Valuation of Information Technology Investments as Real Options

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Abstract. This article describes a methodology for evaluating information technology investments using the real options approach. IT investment projects are categorized into development and acquisition projects depending upon the time it takes to start benefiting from the IT asset once the decision to invest has been taken. A couple of models that account for uncertainty both in the costs and benefits associated with the investment opportunity are proposed for these project types. Our stochastic cost function for IT development projects incorporates the technical and input cost uncertainties of Pindyck's model (1993) but also considers the fact that the investment costs of some IT projects might change even if no investment takes place. In contrast to other models in the real options literature in which benefits are summarized in the underlying asset value, our model for IT acquisition projects represents these benefits as a stream of stochastic cash flows.

1 Introduction

Investments in IT have experienced an unprecedented growth in the last two decades. On average, the world IT market (hardware, software and computer services) grew at an annual rate of 10 percent between 1987 and 1995, nearly twice that of world GDP (OECD 1997). Some

authors have argued, however, that a considerable proportion of IT projects are undertaken without a proper analysis of the associated investments (Benaroch and Kauffman 1999). Traditional tools for project evaluation, like the IRR or the NPV, are inadequate for coping with the high uncertainty that characterizes most IT projects (McGrath 1997).

In this article, investments in IT are analyzed using the real options approach (Amram and Kulatilaka 1999, Luehrman 1998). In contrast with the traditional NPV method, this approach recognizes the ability of managers to delay, suspend or abandon a project once it has started. This approach helps to structure the project as a sequence of managerial decisions over time, clarifies the role of uncertainty in project evaluation and allows us to apply models that have been developed for valuing financial options to project investments (Bodie and Merton 1999). As discussed by Lucas (1999, Chap. 10), IT investments having a high upside potential, high uncertainty and indirect returns are good candidates for being evaluated with an options framework.

Project evaluation using real options has been a subject of much research during the last fifteen years (Dixit and Pindyck 1994, Ingersoll and Ross 1992, McDonald and Siegel 1986, Brennan and Schwartz 1985). However, most research related to the valuation of information technology (IT) investment projects as real options has been limited to the application of the Black-Scholes (B&S) formula (1973) by assuming that the cost of the project is known with certainty. For example, Benaroch and Kauffman (1999, 2000) use a Black-Scholes approximation for valuing a project involving the deployment of point-of-sale debit services in an electronic banking network. In their article, the investment opportunity is modeled as a pseudo-American call option that pays dividends, and the value of the underlying asset on a particular period is computed by subtracting the present value of the cash flows foregone during waiting from the present value of

the project cash flows at time zero. Panayi and Trigerogis (1998) use real options pricing for evaluating an IT infrastructure project for the state telecommunications authority of Cyprus that had two stages: an initial one in which the organization developed the information systems needed for its future operation, and a second stage in which it proceeded to expand its network. The value of the project includes the value of the growth option for the second stage which is computed as a European call option maturing at the year in which network expansion was scheduled. Other researchers have analyzed IT investment projects using Magrabe's formula (Margrabe 1978) for valuating the exchange of one risky asset for another. In this approach, the investment opportunity is modeled as an option to exchange an uncertain cash flow of costs for another uncertain cash flow of benefits. Kumar (1996, 1999) use this formula to quantify the value provided by decision support systems in several decision scenarios such as commodity trading and marketing, and compared the results with those obtained by a direct application of BS. Finally, Taudes et. al. (2000) used B&S in a real-life case study concerned whether to continue using the software platform SAP R/2 or switching to its newer release SAP R/3.

The direct application of B&S to an IT investment project involves an important simplification of reality. On one hand, the B&S formula applies only to European type options, whereas real investments are typical American type because there is not a fixed maturity date and a project manager has discretion as to when the exercise the option to invest. Moreover, most projects involve compound options that allow temporary suspension of the investment. Finally, B&S assumes that there is a tradeable underlying asset whereas the underlying state variables of investment projects are typically not traded (e.g., cost, cash flows, etc.).

In this paper we extend previous research on the evaluation of IT investment projects as real options by jointly modeling the uncertainty in project costs and project cash flows, as well as the

change in the cost of an IT asset over time. In contrast with other models for the valuation of investment projects under uncertainty, our valuation models are applicable to projects in which the completion costs are expected to change according a particular trend regardless of whether investment takes place. An example of such a project could be the acquisition of an IT asset (e.g., hardware) whose price decreases rapidly over time. However, other types of IT investment projects could also exhibit a trend in completion costs derived by external or internal factors. For example, if the demand in the market for certain technical skills is predicted to increase during the course of the project, this might cause the development costs to rise accordingly.

The approach described is based in the framework developed by Schwartz and Moon (2000) in which the uncertainties of an R&D project are summarized by three stochastic processes related to the investment cost, the future payoffs and the possibility that a catastrophic event may occur before the project is completed. However, IT investment projects are categorized into development and acquisition projects depending upon the time it takes to start benefiting from the IT asset once the decision to invest has been taken (see Figure 1):

- In an *IT acquisition* project, the organization has the option of spending an amount of money (K) to acquire an IT asset. At any point of time (t) during an interval T, K is known with certainty; however, future changes in K are uncertain. After the asset is acquired, the organization starts receiving a set of cash flows (C) representing the differential benefits derived from acquiring the IT asset. Given that both the cost and the benefits are uncertain, it might be better to wait before making the investment. Furthermore, if the cost of a particular IT asset decays over time, there is an additional incentive for waiting before acquiring the asset. However, benefits also decrease with time because waiting will reduce the length of period in which the organization will be able to receive the cash flows associated with the

investment. Therefore, both elements have to be taken into consideration for making an optimal decision.

- In an *IT development* project, the asset is not acquired instantaneously; rather, it is the result of a development project having an uncertain duration (τ) in which the firm keeps investing at a rate that is less than or equal to a maximum investment rate (Im). Only until the project is completed and the remaining cost (K) is zero, the firm receives the underlying asset (V).

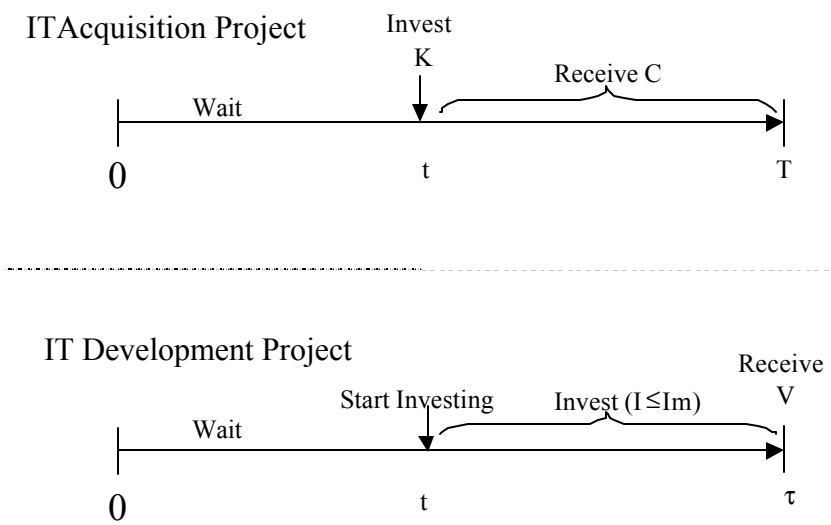

Figure 1: Two types of IT Investment Projects

Both models are complementary and can be considered as particular cases of the generic IT investment project shown in Figure 2. In this project, the firm invests an initial amount (K) to acquire an IT asset but has to keep investing during a period of uncertain duration (τ_2) until the project is complete in order to receive the underlying asset (V). Also, after some period of uncertain length (τ_1), the organization starts receiving a set of cash flows (C) representing the differential benefits derived from acquiring and developing the IT asset. As times moves forward, the values of V, C and K change stochastically.

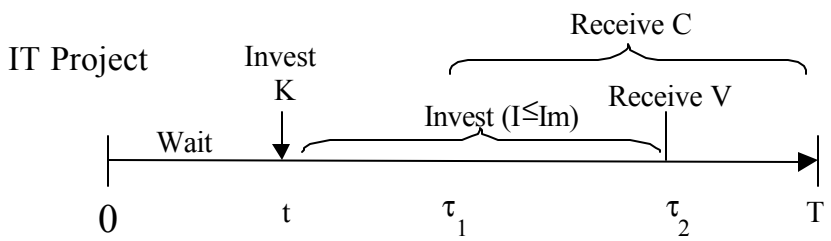

Figure 2: Generic IT Investment Project

To develop a model for the generic IT investment project is not trivial because the time in which cash flows start to be received is also a random variable. However, if we assume a deterministic time to start receiving the cash flows, we can easily adapt the acquisition model for this purpose (as shown in Section 4). In addition, most investments in IT infrastructure can be evaluated using the first model by considering that the time required for acquiring the asset is short in comparison to the overall life of the technology. This is generally the case of those assets that are purchased form suppliers. On the other hand, a software development project taking a considerable amount of time might be better represented using the second model, since the benefits of this technology are not obtained until the project is completely finished.

The stochastic cost function used in the model for *IT development* projects is an extension of Pindyck's (1993) in order to account, for instance, for the rapid decrease in the costs of some IT assets. As a result, the positive effect that learning has in solving for technical uncertainty competes with the attractiveness to wait for cost to be lower.

Finally, in the *IT acquisition model* the benefits of the project are directly modeled as a stream of future differential cash flows. Representing the stochastic evolution of these cash flows might be more intuitive and powerful than tracking the changes of an underlying asset as other real options models do. With this representation, for instance, we can model the situation in which cash flows are received only over a period of time in which the technology is useful (as we did in the *IT acquisition* model).

In summary, the main contributions of this article are: a) the development of more sophisticated contingent claim models to value IT investments relative to those that have been used in the existing literature; b) the categorization of IT investment into IT development and IT acquisition projects depending upon their particular characteristics; c) the inclusion of a drift in the stochastic process describing the evolution of the estimated cost to completion which allows for systematic increases or decreases in costs over time; d) the incorporation of a stochastic process describing the evolution of the incremental cash flows as a more fundamental variable rather than modeling the evolution of the underlying value of the project; and e) the application of the proposed models to provide insights about the effect of key parameters in the value of the investment options. These contributions, however, are not limited to IT investments since the basic framework developed in the paper can also be applied to other type of high uncertainty investments in which flexibility plays a major role.

The next section presents the proposed valuation model for IT projects in which the IT asset (e.g., a software package) takes time and money to develop. Section 3 describes the proposed valuation model for IT acquisition projects. Section 4 demonstrates the application of our models for the valuation of a real world example involving the deployment of point-of-sale debit services by a banking network. Finally, Section 5 discusses some possible extensions to the proposed models and provides some conclusions of our work.

2 Valuation Model for IT Development Projects

In IT development projects investment takes time. The decision maker has an estimate of the remaining cost to completion of the project assuming that investment could be done instantaneously (K) and of the value of the asset received on successful completion of the project

(V). In our model investment in the project proceeds unless a catastrophic event[1] causes the project to be permanently abandoned, or the expected value of the underlying asset drops below a critical value V*(K) and the project is temporarily suspended. The decision maker has to monitor the stochastic changes in K and V to determine the proper course of action.

2.1 Cost Uncertainty

The estimated remaining cost to completion of the project assuming that investment could be done instantaneously K(t) follows a controlled diffusion process given by the following expression:

$$\mathrm{d}K = -I\ \mathrm{d}t + \delta K \mathrm{d}t + \beta(IK)^{1/2}\, dz + \gamma K \mathrm{d}w \tag{1}$$

where dz and dw are increments of uncorrelated Wiener processes. The first term in Equation (1) is the control of the diffusion process: as investment proceeds the estimated remaining cost to completion decreases. The second term describes the change in cost experienced by some IT assets over time[2]. The third term corresponds to what Pindyck calls *technical uncertainty* which is related to the physical difficulty of completing the project (even if all the input costs were deterministically known) and therefore can only resolved by investing in the project. The last

[1] A catastrophic event refers to any event that kills the project and which is unrelated to its cost or benefits. For example, the death or departure of a key employee, a high-level decision to stop investment or a technological failure that makes it impossible to continue forward.

[2] Parameter δ will depend upon the type of IT asset being considered. For example, the cost of microprocessors has dropped exponentially over time; every 18 months, the price of some microprocessor has reduced in half. Therefore, this product would have a value of $\delta = -\ln(2)/1.5 = -0.46$.

term refers to uncertainty about *input costs* (e.g., prices of labor and materials) that are external to what the firm does and might be partially correlated with the overall economic activity.

2.2 Asset Value Uncertainty

The estimated value of the asset that the firm receives upon successful completion of the project follows the stochastic process:

$$\mathrm{d}V = \grave{\imath}_{V} V \mathrm{d}t + \acute{o}\, V dy \tag{2}$$

where □ is the instant standard deviation of the proportional changes in V, □$_V$ is a *drift* parameter reflecting changes in the value as time proceeds, and *dy* is an increment to a Gauss-Wiener process that is uncorrelated with the technical uncertainty in expected costs but that may be correlated with overall economic activity.

We allow the stochastic changes in the asset value to be correlated with the stochastic changes in the input cost to completion:

$$\mathrm{dw}\,\mathrm{dy} = \rho_{VK}\ \mathrm{dt} \tag{3}$$

A negative ρ_{VK} could represent, for instance, that the inability to control the costs of the development project are associated with lower benefits after the project is completed.

2.3 Value of the Investment Opportunity

Let F(V,K) be the value of the investment opportunity. Since V and K are not traded assets, but represent the expected values of a pair of random variables, they have risk premiums associated with them (η_V and η_K respectively). We apply Ito's Lemma to obtain the following expression for the differential d*F*:

$$dF = \frac{\partial F}{\partial V} dV + \frac{\partial F}{\partial K} dK + \frac{1}{2}\frac{\partial^2 F}{\partial V^2} dV^2 + \frac{1}{2}\frac{\partial^2 F}{\partial K^2} dK^2 + \frac{1}{2}\frac{\partial^2 F}{\partial V \partial K} dV dK \tag{4}$$

Substituting this formula and Equations (1), (2) and (3) into the corresponding Bellman equation of optimality, the following second order elliptic differential equation is obtained for F(V,K) (subscripts to denote partial derivatives):

$$\underset{I}{\text{Max}} \begin{bmatrix} \frac{1}{2}\sigma^2 V^2 F_{VV} + \frac{1}{2}\beta^2 IK F_{KK} + \frac{1}{2}\tilde{\alpha}^2 K^2 F_{KK} + \tilde{\rho}_{VK}\sigma\tilde{\alpha} VKF_{VK} + \left(\mu_V - \varsigma_V\right) V F_V \\ -\left(I - \delta K - \varsigma_K\right) F_K - (r_f + \lambda) F - I = 0 \end{bmatrix} \tag{5}$$

Equation (5) is a linear function of I. Therefore, the optimal investment policy is a bang-bang solution, that is, investment will be either 0 or the maximum investment rate (I_m) depending on whether the slope of the corresponding line is positive or negative:

$$I = \begin{cases} I_m & \text{if } \frac{1}{2}\beta^2 KF_{KK} - F_K - 1 \geq 0 \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

As a result, Equation (5) has a free boundary along the curve of critical asset values V*(K) such that I=Im when the asset value is greater than V*(K) and 0 otherwise.

Equation (5) is subject to the following boundary conditions:

$$F(V,0) = V \tag{7}$$

$$F(0,K) = 0 \tag{8}$$

$$\lim_{K \to \infty} F(V,K) = 0 \tag{9}$$

Equation (7) indicates that when the project is completed (K=0) we obtain the underlying asset V. Equation (8) describes the fact that, regardless the remaining cost, whenever the asset value drops to zero the value of the investment opportunity is zero, since zero is an absorbing boundary

for V. Finally, equation (9) indicates that when the remaining costs are very large the value of waiting decreases asymptotically to zero.

2.4 Traditional NPV Criteria and Option Value

The Net Present Value of the project, NPV(V,K) is obtained by subtracting the expected discounted present value of the costs K_{PV} from the expected discounted value of the benefits V_{PV}:

$$NPV(V,K) = V_{PV} - K_{PV} \tag{10}$$

In the NPV approach it is implicitly assumed that once investment starts it will be carried to completion. The duration of the project D for the purpose of computing the NPV method can then be obtained from Equation (1) by setting K=0 when the project is completed and assuming that there is no uncertainty ($\beta=\gamma=0$):

$$D = \frac{1}{\delta}\ln\left(1 - \delta\frac{K}{I_m}\right) \tag{11}$$

However, to take into account the risk premium in the cost process, we need to adjust D by subtracting η_K from I_m in the computation of the risk adjusted duration:

$$D^* = \frac{1}{\delta}\ln\left(1 - \delta\frac{K}{I_m - \eta_K}\right) \tag{12}$$

Once the decision to invest has been taken, the value of the asset at the end of the project V(D*) assuming no uncertainty ($\sigma=0$) is obtained from the current value of the asset at time t=0 using the following expression:

$$V(D^*) = V(0)\, e^{m_V D^*} \tag{13}$$

Since a catastrophic event might cause the permanent interruption of the project, λ can be interpreted as a 'tax rate' on the value of the project (Brennan and Schwartz 1985). Therefore, the risk-adjusted discount rate for V(D*) is ($r_f + \lambda + \eta_V$), where η_V is the risk-premium associated with the asset value process. Then, the present value of the asset value is given by:

$$V_{PV} = V(0)\, e^{-(r_f + l + h_V - m_V)D^*} \tag{14}$$

The expected discounted value of the costs, K_{PV} is obtained by discounting the flow of investments $I(t)=I_m$ during the duration of the project:

$$K_{PV} = E_o \left[\int_0^{D^*} I_m e^{-(r_f + \lambda)} \mathrm{d}t \right] = \frac{I_m}{r_f + \lambda} \left[1 - e^{-(r_f + \lambda) D^*} \right] \tag{15}$$

Note that the same result for the NPV of the project can be obtained directly by solving Equation (5) with all the volatility terms in the equation equal to zero and the control I at the maximum rate I_m.

The difference between the value of the investment opportunity F(V,K) and NPV(V,K), which is always positive, gives the value of the *option* that the organization has for *waiting* before investing in the IT asset and the value of the option to *stop and restart* investing if conditions change. Table 1 shows the different situations that may be encountered in an IT development project. Whenever V<V*(K), the optimal decision is to wait (if possible) before proceeding with the acquisition of the IT asset, *even* if the NPV rule would recommend to acquire the IT asset immediately (NPV(V,K) > 0). Conversely, when NPV is negative, the firm can wait for the costs to decrease or for the expected value of the asset to increase so that NPV becomes positive.

Table 1. Optimal Decisions for IT Development Projects under Uncertainty

Net Present Value	*Asset Value*	*Value of Waiting*	*Optimal Decision*
NPV(V,K) > 0	V<V*(K)	+	Wait (if possible) or invest (if waiting is not allowed)
	V>V*(K)	0	Invest at rate $I=I_m$
NPV(V,K) ≤ 0	V<V*(K)	+	Wait (if possible) or abandon (if waiting is not allowed)

2.5 Example of an IT Development Project

Suppose that an organization is evaluating whether to invest in the development of a new software package. Once it is completed, the software may be sold or licensed to third parties (e.g., if the organization is a software development company), or used for its own internal purposes for improving the productivity of its own operations. In any case, the organization is uncertain about the value it might receive from selling or using the package. The engineering and marketing departments expect the overall costs of the project to be less than 10 million and the overall benefits to be less than 30 million. However, both variables change stochastically over time. Using the parameters shown in Table 2, we will apply our valuation model to determine when should the company start investing in the project and contrast these results with the conventional NPV criteria.

Table 2. Parameters for the Example IT Development Project (Base Case)

Cost Parameters			*Asset Value Parameters*		
Range of Costs	0 to 10 million		Range of Asset Values	0 to 30 million	
Technical Uncertainty	β	0.5	Drift in Asset Value	μ_V	0.01
Input Costs Uncertainty	γ	0.05	Asset Value Uncertainty	σ	0.35
Rate of Cost Change	δ	-0.3	Risk premium on Asset Value	η_V	0.08
Adjustment for Risk in Costs	η_K	0	*Other Parameters*		
Maximum Investment per year	I_m	5 million	Risk-free rate	r_f	0.06
Correlation between K and V	ρ_{KV}	-0.1	Catastrophe Probability rate	λ	0.1

We solved the second order elliptic equation of the model (Equation (5)) using an iterative procedure known as *successive over relaxation* (Press, Teukolsky 1992, p. 854). Figure 3 shows the impact of the different types of uncertainties in the computation of the critical asset values V*(K) that are needed to make the investment immediately. When uncertainties are considered, higher critical asset values are required in order to start the project in comparison to those determined using the conventional NPV criteria. In other words, the project should be "deep in the money" before committing resources. Note also that the critical asset values of the base case are lower than those obtained when only uncertainty in the asset value is considered (β=0) and higher than those corresponding to the situation in which only the costs are uncertain (σ=0). Cost uncertainty ($\beta > 0$) makes a project more attractive because its value is a convex function of the costs and because one has the option of abandoning the project midstream if the expected cost to completion becomes too large. Technical uncertainty also makes investing more attractive

because it reveals information about costs (i.e., one "learns" about the costs by undertaking the development of the project).

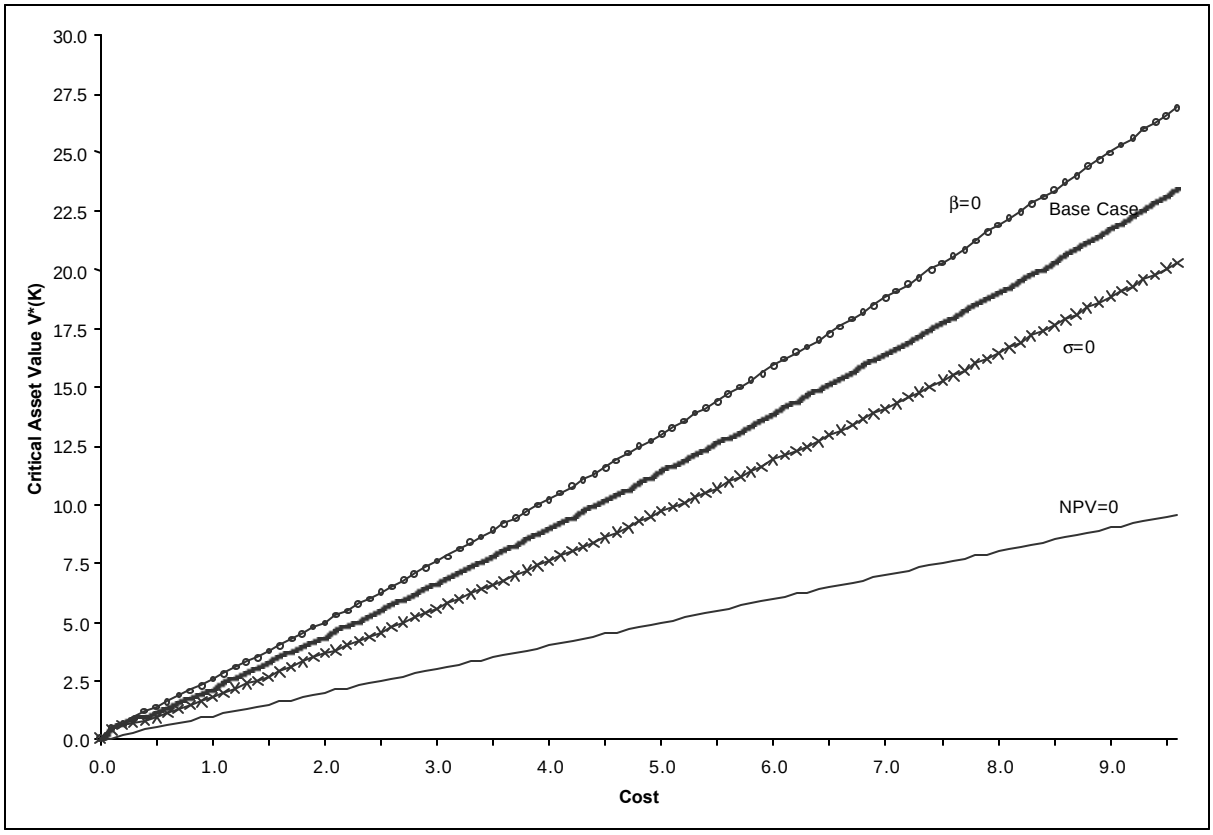

Figure 3. Impact of Uncertainties in Critical Asset Values for the Example Development Project

Figure 4 compares the critical asset values of the project with those obtained when there is no decay in the cost of the IT asset over time ($\delta = 0$). In this case, the critical NPV asset values V*(NPV=0) are higher because the organization will have to invest more and because the asset value will be received later (since the project will take a longer time to complete). Note, however, that the difference between the critical asset values determined by the model V*(K) and those determined by the NPV method V*(NPV=0) are closer when no decay in the cost of the IT asset is expected ($\delta = 0$). In other words, there is no additional value in waiting for K to decrease before committing resources.

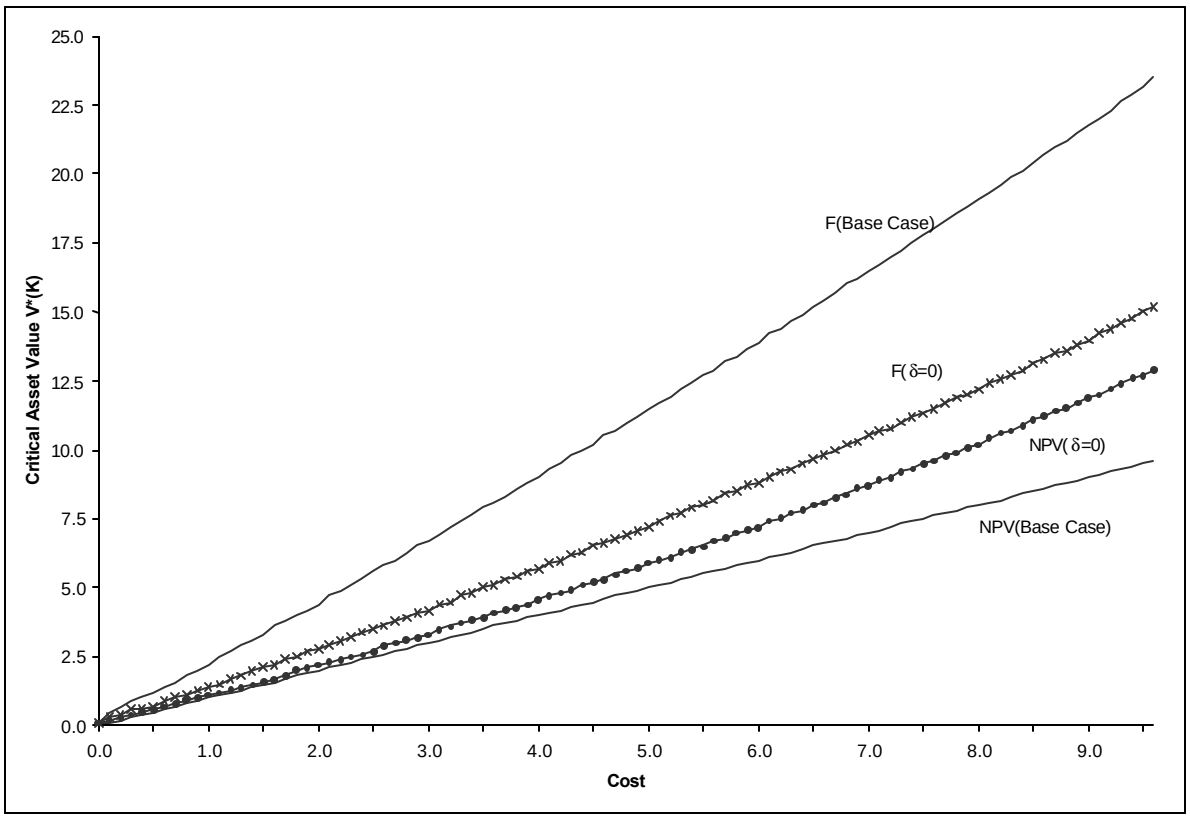

Figure 4. Impact of Cost Decay (δ) in Critical Asset Values for Example Development Project

3 Valuation Model for IT Acquisition Projects

In IT acquisition projects, the decision to invest at a particular time $0 \leq t \leq T$ is equivalent to *exercising* an *American* option before maturity. Once the decision is taken, the cost incurred may not be reversed and the only uncertainty remaining is that of the cash flows that will be received during the remaining time (t,T). It is assumed that the investment is instantaneous. As we will see, the volatility of investment costs and future cash flows might make attractive to wait before making the investment even if the expected Net Present Value of the project is positive. Therefore, the decision maker has to monitor the stochastic changes in the investment costs and cash flows to determine when it is convenient to acquire the IT asset.

3.1 Cost Uncertainty

The cost of acquiring the IT asset (K) evolves according to the following expression:

$$\mathrm{d}K = \delta K \mathrm{d}t + \gamma K \mathrm{dw} \tag{16}$$

As in the valuation model for IT development projects, the term (δ K dt) describes the change in cost experienced by some IT assets through time. The estimated cost of the IT asset only changes in response to exogenous variations in price and to random changes in input labor costs.

3.2 Cash flow Uncertainty

The differential cash flows (benefits of the investment in IT) obtained once the IT asset has been acquired behave according to the following expression:

$$\mathrm{d}C = \alpha\, C \mathrm{d}t + \phi\, C\, \mathrm{dx} \tag{17}$$

The term (α C dt) describes the change in cash flow over time. A positive α might be used for modeling situations in which the rate of benefits increases during the life time of the asset. For instance, the additional sales resulting from doing a better segmentation of customers with the help of a Data Warehouse increases over time, as more information is incorporated into the system. Similarly, the benefits of having a network might increase as more users take advantage of this infrastructure. On the other hand, a negative α might be used, for example, to represent the situation in which the additional cash flows decrease over time due to increased competition (e.g., other competitors introduce similar technology and reduce our competitive advantage).

The second term (ϕ C dx) represents the stochastic variation of C, where dx is an increment to a Gauss-Wiener process that might be correlated with the overall economic activity as well as with the stochastic process associated with the costs.

3.3 Value of the IT Asset

The value of the IT asset at a particular time $0 \leq t \leq T$ is the expected present discounted value of the stream of future differential cash flows C under the risk neutral measure Q from the moment in which the organization acquires the asset until the end of the interval in which the technology provides these cash flows:

$$V(C,t) = E_Q\left[\int_t^T C(\tau)\, e^{-r_f \tau} d\tau\right]$$

where the risk neutral process representing how cash flows evolve becomes:

$$dC = (\alpha - \eta_C)\, C dt + \phi\, C\, dx^* = \alpha^* C dt + \phi\, C\, dx^*$$

In this expression, η_c is the risk-premium due to cash flow uncertainty. Integration over the interval (t,T) gives:

$$V(C,t) = \frac{C}{r_f - \alpha^*}\left[1 - e^{-(r_f - \alpha^*)(T-t)}\right] \tag{18}$$

3.4 Value of the Investment Opportunity

Let F(C,K,t) be the value of the investment opportunity. Since C and K are not traded assets but represent the expected values of a pair of random variables, they have risk premiums associated with them. We can use Ito's Lemma to obtain the following expression for the differential dF:

$$dF = \frac{\partial F}{\partial t} dt + \frac{\partial F}{\partial C} dC + \frac{\partial F}{\partial K} dK + \frac{1}{2}\frac{\partial^2 F}{\partial C^2} dC^2 + \frac{1}{2}\frac{\partial^2 F}{\partial K^2} dK^2 + \frac{1}{2}\frac{\partial^2 F}{\partial C \partial K} dC dK \tag{19}$$

By substituting Equations (16), (17) and (19) into the corresponding Bellman equation of optimality, the following second order parabolic differential equation is obtained:

$$\frac{1}{2}\phi^2 C^2 F_{CC} + \frac{1}{2}\tilde{a}^2 K^2 F_{KK} + \tilde{n}_{CK}\,\phi\,\tilde{a} C K F_{CK} + (\acute{a} - \varsigma_C) C F_C + (\delta - \varsigma_K) K F_K + F_t - r_f F = 0 \tag{20}$$

The solution to Equation (20) must satisfy the following boundary conditions:

$$F(C, K, T) = 0 \tag{21}$$

$$F(C, K, t) \geq \max\{0, V(C, t) - K(t)\} \tag{22}$$

Equation (21) indicates that the value of the investment opportunity at time T will be zero, since no stream of cash flows occurs after this time. Equation (22) indicates that at any time t, the value of the investment opportunity is always a non negative number that exceeds or is equal to the difference between the value and the cost of the IT asset. This is always true, since we can always exercise the option to invest in the IT asset and get the difference between V(C,t) and K(t). However, there will be situations in which the value of the investment opportunity will be *larger* than this difference as discussed in the next section.

3.5 Traditional NPV Criteria and Option Value

The Net Present Value of the project at time *t* is obtained by subtracting K(t) from V(C,t):

$$NPV(C, K, t) = V(C, t) - K(t) \tag{23}$$

Table 3 shows the different situations that may be encountered when evaluating IT investment projects of the type being modeled. Whenever the difference between F(C,K,t) and NPV(C,K,t) is positive, the optimal decision is to wait (if possible) before proceeding with the acquisition of the IT asset, *even* if the NPV rule would recommend to acquire the IT asset immediately (NPV(C,K,t) > 0). Only when V(C,t) is sufficiently larger than K, the value of the investment opportunity F(C,K,t) will equal the expected net present value NPV(C,K,t) and it will be optimal

to invest. Conversely, when NPV(C,K,t) is negative, the firm can wait for the costs to decrease or for the expected cash flows to increase so that NPV becomes positive.

Table 3. Optimal Decisions for IT Acquisition Projects under Uncertainty

Net Present Value	*Value of Investment Opportunity*	*Option Value*	*Optimal Decision*
NPV(C,K,t) > 0	F(C,K,t) > NPV(C,K,t)	+	Wait or acquire the asset at cost K (if waiting is not allowed)
	F(C,K,t) = NPV(C,K,t)	0	Acquire the asset at cost K
NPV(C,K,t) ≤ 0	F(C,K,t) > 0 ≥ NPV(C,K,t)	+	Wait (if possible) or do not acquire the asset (if waiting is not allowed)

In the following section we illustrate how the IT acquisition model can be applied for the valuation a real world example.

4 Valuating the Yankee 24 Project

Benaroch and Kauffman (1999) use a portfolio of Black-Scholes European options to approximate the optimal exercise time of the American option associated with an investment project involving the deployment of point-of-sale (POS) debit services by the Yankee 24 shared electronic banking network of New England. In this section we apply an extension of the IT Acquisition model developed in Section 3 to this real world problem using the data provided in the Benaroch and Kauffman article. Our purpose is a) to illustrate how the IT acquisition model could be applied to a real project that has been documented in the IT literature; b) to incorporate the true American option nature of the investment in the modeling process, and c) to demonstrate

that our model provides additional capabilities by allowing the decision maker to measure the effect of cost uncertainty.

Table 5 shows the revenues, costs and cash flows of the Yankee 24 project as reported by Benaroch and Kauffman (1999). Revenues were estimated using historical data from POS transactions in California and assuming that the New England market would behave similar to the market of California except for size. A constant monthly growth rate of transaction volume that replicates the observed data was computed and figures were aggregated per semester. Operational marketing costs were estimated to be $40,000 per year and an initial investment of $400,000 was needed to develop the network. The volatility of the expected revenues was estimated to be between 50% and 100% based on a series of interviews with decision makers of the company, and 50% was used to compute the investment opportunity. The time required to develop the network was assumed to be fixed and equal to one year. Regardless of the time of entry, within the period of analysis, the firm was assumed to be able to capture the revenues resulting from the market size one year after the initial investment. Finally, the time horizon of the project was considered to be five years and a half.

Table 4. Cash flows for the Yankee 24 Investment Project (Benaroch and Kauffman 1999)

Period	Year-Month	No. of Transactions	Revenue	Operation Cost	Cash flow
0.0	Jan-87				
0.5	Jul-87				
1.0	Jan-88	3,532	$ 353	$ 20,000	$ (19,647)
1.5	Jul-88	8,606	$ 861	$ 20,000	$ (19,139)
2.0	Jan-89	20,969	$ 2,097	$ 20,000	$ (17,903)
2.5	Jul-89	51,088	$ 5,109	$ 20,000	$ (14,891)
3.0	Jan-90	124,470	$ 12,447	$ 20,000	$ (7,553)
3.5	Jul-90	303,258	$ 30,326	$ 20,000	$ 10,326
4.0	Jan-91	738,857	$ 73,886	$ 20,000	$ 53,886
4.5	Jul-91	1,800,149	$ 180,015	$ 20,000	$ 160,015
5.0	Jan-92	4,385,877	$ 438,588	$ 20,000	$ 418,588

Figure 5 shows how the Yankee 24 investment project can be conceptualized as an *IT acquisition project* for determining its value. It is more appropriate to use this model than the *IT development model* because a) the duration of the time required for developing the network is known with certainty (τ = 1 year), and b) it is assumed that the firm can invest the $400,000 required instantaneously at any time. However, in order to apply the IT acquisition model to this problem, the following modifications were made:

- The operational marketing costs were added to the initial investment. Since the operation cost per year is constant, we modified Equation (16) to include a constant change in cost rather than a proportional one. This change represents the amount of the operating costs that would not be incurred if investment is delayed. Therefore, the cost of acquiring the IT asset (K) evolves according to following expression:

$$dK = \delta dt + \gamma K dw \tag{24}$$

where δ is the marketing operational cost per year (δ = -$ 40,000) and γ is the volatility of the costs. Since these costs are paid starting one year after the decision to invest has been made, we use $\delta = -\$\,40{,}000 \exp(-0.07*1) = -\$37{,}200$ given a risk free rate of 7%.

- Since the cash flows are received starting τ years after the investment is made, the value of the asset V(C,t) becomes:

$$V(C,t) = \frac{C}{r_f - \alpha^*}\left[e^{-(r_f-\alpha^*)\tau} - e^{-(r_f-\alpha^*)(T-t)}\right] \tag{25}$$

where $\alpha^* = (\alpha - \eta_C)$ and τ = 1 year. Note that this expression reduces to Equation (18) when cash flows start to be received immediately (τ = 0).

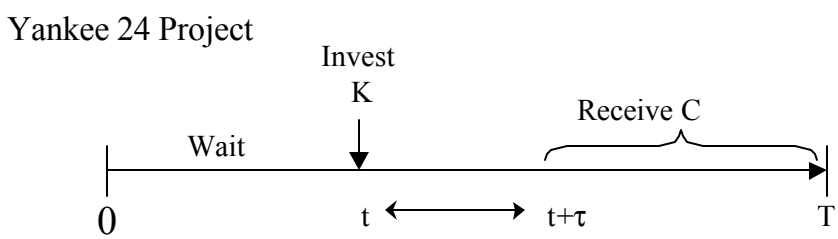

Figure 5: Conceptualization of the Yankee 24 Project as an IT Acquisition Project

The total investment cost K(0) can be computed by adding the initial investment cost of $400,000 and the present value of the marketing operational costs during the period (τ,T):

$$K(0) = \$400{,}000 + \frac{\$40{,}000}{r_f}\left[e^{-r_f\tau} - e^{-r_f T}\right] = \$400{,}000 + \frac{\$40{,}000}{0.07}\left[e^{-0.07} - e^{-0.07*5.5}\right] = \$543{,}968$$

Since the revenues were computed by the authors assuming a constant growth rate of the number of transactions processed, the growth rate of the cash flows per semester (α/2) can be obtained by taking the constant quotient of any consecutive semester cash flows:

$$\alpha/2 = \ln(C(t+1)/C(t)) = \ln(2.44) = 0.892; \quad \therefore \alpha = 1.784$$

The expected rate of cash flow at time 0, C(0), required by the model can be computed by discounting the cash flow for the Jan-88 semester to time 0 (an interval of 1.25 years assuming that the cash flow is received at the middle of the semester) and then annualizing it:

$$C(0) = 2 * \$353 * \exp(-1.784 * 1.25) = \$75.9$$

Finally, applying Ito's Lemma it can be shown that the volatility of the cash flows is equal to the volatility of the asset $f = s = 0.5$.

Table 5 summarizes the parameters for the base case of the Yankee 24 project. Even though the original example considered the costs to be constant, we solve the partial differential equation for a range of costs from \$0 to \$ 600,000 in order to analyze what happens when cost volatility is introduced. The range of cash flows goes from \$0 to \$100,000 given that the initial rate of cash flows is \$75.9 and that the highest expected rate of cash flow in year 4 is \$75.9*exp(1.784*4)= \$95,360. The risk premiums in the costs and in the cash flows are 0 and 5% respectively, according to the information provided by the authors.

Table 5. Parameters for the Yankee 24 Project (Base Case)

Cost Parameters			*Cash flow Parameters*		
Range of Costs	0 to $ 600,000		Range of Cash flows	0 to $100,000 per year	
Input Costs Uncertainty	γ	0.0	Drift in Cash flow Value	α	1.784
Cost Change	δ	-$37,200	Cash flow Uncertainty	ϕ	0.5
Adjustment for Risk in Costs	η_K	0	Risk premium on Cash flow Value	η_C	0.05
Other Parameters			Time to Maturity	T	5.5 years
Risk-free rate	r_f	0.07	Correlation between C and K	ρ_{CK}	0.0

Table 6 shows the results of our evaluation of the Yankee 24 project at the beginning of each semester. These values were obtained by solving the corresponding partial differential equation using increments of $20 in cash flow values and $6,000 in cost values. Columns 4 and 5 provide the values of the investment opportunity (F) and the NPV of the project corresponding to the points of the (C x K) grid that are closest to the expected values of these variables at the start of each period. At the beginning of the project, for instance, the value of the investment opportunity is $136,400 (C≈ $80 and K≈ $546,000) even though the NPV of immediate investment is -$92,700. Column 6 shows the option value of the project which is computed as the difference between F and max{0,NPV}. Note that only on Jul-90 the value of the option is zero implying that for the expected cost and rate of cash flows at that time it would be optimal to undertake the project (i.e., the expected rate of the cash flows is above the corresponding critical value). For every other period, the optimal decision would be to wait even if the NPV is positive. Column 7 gives the critical cash flows C*(F) above which it would be optimal to invest immediately. In

reality, however, the decision maker will wait to observe the *actual* cash flows before taking any action.

An advantage of the framework we have developed is that, in addition to allow modeling uncertainty in the cash flows, we can also evaluate the impact of uncertainty in the costs. To illustrate this point we solved for the value of the project assuming an input cost uncertainty of γ=0.5. Column 7 of the table shows the results of this valuation. Note that the value of the investment opportunity is always higher than the corresponding values when only cash flow uncertainty is taken into consideration.

Table 6. Value of the Investment Opportunity, NPV and Option Value for the Yankee 24 Project (thousands)

Period	Expected Rate of Cash Flow	Expected Cost	F	NPV	Option	Critical Cash Flow C*(F)	F γ=0.5
Jan-87	$0.08	$546	$136.4	-$92.7	$136.4	$8.68	$153.4
Jul-87	$0.18	$528	$127.6	-$84.5	$127.6	$7.66	$139.6
Jan-88	$0.46	$504	$147.0	-$11.6	$147.0	$7.04	$163.2
Jul-88	$1.10	$486	$144.1	$24.4	$119.7	$6.74	$163.3
Jan-89	$2.70	$468	$148.6	$72.4	$76.2	$7.34	$169.8
Jul-89	$6.56	$450	$147.0	$109.6	$37.4	$10.54	$168.3
Jan-90	$16.02	$432	$142.0	$134.0	$8.0	$18.16	$158.9
Jul-90	$39.08	$414	$116.8	$116.8	$0.0	$36.70	$122.4
Jan-91	$95.36	$396	$3.5	-$3.2	$3.5	$96.16	$10.0

Figures 13 and 14 show the value of the investment opportunity and the option value for different cash flow rates when t=0 (Jan-87) and K= $546,000. For this cost and this range of cash flow rates it is not optimal to undertake the project because the option value is always positive. As discussed previously and can be seen in the figures, uncertainty in costs always increases the option value and the value of the investment opportunity. Also, the option value reaches a peak when NPV is close to zero and the decision to invest is marginal.

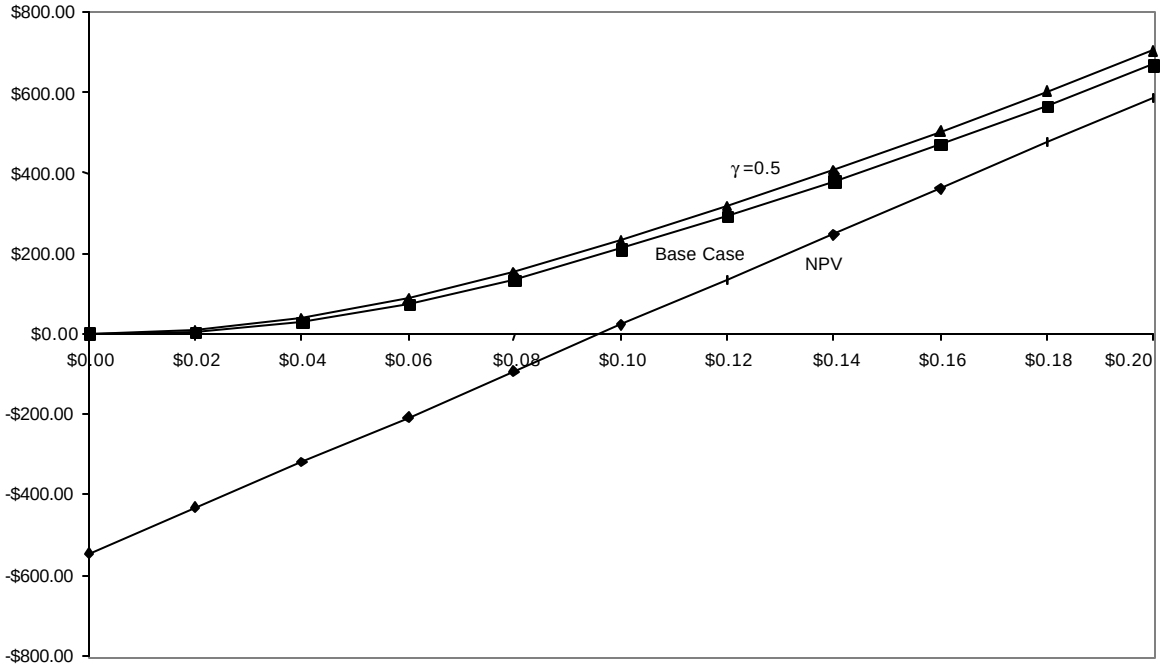

Figure 6. Impact of Cost Uncertainty in the Value of the Investment Opportunity and NPV for the Yankee 24 Project (t= 0, K(0)=$546) (thousands)

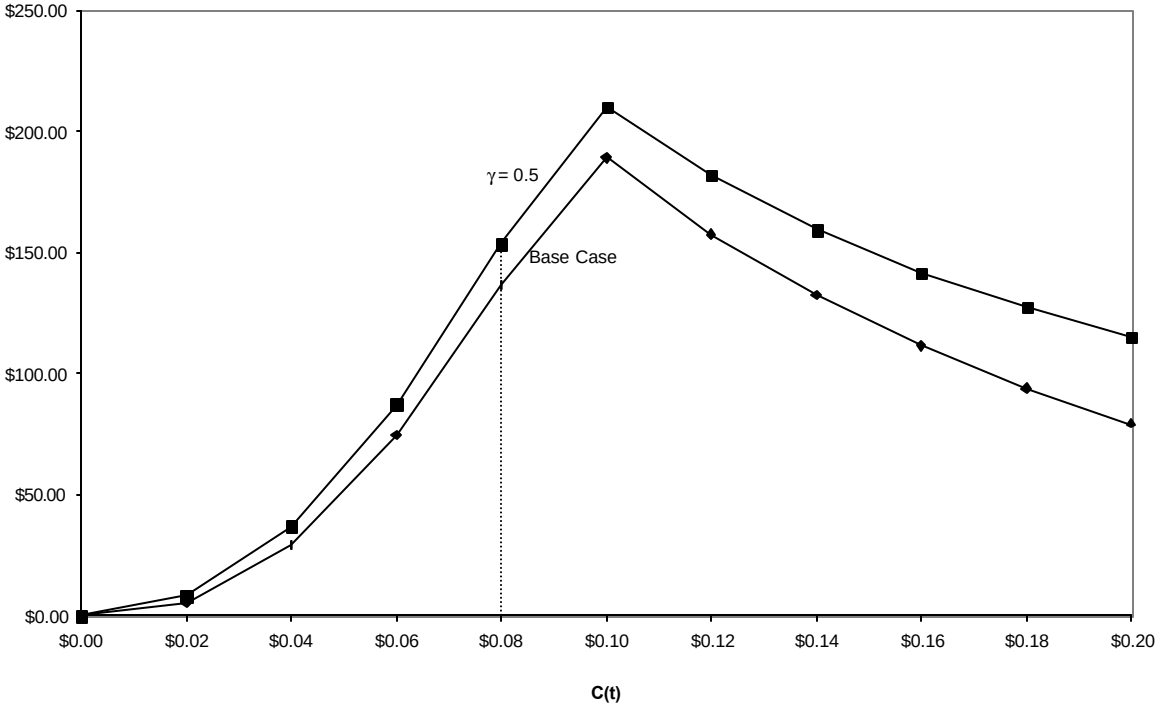

Figure 7. Impact of Cost Uncertainty in the Difference between the Value of the Investment opportunity and NPV (> 0) for the Example Acquisition Project (t= 0, K(0)=546) (thousands)

The application of the IT acquisition model addresses two of the issues recognized by Benaroch & Kauffman regarding the limitations of using a B&S for solving this problem, namely the assumption that the option's exercise price is known with certainty, and the fact that the American investment option is approximated with a portfolio of European options. In addition, the optimal exercise strategy in our approach is specified in terms of a critical cash flow above which it is optimal to invest in the project. Rather than determining in advance when we should exercise the option, our model provides a framework for making a decision once the project manager observes what are the current cash flows and costs at any point in time.

5 Summary and Conclusions

In this paper we develop two models for the valuation IT investment projects using the real options approach. The first model is suited for the evaluation of IT projects in which a firm invests an uncertain amount of money over an uncertain period of time to *develop* an IT asset that can be sold to third parties or used for its own purposes. The second model is suited for the valuation of investments in which a firm *acquires* an IT asset for its own use. In this model, investment is assumed to be instantaneous and the benefits associated with the investment are represented as a stream of differential cash flows over a period of time in which the technology is considered to be useful. This type of project is similar to an exchange option in which the exercise price (the cost) and the asset received are both uncertain.

Our model for *IT development* projects incorporates the effects of the technical and input cost uncertainties related to the overall completion cost of the project, the uncertainty in time required for developing the IT asset and the possibility that a catastrophic event causes the permanent abandonment of the development effort. Benefits are summarized in the value of an underlying asset that also evolves stochastically over time. While this approach constitutes a good

representation for cases in which the IT asset will be sold to third parties, for situations in which the firm will use the asset it would seem to be more appropriate to consider the benefits in terms of differential cash flows as we did in our model for *IT acquisition* projects. To develop such a model is not trivial because the time in which cash flows start to be received is also a random variable: once we decide to build the IT asset we are uncertain about the time in which the project will be finished. However, if we assume a deterministic time to develop the IT asset and that once investment starts it will not be discontinued until the project is completed, as we did in the real world application in Section 4, we can easily adapt the acquisition model for this purpose.

Both models provide more flexibility for representing cost changes than previous models because we include a trend in completion costs, reflected by δ, regardless of whether investment is taking place. For instance, in the Yankee-24 example, we used the δ parameter to represent the amount of operating costs that we would not have to incur if the project was postponed to a later date. An opposite case would be to use δ for representing an upward trend in implementation fees.

The additional effort involved in estimating the cost parameters of our models will be justified in those cases in which development or acquisition costs play a major role in the decision. The benefit of having a more sophisticated model is more tangible in those projects in which the decision of exercising or deferring the investment decision might be affected by such an analysis. If the asset value is much higher than the critical asset value, both a real options model and a traditional NPV analysis would recommend to undertake the investment. Also, projects whose costs do not have a high volatility or a particular trend can be modeled by setting some of our parameters to zero. However, even in the case in which the project manager is not willing to go

through the effort of estimating the cost parameters, our framework allows the project manager to perform a sensitivity analysis on such parameters.

The models described in the paper are complementary and provide the decision maker with a more rigorous framework for evaluating IT investment projects under uncertainty than the traditional NPV method. In contrast with conventional approaches for project valuation, these models take into consideration the option value of waiting before committing resources and the effect of the volatilities associated with the costs and benefits of an investment project. These models could act as the building blocks of more comprehensive methodologies that extend the scope of our work not only for IT investments but also for other high uncertainty investments in which flexibility plays an important role.

An interesting extension would be to model the process of sequential investments in substituting technologies.[3] In this case, investing in a particular technology provides a firm with the option to invest in a newer substituting technology in the future. The firm needs to determine when to invest into new technologies and when it is better to skip a technology wave and wait for newer technologies to appear in the market. Another extension would be to develop mechanisms for the valuation of IT bundles in which some IT assets are acquired and others are developed, particularly in the case in which the benefits and costs of an IT asset cannot be isolated from those of the other assets.

Acknowledgements

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[3] Grenadier and Weiss (1997) developed a model of the optimal investment strategy for a firm confronted with a sequence of technological innovations. In their model, however, the exogenous stochastic variable is the state of technological progress.

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