market and that no arbitrage opportunities exist. This does not generally hold for IT projects in that a firm cannot ‘sell’ its IT project at any time and recoup its investments, not do markets exist to buy and sell IT project options. (ii) The Black-Scholes model is derived by holding the call option and shorting the underlying asset by the exact amount by which the option is changing value. However, shorting an asset is not very meaningful when the underlying asset is an IT project. (iii) The value of the underlying asset follows a geometric Brownian motion process with drift, which does not hold for IT projects since the asset is not traded.

Since the assumptions of the Black-Scholes model are unlikely to hold for IT projects, it is important to examine whether the B&S model provides close approximations to the true value of the option, or whether its use results in substantial distortions. With this motivation, we propose our research questions as follows: Does the Black-Scholes model provide close approximation for the real option value even though some key assumptions are not valid? Are there systematic patterns of distortion in estimating real option value if the Black-Scholes model is employed?

To analyze this question, we consider a typical scenario involving real options in IT investments – that of a firm deciding to build a prototype before investing in the final IT project. We set up a model for calculating the true option value with the returns on the underlying asset distributed normally and uniformly separately. We also use numerical simulation to calculate the differences in option values estimated by the different models. Finally, we use regression analysis to analyze how the differences in option values are sensitive to changes in underlying parameters. The main result of our paper is that the Black-Scholes model consistently
overestimates the value of a real option compared to the true value over a range of parameter values. We show that, on average, the Black-Scholes model overestimates the option value by more than 10 times. We also show that our proposed model is robust to distributional assumptions about the returns on underlying assets, suggesting that the consequences of choosing an incorrect distribution are not severe. The main contribution of our paper is that we demonstrate that option values, involving specific situations such as IT projects, need to be evaluated carefully and that applying the generic Black-Scholes model may not reflect the true value of the option.

2. Model

We first describe a simple model highlighting a decision to invest in an IT project, as shown in Figure 1. At the start, the firm decides whether to buy an option or not. If the firm does not buy the option, it decides on whether to invest in the project. The decision to invest is made simply if the net expected cash flows are positive, i.e., the benefits from the project exceed the cost of investing in the project.

On the other hand, investing in an option gives the firm the right to invest in the project at a later date. The advantage of this decision postponement is that the firm can obtain additional information in the intervening period, and reduce uncertainty associated with the project. Due to this reduction in uncertainty, the expected cash flows when the firm buys an option are closer to the real cash flows than when the firm does not buy the option. This is akin to getting a signal on the profitability of the project. The firm observes this signal and decides on whether to make investment in the project or not; the decision is again made if the expected benefits from the project are less than the costs.
A special case of real options involving information technology investments is when a firm decides to build a prototype or pilot before investing in the actual project. This is shown in Figure 2. Building a prototype creates a real option because it provides information on whether the project is likely to succeed, by identifying factors such as likelihood of users’ acceptance of the project as well as the risks associated with the project. In other words, a prototype enables IT managers to get feedback and have a better assessment of whether the overall project will be a success. The decision to build a prototype or pilot project incurs a cost, which is the cost of the option, and is a sunk cost. The prototype also generates cash flows, which signal the extent of likely benefits of the final project.
Figure 2: Decision Tree for an IT development project with prototype

If the firm does not build a prototype and invests in the project, the expected return is $\mu_2$. On the other hand, if it builds a prototype, the cash flow generated by the prototype 1 is $y_1$. This signal is drawn from the distribution $F$ having the mean $\mu_1$ and variance $\sigma_1^2$. The cost of producing the prototype is $c_1$. To make the investment decision non-trivial, we assume that the prototype by itself is not profitable.

\[(A1) \quad \mu_1 - c_1 < 0.\]

An advantage of building a prototype is that it provides informative signals on how successful the final IT project (referred to as ‘the project’ in the rest of the discussion) will be, if completed. If the manager gets a high signal from the pilot project, she may decide to invest in the project and incur the full cost of the project. On the other hand, if she gets a low signal from the prototype, she may decide to abandon the project and confine her losses to the cost of the
prototype. Thus building a prototype for a fraction of the cost of the project enables an organization to save millions of dollars if the project did not turn out to be successful.

We denote the signal provided by the prototype as \( \rho y_1 \), where \( \rho > 0 \) represents the extent of correlation between the cash flows generated by the project with the signal generated by the prototype. Therefore, the cash flow generated by the project \( y_2 \), when the firm invests in a prototype, can be decomposed into three components:

\[
(1) \quad y_2 = \mu_2 + \rho y_1 + \varepsilon,
\]

where \( \mu_2 \) is the expected return of the project if the firm does not build a prototype, \( \varepsilon \) is an idiosyncratic shock with mean zero and variance \( \sigma_\varepsilon^2 \). The unconditional mean of \( y_2 \) is \( m = \mu_2 + \rho \mu_1 \). If the prototype is not built, then the project is expected to generate the cash flow \( \mu_2 \). Using the terminology in Benaroch and Kauffman (1999, 2000), we may interpret the unconditional mean \( m \) of \( y_2 \) as the proxy for the (expected) value of the underlying asset associated with the option. The (unconditional) variance \( \sigma_2^2 \) of the cash flow \( y_2 \), provides the measure of the volatility of the underlying asset (Benaroch and Kauffman, 1999, 2000). Thus the variance of the cash flow is expressed as follows based on equation 1:

\[
(2) \quad \sigma_2^2 = \sigma_\varepsilon^2 + \rho^2 \sigma_1^2,
\]

where \( \sigma_\varepsilon^2 \) is the variance idiosyncratic to the project and \( \rho^2 \sigma_1^2 \) is the variance stemming from the volatility of the cash flows generated by the prototype, which serves as a signal for the cash flows generated by the final project.

The cost of investing in the project is \( c_2 \), so this represents the cost of exercising the option (Benaroch and Kauffman, 1999, 2000). In our framework, the call option of pursuing the
project is European (as opposed to American) because it can only be exercised at maturity. Again, to make the investment problem non-trivial, we assume that the project by itself, without building the prototype, is not profitable:

\[ (A2) \mu_2 - c_2 < 0. \]

Conditional on having built the prototype, the firm invests in the project if and only if the expected payoff from doing so, \( \mu_2 + \rho y_1 \), exceeds the cost, \( c_2 \). Therefore, the firm invests in the project if and only if the signal from the prototype 1 is large enough to satisfy

\[ (3) \ y_1 \geq \hat{y}_1 \equiv (c_2 - \mu_2) / \rho. \]

It follows that the likelihood the firm invests in the project (conditional on having built the prototype) is

\[ (4) \ P = 1 - F(\hat{y}_1). \]

In other words, equation (4) describes the probability that the option is exercised, from which we infer the following:

**Lemma 1:** The probability \( P \) that the option is exercised is

- *Increasing in the mean cash flow \( \mu_2 \) generated by the project and the correlation \( \rho \) between the cash flows generated by the project and the prototype;*

- *Decreasing in the cost \( c_2 \) of the project.*

The firm discounts the future at the rate \( r \), and \( T \) periods elapse between the investment in the prototype (which occurs at the beginning of the game) and the project. Hence, we may interpret \( T \) as the time to maturity of the option (Benaroch and Kauffman, 1999, 2000). The Capital Asset Pricing Model (CAPM) is used to infer the firm’s discount rate:
(5) \( r = r_f + \beta (r_m - r_f) \),

where \( r_f \) is the risk-free rate, \( r_m \) is the expected return on the market portfolio, and \( \beta \) is the beta of the firm from the Capital Asset Pricing Model (CAPM).

Contingent on building the prototype, the expected value of the project is

\[
(1 + r)^T \int_{\hat{y}_1}^{\infty} (\mu_2 + \rho y_1 - c_2) dF(y_1).
\]

Contingent on not building the prototype, the expected value of the project is \((1 + r)^{-T} (\mu_2 - c_2)\). In general, the expected value \( \tilde{V} \) of the option is the difference between the two:

\[
(6) \quad \tilde{V} = (1 + r)^{-T} \left\{ \int_{\hat{y}_1}^{\infty} \rho y_1 dF(y_1) - F(\hat{y}_1) (\mu_2 - c_2) \right\}.
\]

The second term reflects in part the cost savings enjoyed by not pursuing the project when it is expected to yield a loss. However, under Assumption (A2), the firm would never pursue the project without having built the prototype, i.e. \( \mu_2 - c_2 < 0 \). Therefore, we have the following:

**Proposition 1:** The expected value of the real option in case of an IT project where the firm develops a prototype before investing in the final project is

\[
(7) \quad V = (1 + r)^{-T} [1 - F(\hat{y}_1)] [\rho E(y_1 | y_1 > \hat{y}_1) - (c_2 - \mu_2)].
\]

Proofs of all propositions and corollaries, unless specified, are shown in the Appendix.

The net cost of building the prototype is \( c_1 - \mu_1 \), which is positive under Assumption (A1) and equals the cost of the option:
Using standard options terminology, we have the following Greeks. The option’s *vega* is how the option’s value varies with the volatility of the underlying asset, $\Lambda = \partial V / \partial \sigma^2$. *Vega* indicates how much the value of the option changes as the volatility of the underlying asset changes. With financial options, *vega* is usually quoted as the change in value for every 1 percent point change in volatility. The option’s *delta* is how the option’s value varies with the value of the underlying asset, $\Delta = \partial V / \partial m$. *Delta* measures the sensitivity of an option’s value to a change in the price of the underlying asset. It is usually normalized so as to represent a number between minus one and one, indicating how much the value of the option changes when the price of the underlying stock rises by one dollar. For financial options, it is particularly useful for investors that do not hold the option until maturity. *Delta* also loosely measures the probability that the option will expire in-the-money (i.e., with the price of the underlying asset exceeding the strike price). Thus, options that are far out-of-the-money (i.e., with the price of the underlying asset significantly below the strike price) have a *delta* of zero, reflecting the belief that there is almost no chance of that option expiring in-the-money. The option’s *xi* is how the option’s value varies with the cost of exercising the option, $\Xi = \partial V / \partial c_z$. The option’s *theta* is how the option’s value varies with the time to maturity, $\Theta = \partial V / \partial T$. *Theta* measures the rate of time decay of an option, i.e. the dollar amount that it loses each day due to the passage of time. Finally, the option’s *rho* is how the option’s value varies with the risk-free rate, $\Phi = \partial V / \partial r_f$, and measures the sensitivity of the option value to the applicable risk free interest rate.

To provide a closed form solution for the option value, we solve for different distributional assumptions separately: first, we assume that the returns of the prototype are
distributed uniformly. Next, we assume that the returns follow a normal distribution. Finally, we
calculate the option value by applying the standard Black-Scholes model.

**Uniform Distribution:** First, suppose instead the signal $y_i$ generated by the prototype is
distributed uniformly over the compact support $[\mu_1 - \sigma_1 \sqrt{3}, \mu_1 + \sigma_1 \sqrt{3}]$, which has the mean $\mu_1$
and variance $\sigma_1^2$. It follows that the variance of the returns on the project is $\sigma_z^2 = \sigma_e^2 + \rho^2 \sigma_1^2$.

**Corollary 1:** Suppose the signal generated by the prototype is distributed uniformly with a mean $\mu_1$ and variance $\sigma_1^2$, then the expected value of the option is

$$V_{\text{Unif}} = \frac{(\mu_z - c_z)(-\hat{y}_1 + \mu_1 + 3^{1/2} \sigma_1) + (\rho / 2)[(\mu_1 + 3^{1/2} \sigma_1)^2 - \hat{y}_1^2]}{(1 + r)^7 (12)^{1/2} \sigma_1}. $$

Further, the option has the following Greeks:

(10.1) The option’s vega $\Lambda = \partial V_{\text{Unif}} / \partial \sigma_z^2$ is positive.

(10.2) The option’s delta $\Delta = \partial V_{\text{Unif}} / \partial m$ is positive.

(10.3) The option’s xi $\Xi = \partial V_{\text{Unif}} / \partial c_z$ is negative.

(10.4) The option’s theta $\Theta = \partial V_{\text{Unif}} / \partial T$ is negative.

(10.5) The option’s rho $\rho = \partial V_{\text{Unif}} / \partial r_f$ is negative.

We infer that the value of the option $V_{\text{Unif}}$ is increasing in the mean signal $\mu_1$ generated by the
prototype, the mean cash flow $\mu_z$ generated by the project, and the correlation $\rho$ between the
cash flow from the project and the signal, implying $V_{\text{Unif}}$ is increasing in $m = \mu_z + \rho \mu_1$ and
$\sigma_z^2 = \sigma_e^2 + \rho^2 \mu_1^2$. We can also show that $V_{\text{Unif}}$ is decreasing in the cost $c_z$ of the project, the
discount rate $r$, and the time $T$ it takes to earn cash flow from the project.
The *vega* is positive implying that an increase in volatility raises the likelihood that the option is exercised along with the upside potential of the option. The *delta* is positive implying that the greater is the expected return on the underlying asset, the higher is the value of having the option to realize the return (by exercising the option). The *xi* is negative implying that the more costly it is to exercise the option, the smaller is the present value of the option. The *theta* is negative implying that the more distant is the time at which the option may be exercised, the smaller is the present value of the option.

**Normal Distribution:** Next, we assume that the cash flows generated by the prototype has a normal distribution with the same mean $\mu_i$ and variance $\sigma_i^2$.

**Corollary 2:** When the signal generated by the prototype is normal with mean $\mu_i$ and variance $\sigma_i^2$, the option value is given as:

$$V_{Normal} = \rho \sigma_i (1 + r)^{-T} \left\{ \left( \frac{\mu_i - \hat{y}_i}{\sigma_i} \right) \left( 1 - \Phi \left( \frac{\hat{y}_i - \mu_i}{\sigma_i} \right) \right) + \phi \left( \frac{\hat{y}_i - \mu_i}{\sigma_i} \right) \right\},$$

where $\Phi$ is the standard normal cdf and $\phi$ is the standard normal pdf. And the option has the following Greeks:

(12.1) The option’s vega $\Lambda = \partial V_{Unif} / \partial \sigma_2^2$ is positive.

(12.2) The option’s delta $\Delta = \partial V_{Unif} / \partial m$ is positive.

(12.3) The option’s xi $\Xi = \partial V_{Unif} / \partial c_2$ is negative.

(12.4) The option’s theta $\Theta = \partial V_{Unif} / \partial T$ is negative.

(12.5) The option’s rho $\rho = \partial V_{Unif} / \partial r_f$ is negative.
Comparing the Greeks in Corollary 1 and 2, we can show that our model has the same Greek properties, irrespective of whether the distribution of the signal is uniform or normal.

**Black-Scholes Model:** Finally, we consider how the real option by building the prototype would be valued if we use the standard Black-Scholes formula to calculate the value of the option. We map the context of an IT project to the standard Black-Scholes as follows: an option is created when a firm invests in a prototype or pilot project before deciding whether to invest in the final project. The underlying asset in consideration is the IT project whose value is the expected return on the project \( m \equiv \mu_2 + \rho \mu_1 \), and the expected variance is \( \sigma_2^2 \). The strike price of the option, in this case, is the cost of exercising the option \( c_2 \), which is the cost that the firm incurs if it decides to invest in the project. Further, \( r_f \) is the risk-free rate, and \( T \) is the time to maturity. Using these parameter values, we can directly apply the Black-Scholes model (Merton, 1973; Black and Scholes, 1973) to calculate the option value.

**Proposition 2:** Suppose an IT project generates cash flows which are distributed with mean \( m \) and variance \( \sigma_2^2 \). Investing in a prototype generates an option whose value from the Black-Scholes model is:

\[
V_{B&S} = mN(d_1) - c_2 e^{-r_f T} N(d_2),
\]

where, \( N \) is the cumulative distribution function of the standard Normal and

\[
dl_1 = \frac{\ln(m/c_2) + (r_f + \sigma_2^2 / 2)T}{\sigma_2 \sqrt{T}}
\]

\[
dl_2 = d_1 - \sigma_2 \sqrt{T}.
\]
**Corollary 2.1:** The option value of building a prototype for an IT project, calculated using the standard Black-Scholes model has the following Greeks:

(15.1) The option’s vega \( \Lambda = \frac{\partial V_{Unif}}{\partial \sigma^2} \) is positive.

(15.2) The option’s delta \( \Delta = \frac{\partial V_{Unif}}{\partial m} \) is positive.

(15.3) The option’s xi \( \Xi = \frac{\partial V_{Unif}}{\partial c_2} \) is negative.

(15.4) The option’s theta \( \Theta = \frac{\partial V_{Unif}}{\partial T} \) is negative.

(15.5) The option’s rho \( \rho = \frac{\partial V_{Unif}}{\partial r_f} \) is positive.

While the vega, delta, xi and theta have the same sign in the Black-Scholes model as in our model, the rho is positive in the Black-Scholes model, whereas it is negative in our model. This intuition is that Black-Scholes model predicts that the value of the option equals its cost in equilibrium (which in turn presumes that the underlying asset is tradable), whereas we do not impose such a constraint. Our rho is negative because the risk-free rate serves akin to a discount factor: the more distant is the potential payoff of exercising the option, the smaller is the present value of the option.

3. Simulation

Next, we compare the option values generated by our model with those of the Black-Scholes model. Since it is analytically intractable to compare the expressions in equations 9, 11, and 2, we use a simulation approach. The objective of the simulation is to examine whether: (i) whether the option value calculated by our model is robust to distributional assumptions, and (ii) there exist any systematic differences between the option value calculated by our model and the option value calculated by the Black-Scholes model. (iii) how sensitive the difference between
option values is to underlying parameters. To conduct the simulation, we assign random values to our independent parameters in the range as mentioned the Table 1 below. Most of these parameter values are chosen based on prior literature (Kauffman and Benaroch, 1999). Values of other parameters such as $\mu_1$, $\mu_2$ and $c_2$ are chosen to cover a broad range of parameter values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
<th>Range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_1$</td>
<td>Mean of returns for the prototype</td>
<td>0.00-2.00</td>
</tr>
<tr>
<td>$\sigma_1$</td>
<td>Standard deviation of returns for the prototype</td>
<td>0.00 – 0.50</td>
</tr>
<tr>
<td>$\mu_2$</td>
<td>Expected returns of the project in the absence of the prototype</td>
<td>2.00-6.00</td>
</tr>
<tr>
<td>$\sigma_e$</td>
<td>Standard deviation of the idiosyncratic shock for the project</td>
<td>0.00-0.50</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Extent of correlation between returns for the prototype and the project</td>
<td>0.50-1.00</td>
</tr>
<tr>
<td>$c_2$</td>
<td>Cost of investing in the project</td>
<td>3.00-6.50</td>
</tr>
<tr>
<td>$T$</td>
<td>Time frame</td>
<td>0.50-5.00</td>
</tr>
<tr>
<td>$r_f$</td>
<td>Market returns</td>
<td>0.05-0.20</td>
</tr>
<tr>
<td>$r_m$</td>
<td>Risk free returns</td>
<td>0.00-0.08</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Stock beta</td>
<td>0.00-2.00</td>
</tr>
</tbody>
</table>

**Table 1: Parameters Summary**

We generate 5,000 observations based on randomly selected values of the above parameters, subject to the following assumptions made in our model (i) the cost of the project is greater than the return in the absence of the prototype, i.e., $\mu_2 < c_2$ - i.e, assumption A2 holds. (ii) $\gamma_1$ in equation 3 is less than the upper limit of the normal distribution – otherwise, this would yield an option value of 0 in the uniform distribution case, i.e. if $\mu_1 + 3^{1/2} \sigma_1 < \mu_2 + \rho \cdot \mu_1$ (iii) the market return is greater than the risk free rate of return, i.e., if $r_m > r_f$

The results of the simulations are as follows: Table 2 shows the Pearson and Spearman correlations between the different options values – the Pearson correlations are on the upper
diagonal, and the Spearman correlations are on the lower diagonal. In the tables below, $V_{\text{Normal}}$, and $V_{\text{Unif}}$ denote the option value as calculated by our model assuming the normal and uniform distribution respectively (equations 11 and 9). $V_{\text{B&S}}$ denotes the option value calculated using the Black-Scholes model (equation 12). It is clear that the option values calculated using our model are very highly correlated, whereas the option values calculated using the Black-Scholes model have a low correlation with the values calculated using our model.

<table>
<thead>
<tr>
<th></th>
<th>$V_{\text{Normal}}$</th>
<th>$V_{\text{Unif}}$</th>
<th>$V_{\text{B&amp;S}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{Normal}}$</td>
<td>1.00</td>
<td>0.81</td>
<td>0.33</td>
</tr>
<tr>
<td>$V_{\text{Unif}}$</td>
<td>0.99</td>
<td>1.00</td>
<td>0.22</td>
</tr>
<tr>
<td>$V_{\text{B&amp;S}}$</td>
<td>0.34</td>
<td>0.34</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Table 2: Pearson and Spearman correlations of option values**

The Spearman correlation between $V_{\text{Normal}}$ and $V_{\text{Unif}}$ is higher than the Pearson correlation; this implies that the relation between the two is highly monotonic, even though it may not be perfectly linear. This is shown in the scatterplot in Figure A1 in the Appendix. The scatterplot between $V_{\text{Normal}}$ and $V_{\text{B&S}}$ is shown in Figure A2 in the Appendix. From the scatterplots, it is clear that $V_{\text{Normal}}$ and $V_{\text{Unif}}$ are concentrated around the 45° line implying that these values are close to each other. On the other hand, the scatterplot in Figure A2 is clearly above the 45° line, implying that $V_{\text{B&S}}$ is higher than $V_{\text{Normal}}$.

To further explore the relation between the option values, we present the descriptive statistics in Table 3. It is evident that the option values calculated using our model are similar when either normal or uniform distribution is assumed. The mean, median and the quartiles of $V_{\text{Normal}}$ and $V_{\text{Unif}}$ are very close to each other, implying that our model is robust to distributional assumptions. On the other hand, the option values using the Black-Scholes model are
significantly higher than those of our model. We perform a matched pair t-test on the difference between the means $V_{B&S} - V_{Normal}$ and $V_{B&S} - V_{Unif}$; and find that both are positive and significant at the $p<0.01$ level. Likewise, the matched pair test for medians confirms that the median of the option value calculated using the B&S model is significantly higher than those of our model. The intuition behind the results is as follows: the Black-Scholes formula overvalues options because it assumes that one can construct a synthetic option using the underlying asset. In other words, it presumes the underlying asset can be shorted, which is not a reasonable assumption for IT assets. Because our formula does not allow for this possibility, the value of the option is diminished.

<table>
<thead>
<tr>
<th></th>
<th>Quartile 1</th>
<th>Median</th>
<th>Quartile 3</th>
<th>Mean</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{Normal}$</td>
<td>0.06</td>
<td>0.24</td>
<td>0.53</td>
<td>0.33</td>
<td>0.32</td>
</tr>
<tr>
<td>$V_{Unif}$</td>
<td>0.07</td>
<td>0.25</td>
<td>0.55</td>
<td>0.38</td>
<td>0.49</td>
</tr>
<tr>
<td>$V_{B&amp;S}$</td>
<td>1.61</td>
<td>2.12</td>
<td>2.73</td>
<td>2.20</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Table 3: Mean and standard deviation of Black-Scholes real option value compared with true value when cash flows are distributed normally and uniformly.

To highlight the difference in the option values between our model and the Black-Scholes, we plot the density functions of the log of ratios in Figure 3. The solid curve represents $\ln(V_{B&S}/ V_{Normal})$, the dashed curve represents $\ln(V_{B&S}/ V_{Unif})$, and the dotted curve represents $\ln(V_{Normal}/ V_{Unif})$. Our simulation results show that $\ln(V_{B&S}/ V_{Normal})$ is greater than zero in 100% cases and $\ln(V_{Normal}/ V_{Unif})$ is greater than zero in 99.5% cases. This is also evident in the diagrams in Figure 3.
To further highlight the overestimation of the Black-Scholes model over our model, we show the descriptive statistics of the log of the ratio of option values in Table 4. The mean of
\( \ln(V_{B&S}/V_{Normal}) \) is 2.5, which suggests that the Black-Scholes model, on average, overestimates the true value (with normal distribution) by more than 10 times \( (e^{2.5} = 12.1) \).

<table>
<thead>
<tr>
<th></th>
<th>Quartile 1</th>
<th>Median</th>
<th>Quartile 2</th>
<th>Mean</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \ln(V_{B&amp;S}/V_{Normal}) )</td>
<td>1.44</td>
<td>2.15</td>
<td>3.32</td>
<td>2.50</td>
<td>1.37</td>
</tr>
<tr>
<td>( \ln(V_{B&amp;S}/V_{Unif}) )</td>
<td>1.38</td>
<td>2.12</td>
<td>3.25</td>
<td>2.58</td>
<td>1.81</td>
</tr>
<tr>
<td>( \ln(V_{Normal}/V_{Unif}) )</td>
<td>-0.08</td>
<td>-0.02</td>
<td>0.01</td>
<td>0.08</td>
<td>0.67</td>
</tr>
</tbody>
</table>

**Table 4: Ratio of log of means**

Finally, to highlight how the overestimation of the Black-Scholes model is influenced by the model parameters, we run a OLS regression with the following model

\[
Y = \alpha_0 + \alpha_1 \cdot \mu_1 + \alpha_2 \cdot \sigma_1 + \alpha_3 \cdot \mu_2 + \alpha_4 \cdot \sigma_2 + \alpha_5 \cdot \rho + \alpha_7 \cdot T + \alpha_8 \cdot r_f + \alpha_9 \cdot r_m + \alpha_{10} \cdot \beta
\]

where the dependent variable \( Y \) is \( \ln(V_{B&S}/V_{Normal}) \), \( \ln(V_{B&S}/V_{Unif}) \) or \( \ln(V_{Normal}/V_{Unif}) \) in columns 1, 2 and 3 respectively of Table 5. The independent values are the model parameters as defined in Table 1. Regression analysis is a common technique to check the sensitivity of values generated by the simulation to the parameter values (Banker, Gadh, Gorr 1993). The results of the regression are shown Table 5 below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( \ln(V_{B&amp;S}/V_{Normal}) )</th>
<th>( \ln(V_{B&amp;S}/V_{Unif}) )</th>
<th>( \ln(V_{Normal}/V_{Unif}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.49***</td>
<td>2.58***</td>
<td>0.08***</td>
</tr>
<tr>
<td>( \mu_1 )</td>
<td>-1.32***</td>
<td>-1.60***</td>
<td>-0.28***</td>
</tr>
<tr>
<td>( \sigma_1 )</td>
<td>-0.54***</td>
<td>-0.27***</td>
<td>0.27***</td>
</tr>
<tr>
<td>( \mu_2 )</td>
<td>-2.06***</td>
<td>-2.58***</td>
<td>-0.52***</td>
</tr>
<tr>
<td>( \sigma_x )</td>
<td>-3.17***</td>
<td>-3.68***</td>
<td>-0.50***</td>
</tr>
<tr>
<td>( \rho )</td>
<td>1.05***</td>
<td>1.10***</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>$c_2$</td>
<td>$T$</td>
<td>$r_f$</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td>2.26***</td>
<td>0.31***</td>
<td>2.11***</td>
</tr>
<tr>
<td></td>
<td>2.80***</td>
<td>0.30***</td>
<td>2.74***</td>
</tr>
<tr>
<td></td>
<td>0.54***</td>
<td>-0.01</td>
<td>0.63*</td>
</tr>
</tbody>
</table>

Table 5: Regression Analysis

We find that the extent of overestimation of the Black-Scholes model is positively correlated with the cost of exercising the option, the correlation between the prototype and the project value, the time elapsed between the prototype and the project, the risk free and market returns, and the stock beta. On the other hand, the overestimation is negatively correlated with the means and standard deviations of the prototype and the projects.

4. Conclusions and Discussion

Option theory is being increasingly used in a variety of situation involving non-financial assets. However, the Black-Scholes model, which is historically derived from financial markets, is commonly used to value all types of options. In this paper, we highlight the limitations of such an approach by proposing an alternate model to value the options in a specific scenario involving IT projects where the firm decides to build a prototype before investing in the project. We use numerical simulation to compare the option values generated by our model with those generated by the Black-Scholes model. The main results of the paper are as follows: we find that, compared to our model, the Black-Scholes model consistently overestimates option value by more than 10
times. We further show that the extent of overestimation is positively correlated with the cost of exercising the option, the correlation between the prototype and the project value, the time elapsed between the prototype and the project, the risk free and market returns, and the stock beta. On the other hand, the overestimation is negatively correlated with the means and standard deviations of the prototype and the projects. We test our model under different distributional assumptions and find that the results are robust, implying that making incorrect distributional assumptions does not change the option value calculated in our model.

The main contribution of this paper is that we highlight the limitations of applying the Black-Scholes model in situations involving real options. Our results show that substantial distortions can be created in the option values if managers blindly apply the Black-Scholes model, instead of understanding the structure of the underlying problem. This is mainly due to the fact that while the Black-Scholes model is derived in the context of financial instruments, the dynamics of option creation are different in different situations, and no ‘one-size-fits’ approach can be used. Our model calculates the option value in a specific situation without making any arbitrary assumptions.

The strength of our approach is that our model is robust to assumptions regarding the underlying distributions. We show that the correlations between the option value calculated under the normal and uniform distributions are very high, and the mean, median, and the quartile values are very close.

A limitation of our paper is that we consider a particular type of option in IT projects – when an option is created due to investment in a prototype. It is conceivable that the analysis for other option types such as abandonment or deferral option (Kambil et al, 1993) may be different.
However, the underlying rationale about the lack of suitability of the Black-Scholes assumptions for IT projects is still likely to hold. Moreover, we can extend the model to other situations involving real options, with minor modifications. For example, we can extend this model to the case of new technology development where a firm launches a version of a product, and decides to launch more enhanced versions of the product at a later date depending on the how well the first version of the product is accepted.
References


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• Kogut B and N Kulatilaka (2001) 'Capabilities as Real Options' Organization Science, 12(6), pp. 744-758


Solving the decision tree in Figure 2

The decision tree can be analyzed as follows: a firm decides whether to build a prototype or not before investing in the project. If the firm does not build a prototype and invests in the project, it expects a payoff of $\mu_2$ from the project. The cost of investing in the project is $c_2$. Therefore, by cash flows from the investing in the project without investing in the prototype is $\mu_2 - c_2$. The cash flows for not investing in the project and not building a prototype is 0. As per our assumption that the project is not profitable if the firm does not invest in the prototype (Assumption A2), the optimal decision at this stage is not to invest in the project. Therefore, not building a prototype yields a payoff of 0.

If the firm decides to build a prototype, it incurs a cost of $\mu_1 - c_1$, where $\mu_1$ is the signal generated by the prototype and $c_1$ is the cost of building the prototype. Investing in the prototype also creates an option of investing in the full project at a later date. The signal generated by the prototype also conveys the attractiveness of the final project, so that the return on the final project if the prototype is built is $\mu_2 + \rho \cdot \mu_1 - c_2$, where $\rho$ is the extent of correlation between the signal generated by the prototype with the returns of the second stage, and $c_2$ is the cost of investing in the project. Therefore, the expected cash flows generated by the project is $\mu_2 + \rho \cdot \mu_1 - c_2$, and the expected cash flows of not building a project is 0. Therefore, the firm invests in the project is $\mu_2 + \rho \cdot \mu_1 - c_2 > 0$. 
Investing in the prototype costs $c_1 - \mu_1$, and give the firm an option (of value $V$) of investing in the project. Therefore, the firm invests in the prototype if $c_1 - \mu_1 < V$. $V$ is the value of the option and is calculated through equation (9) or (11).

Scatterplot of $V_{\text{Normal}}$ on the X-axis and $V_{\text{Unif}}$ on the Y-axis. The straight line depicts the 45 degree line.

Figure A1: Scatterplot of $V_{\text{Normal}}$ on the X-axis and $V_{\text{Unif}}$ on the Y-axis.
Scatterplot of $V_{Normal}$ on the X-axis and $V_{B&S}$ on the Y-axis. The straight line depicts the 45 degree line.

Figure A2: Scatterplot of $V_{Normal}$ on the X-axis and $V_{B&S}$ on the Y-axis.