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 each of 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 costs of some IT assets (e.g., hardware) decrease rapidly even if no investment takes place. In the case of IT acquisition projects, benefits are modeled as a stream of stochastic cash flows and this provides a more realistic approach for the analysis of projects in which the value of the underlying asset is difficult to estimate.

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). Benefits such as improved quality or service are difficult to estimate because their materialization depends not only upon the technology per se, but also on multiple organizational factors. Costs are also highly uncertain due to the rapid changes in input costs provoked by the appearance of new substituting technologies and the limited usage of proper metrics for estimating project efforts.

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. An investment is modeled with the equivalent of a stock *call option* in which the project manager has the right, but not the obligation, of buying something of value at a future date. 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 stock options to project investments (Bodie and Merton 1999).

Project evaluation using real options has been a subject of much research during the last fifteen years (Dixit and Pindyck 1994). Brennan and Schwartz (1985) developed a model for evaluating natural resource investments with stochastic output prices that takes explicit account of managerial control over the output rate of the resource. Ingersoll and Ross (1992) demonstrated that even for the simplest projects with deterministic cash flows, interest-rate uncertainty has a significant effect on investment. For determining the project's value, they divided the problem into two parts depending upon whether the commitment to invest had been made or not, and obtained a sufficient condition for an investment to be postponed when uncertainty increases. Pindyck (1993) developed a general model for irreversible investment decisions in projects subject to two types of cost uncertainty: a *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, and an 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.

Most research related to the valuation of information technology (IT) investment projects as real options, however, has been limited to the application of the Black-Scholes (BS) formula (1973) by assuming that the cost of the project is known with certainty. For example, Benaroch and Kauffman (1999) used a Black-Scholes approximation (Hull 1997, p. 252) for valuating a project involving the deployment of point-of-sale debit services in an electronic banking network. In their model, the investment opportunity was modeled as a pseudo-American call option that pays dividends, and the value of the underlying asset on a particular period was 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) used 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 included the value of the growth option for the second stage which was 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) used this formula to quantify the value provided by decision support systems (DSS) in several decision scenarios such as commodity trading and marketing, and compared the results with those obtained by a direct application of BS.

Option pricing has also been proposed as a useful approach for modeling investments in R&D. R&D projects have many commonalities with IT investment projects. High uncertainty in costs and values, asymmetry between gains and loses and flexibility during project execution are some characteristics of both types of initiatives. Also, as in the case of some IT projects, the value of a R&D investment is not primarily determined by the cash flows coming from the initial investment but by the future investment opportunities it provides. Perlitz et al. (1999) applied Kemna's (1993) adjustment of Geske's formula (1979) for the valuation of compound options to a project involving the discovery of a new drug. Jägle (1999) solved a similar problem using an options-tree approach based on the binomial model.

Based on Pindyck's results, Schwartz and Moon (2000) developed a model for evaluating R&D investments that summarizes the uncertainties of an R&D project into three stochastic processes. These processes are related to the investment cost, the future payoffs and the possibility that a catastrophic event may occur before the project is completed. The value of the investment opportunity is modeled as a contingent claim which has its underlying state variables the value of the asset obtained at the completion of the project and the expected cost of completion. They applied their model to a hypothetical R&D project associated with the development of a new drug and demonstrate that the real options approach provides a useful framework for decision making under uncertainty. In their framework, the overall project may be decomposed into various stages, each of them with particular uncertainty. As a result, their model provides information not only on the overall value of the project, but also on whether investment should be made to continue with the project after a phase has been completed.

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 decay in the cost of IT assets. The valuation models for IT investments described take as a basis the framework developed by Schwartz and Moon. 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 ($\bar{\tau}$) 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).

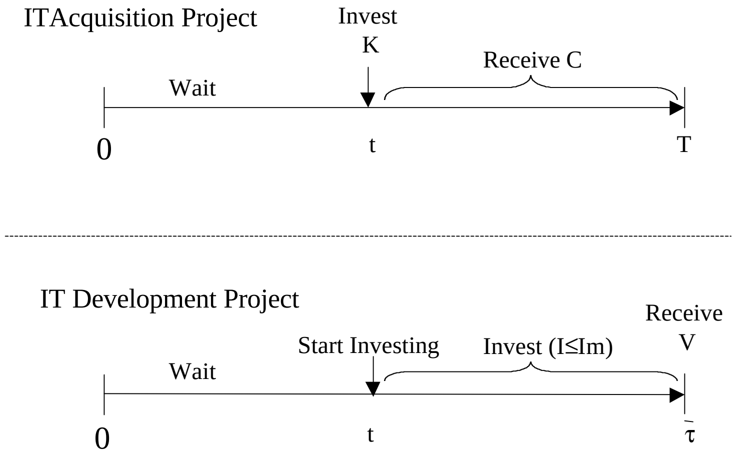

Figure 1: Two types of IT Investment Projects

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 ($\bar{\tau}_2$) until the project is complete in order to receive the underlying asset (V). Also, after some period of uncertain length ($\bar{\tau}_1$), 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.

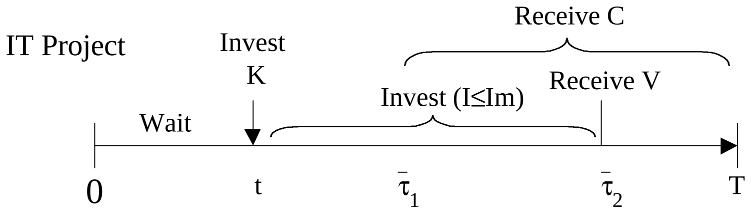

Figure 2: Generic IT Investment Project

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 5). 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 in order to account 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. Also, the model for IT acquisition projects considers the benefits as a stream of stochastic cash flows that the organization starts to receive after the IT asset is acquired. This approach contrasts with previous models in which the stochastic process of the asset value is incorporated directly into the model. With the new approach, the decision maker can account for the effect of volatilities of benefits *after* the asset is received.

The next section describes some characteristics of IT investments as a background for subsequent discussion. Section 3 presents the proposed valuation model for IT projects in which the IT asset (e.g., a software package) takes time and money to develop. As a result, the uncertainty associated with the development costs plays a major role in the decision making process. Section 4 describes the proposed valuation model for IT acquisition projects. In this case the uncertainty of the cash flows that the organization expects to receive has an important effect in the value of the investment opportunity. In these sections, a couple of examples are presented in order to illustrate the different results that are obtained with these models and the traditional NPV method for project valuation. Section 5 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 6 discusses some possible extensions to the proposed models and provides some conclusions of our work.

2 Value, Risks and Classes of Information Technology Investments

Estimating the value of an IT investment project is a particularly challenging task because there are many factors that affect the payoffs and costs of the project. IT projects usually involve the acquisition or development of multiple assets of different nature. Some of these assets are related to the IT infrastructure per se (e.g., hardware components) while others involve the application software that support specific business processes. A particular asset might have no or little value unless other assets are present or it may have a value due to the support it provides to other IT components. For instance, a programming language is generally not valuable unless it is used to develop or interpret an application program. Also, purchasing a software package might imply upgrading the server that is also used to run other application and this would have some side benefits even if the activity of implementing the software package is interrupted after the project has started.

Even when the benefits of a particular IT asset can be isolated from other decisions taken with respect to the IT infrastructure, the benefits and costs of an IT project have a high degree of uncertainty because their realization is affected by multiple organizational elements. In addition, there are multiple alternatives for developing information systems that imply different project phases and cost schemes. The traditional life-cycle model that divides an IS project in analysis, design, development, deployment, testing and maintenance phases is only one of the methodologies that can be used for software development. Prototyping, rapid application development, package customization and outsourcing are now some of the other choices that an organization has to evaluate to implement an IT project. Choosing among these alternatives has implications on the options available for the project manager once the project has started.

In this section we present a summary of some of the research that has been done to identify the business value, the risks and the classes of IT projects. This will provide some background for the discussion of the valuation models that are presented in the following sections.

2.1 Business Value of IT

The business value derived from information technology investments has been a subject of intense debate over the past ten years (Hares and Royle 1994). While some analysis (Loveman 1994) have shown that IT has had no bottom line impact in the profitability of an organization, others (Brynjolfsson and Hitt 1993) claim that IT investments have an important impact on productivity. Hitt and Brynjolfsson (1996) argue that the contrasting results of these studies is partially originated because each analysis is focused on three complementary but different issues associated with the impact of IT in business: productivity, profitability and consumer value:

- Impacts on *productivity* are analyzed by considering that the organization has a method for transforming various inputs into outputs. This method is traditionally represented by a *production function* that is monotonically increasing. Each additional unit of an input contributes to an increment in the output level until a equilibrium point in which the net marginal product of any input is zero. An increase in productivity due to IT occurs when an IT investment allows an organization to use less inputs for producing the same level of output.

- Effects on *profitability* are associated with the ability of a firm to capture the value of IT to create competitive advantage. A firm might create additional economic value by applying its unique competencies in the management of IT to differentiate itself from its competitors.

- Finally, impacts on *consumer value* are derived from the surplus that consumers obtain from paying a market price that is less than the one they would be willing to pay to obtain a particular output of the firm. When an IT investment contributes to reduce the price of a product or service, the surplus of existing customers is increased, and new surplus is created for those additional consumers that are willing to pay the lower price.

In an analysis of IT spending in 370 large firms from 1988-1992, Hitt and Brynjolfsson found that while IT has increased productivity and created substantial value for consumers, there is no evidence that these benefits have been translated into higher business profitability. This confirms the results of other authors like Strassman (1997) who has criticized repeatedly the belief that more spending on IT leads to better economic performance. In the following sections, we discuss some of the models that have been used to estimate the impacts of an IT investment along each of these dimensions.

2.1.1 Impacts on Productivity

The impacts of IT investments on productivity have been analyzed at different levels of aggregation by several authors. Some authors have studied the overall impact of such investments on the economy (Thurm 2000), while others have concentrated on particular sectors or firms. At the end of the 80s, the fact that companies kept on spending increasing amounts of money in computer investments despite that nobody had demonstrated evidence of positive impacts of IT in productivity was considered to be a *paradox* (Lucas 1999). While the debate on this issue is still a matter of discussion among economists, some recent analysis have given new explanations for this phenomena.

Hitt and Brynjolfsson (1996) analyzed the impacts of IT investments on productivity by developing a production function in which the Value added output was expressed as a function of three inputs measured in constant 1990 dollars: IT Stock (including Computer Capital and information systems labor), Non-Computer Capital and Labor. Using ordinary least squares and seemingly unrelated regression to account for productivity correlation across time, they found that the gross marginal product of IT Stock, computed as the elasticity of value added divided by the percentage of IT in value added, was 94.9% (R^2 was 97.2% and 1109 data points were used). After subtracting the cost of the additional capital associated with the IT investment, there was strong support that IT Stock had a positive impact on productivity.

Morrison (1997) analyzed the impacts information technology equipment in U.S. manufacturing industries using data from the Bureau of Labor Statistics, the Bureau of Economic Analysis and the Census of Manufactures for 1952-1991. Using a three-stage least square procedure, she found that a surge in returns of high-tech capital investment in the late 1970s was followed by some over-investment in the mid to late 1980s. She also found that IT investments became more justifiable at the beginning of the 1990s, but that the net returns varied considerably across manufacturing industries. In general, returns were higher for non-durable-goods industries than for durable-goods industries. The results obtained by Morrison are significantly different from those of Hitt and Brynjolfsson. This might be a consequence of the distinct methodologies in which both studies computed the benefits associated with IT investments, the different data samples used for the analysis or the different level of aggregation of the studies.

In contrast, Lehr and Lichtenberg (1998, 1999) found that computers not only contributed to productivity growth during the period 1977-1993, but yielded excess returns relative to other types of capital (i.e., its relative marginal benefit exceeded its relative marginal cost). They explain the productivity paradox by noting that labor productivity depends both on the overall capital intensity as well as on the composition of capital. Their results indicate that the types of computers and how they are used makes an important difference; in particular, they found that personal computers have an important positive impact in productivity. Dewan and Min (1997) also found that IT capital is a net substitute for ordinary capital and labor in all sectors of the economy and agree with Lehr and Lichtenberg that the slow improvements in labor productivity might be due to the offsetting effects of more IT capital and less non-IT capital per worker.

Other authors, such as Kelley (1994) have argued that studying the impact of IT on productivity requires being more specific about the context in which IT affects a particular process. Kelley states that, although some technological changes may have system-wide effects, most IT applications are process-specific innovations, and their benefits are confined to the process in which the technology is deployed. Using 1987 survey data from 584 U.S. establishments engaged in the machining process in 21 different industries, she obtains an estimate of the impact of a particular IT (Programmable automation PA) in a specific process (precision metal-cutting), avoiding “the confounding aggregation problems that have plagued earlier econometric studies.” In her model, Kelley defines a composite measure called *production hours per unit of output* that is computed by adding the inputs the hours of direct and indirect labor, regardless of their occupational classification, to the hours of machine time utilized in metal-cutting operations necessary to make the product. This measure is less susceptible of being manipulated by accounting procedures, and is used to indicate the improvements in productivity obtained when using PA technology versus conventional equipment. She finds that, after controlling for product attributes and other factors, the average direct effect of PA is estimated to reduce unit production hours by over 40%. Nevertheless, she indicates that the advantages of PA technology are not enjoyed to the same extent by all users and that some organizations are much better positioned to exploit the new technology.

2.1.2 Impacts on Profitability

Earlier discussions about the manner in which IT could contribute to the creation of competitive advantages described cases of firms that had taken advantage of IT to change the forces controlling the competition. Successful firms created "barriers to entry" for new competitors, imposed "switching costs" for their customers, modified the "value chain" associated with their products or services, or changed the basis of the competition (McFarlan 1984, Porter and Millar 1985). More recently, Mata et al. (1995) have explained the relationships between IT and the creation of sustainable competitive advantages by using the resource-based perspective developed in strategic management theory. They conclude that managerial IT skills are the only likely source of sustainable competitive advantages.

Hitt and Brynjolfsson (1996) analyzed the impacts of IT investments in profitability by extending Strassman's model (1990) with additional control variables. Their model assumed that firm profitability is a function of the ratio of IT Stock to firm employees. They ran multiple regressions using three alternative measures of profitability (Return on Assets, Return on Equity and Total Shareholder Return) for each year of their sample (1988-1992) on 370 large firms, but found that the impact of IT on profitability is null or slightly negative. As a result, they conclude that the failure to find a strong result might be the due to inadequate modeling given the lack of a more rigorous theory and firm-specific variables. Tam (1998) performed a similar analysis for estimating the impacts of IT investments on firm performance in four newly industrialized economies and also encountered mixed results. He concluded that the impact of IT investment on firm performance is not a direct one and is likely to be affected by management orientation and financing decisions unique to a national setting.

Strassman (1997) arrived to similar conclusions using financial results and computer spending figures for 468 corporations. The lack of relation between IT spending and profits did not change when alternative measures were used for this variables. Profit, expressed as Return on Assets, Return on Net Investment or Economic Value Added, divided by Equity, was never related to either IT spending per asset or IT spending per revenue dollar.

These results are discouraging but understandable. If the impacts of IT in productivity are different across industries, firms and processes, the impacts on profitability are even more dependent upon organizational and market attributes and should have more variance. In a competitive market, the benefits obtained by increases in productivity might be directly transferred into lower prices for consumers, and this situation would convert the added value into consumer surplus instead of profits. Therefore, the impacts of IT in profitability depend not only on what the firm does, but also in its overall competitive arena.

Nevertheless, recent evidence seems to indicate that the clearest explanation for the increase in US productivity during 1998 and 1999 are the strong investments in information technologies that have been made by US corporations during the 90s (Silverstein 2000, Thurm 2000).

2.1.3 Impacts on Consumer Surplus

To estimate the impact of IT on consumer surplus, Hitt and Brynjolfsson (1996) used a translog utility function in which the increase in consumer surplus between two periods was dependent upon the ratio of IT Stock to Value Added and the Prices of IT Stock in these periods. Their research shows that a 4% per year decreasing cost of IT Stock (a net effect of the 20% per year drop of computer prices in the 1988-1992 period, and the increase of IS labor prices) created $14.5 billion of consumer surplus.

2.2 IT Project Risks

Cash et al (1992) developed a framework to evaluate IT project risks as a function of three elements: how structured is the project, how much experience does the organization have with the technology to be used, and how big is the project. Small, well-structured projects dealing with technologies familiar to the organization have very low risk, while ill-defined big projects involving new technologies have the highest risk.

How structured is a project depends upon several factors. A project whose implementation requires changes in several functions of the business are likely to be less structured than those involving only one unit, given that a higher coordination among the different actors is needed. A similar situation occurs when the project involves many changes to existing business processes whose effects are difficult to establish at the beginning of the project.

The structure of the project is also a proxy for other organizational factors that affect the execution of the project, including the attitude of the end-user, the commitment of top management and the time that people will spend in the development of the project. A project in which the user has a positive attitude is less risky than one in which the user opposes its development. Commitment from the top executives might help overcoming the obstacles that are faced during the development of the project. Full time involvement has shown to improve the effectiveness of the project team and the communication between IT and business people.

Technology risk, on the other hand, is very much affected by the knowledge and skills that the corporation has with respect to the hardware, software and procedures associated with the project. Many IT projects have failed because either the IT developers or the users do not have the necessary experience with the technology being implemented.

Finally, project size is a proxy measure that reflects the amount of work to be done and the resources needed for such endeavor. Size is in some sense relative to the capability of the organization for delivering such projects. As a result, a project that might be considered big for a particular corporation might be categorized as medium for another one.

2.3 Classes of IT Investments and Option Pricing

Benaroch and Kauffman (1999) discussed the applicability of option pricing to the valuation of different classes of IT investment projects depending upon their inherent characteristics. They suggest that option pricing might be an adequate framework for evaluating the following types of IT investments:

- *IT infrastructure investments* provide growth opportunities for future investments and are often made without any immediate expectation of payback. Benefits are obtained only after a future investment translate these opportunities into operational IT projects that support a specific business process.

- *Emerging technology investments* are characterized both by a high uncertainty of their the value payoffs and costs. In this type of investments, the technical uncertainty can only be resolved during the execution of the corresponding project.

- *Prototyping investments* provide significant value by reducing the risk of a future application development project. Prototyping allows the users to better refine their requirements and this provides more structure to software development initiatives.

- *Technology-as-product investments* represent the case in which a core technology becomes the core of a new product. Similar to R&D projects, option pricing can be useful to decide when to enter, abandon or resume the development of such a product.

Lucas (1999, Chap. 10) also presented a taxonomy of IT investment opportunities by taking into consideration the type of IT investment as well as the motivation and urgency associated with them. IT investments having a high upside potential, high uncertainty and indirect returns are good candidates for being evaluated with an options framework. IT investments that cannot be postponed, such as those motivated by a competitive necessity or by a required need of doing business benefit less from this approach because waiting is generally not possible.

3 Valuation Model for IT Development Projects

In IT development projects, the uncertainty associated with the project costs continue to play a major role *after* the decision to start investing has been taken. In contrast with IT acquisition projects, no major cost is incurred when the project is started and no benefits are received until the project is completed. At time t, the decision maker has an estimate of the expected remaining cost of the project (K) and of the value of the asset that will be received when the project is finished (V). However, both variables are stochastic and the uncertainties are only resolved during the course of the project.

In our model the project is optimally executed without interruptions unless a catastrophic event 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. However, the volatility of costs and value might make attractive to wait before starting to invest even if the expected Net Present Value of the project is positive. The decision maker has to monitor the stochastic changes in K and V and determine when it is convenient to start the development of the IT asset or to abandon it.

The valuation model for IT development projects is based on Schwartz and Moon's (2000) model for evaluating R&D investments and on Pindyck's model (1993) for investments of uncertain costs. However, our model incorporates a new cost function that recognizes the decrease in the cost of IT assets over time regardless of whether the project has started or not.

3.1 Cost Uncertainty

In Pindyck's model (1993) for investment under uncertainty, the expected cost of completion of a project K(t) is assumed to follow a controlled diffusion process given by the following expression:

$$\mathrm{d}K = -I\ \mathrm{d}t + g(I, K)\ dz, \tag{1}$$

where I is the rate of investment, dz is an increment to a Wiener process that might or might not be correlated with the economy and the stock market, and g is a function such that $g_I \geq 0$, $g_{II} \leq 0$, and $g_K \geq 0$. According to this model, the expected cost to completion declines with ongoing investment but also changes stochastically. If $g_I > 0$, the effect of the stochastic component increases as we invest more in the project; if $g_{II} < 0$, the changes in these increasing effects will be smaller as we proceed forward; finally, if $g_K > 0$, the effect of the stochastic component decreases when the expected cost of completion is reduced.

Using this expression, and assuming a maximum rate of investment I_m and a given asset value V received at the end of the project (t= $\bar{\tau}$), Pindyck obtains the following formula for the value of the investment opportunity:

$$F(V, K) = \max_{I(t)} E_o \left[Ve^{-\mu\bar{\tau}} - \int_0^{\bar{\tau}} I(t) e^{-\mu\bar{\tau}} \mathrm{d}t \right],$$

subject to Eq. (1), $0 \leq I(t) \leq I_m$, and $K(\bar{\tau}) = 0$, where $\bar{\tau}$ is a stochastic variable representing the duration of the project, and is an appropriate risk-adjusted discount rate. In other words, the value of the investment opportunity is the maximum expected value that may be obtained for any investment policy *I(t).*

Pindyck also provides the following additional conditions for F(V,K) to make economical sense: a) F(V,K;I$_m$) is homogeneous of degree one in V, K and I$_m$; b) $F_K < 0$, so that an increase in the expected cost of an investment reduces its value; c) the instantaneous variance of dK is bounded for all finite K and approaches to zero as K □ 0; d) if the firms invests at the maximum rate Im until the project is complete, $E_O \left[\int_0^{\bar{\tau}} I_m \mathrm{d}t \right] = K$, so that K is indeed the expected cost to completion. The following expression for function g of Eq. (1) satisfies these restrictions:

$$g(I, K) = \beta\, K(I / K)^{\varphi} \text{ with } 0 \leq \varphi \leq 1/2$$

Since the extreme values of φ (0 and ½) result in simple corner solutions for optimal investment (i.e., the optimal investment strategy is either to invest zero or to invest at the maximum possible rate) the two cases are combined in the following equation:

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

where dz and dw are increments of uncorrelated Wiener processes. The second term in Eq. (2) 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 third 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.

Following Pindyck's reasoning, our model assumes that the expected cost to completion behaves as follows:

$$\mathrm{d}K = -I\ \mathrm{d}t + \delta K \mathrm{d}t + \beta(IK)^{1/2}\ dz + \gamma K \mathrm{d}w\,, \tag{3}$$

The term (δ K dt) describes the change in cost experienced by some IT assets over time. 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 δ = - ln (2)/1.5 = - 0.46.

3.2 Asset Value Uncertainty

In our valuation model for IT development projects we use a similar formulation of that proposed by Schwartz and Moon (2000) for evaluating R&D investments. This formulation assumes that the estimated value of the asset that the firm receives upon successful completion of the project follows this stochastic process:

$$\mathrm{d}V = \grave{\imath}_V V \mathrm{d}t + \acute{o} V dy \tag{4}$$

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 (Y) that is uncorrelated with the technical uncertainty in expected costs but that may be correlated with the market portfolio.

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

$$\mathrm{dw}\,\mathrm{dy} = \rho_{VK}\ \mathrm{dt} \tag{5}$$

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.

3.3 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 can use Ito's Lemma to obtain the following expression for the differential dF:

$$dF = \frac{\partial F}{\partial V} dV + \frac{\partial F}{\partial K} dK + \frac{1}{2}\frac{\partial^2 F}{\partial V^2} dV^2 + \frac{1}{2}\frac{\partial^2 F}{\partial K^2} dK^2 + \frac{1}{2}\frac{\partial^2 F}{\partial V \partial K} dV\,dK \tag{6}$$

Substituting this formula and Eqs. (3), (4) and (5) 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):

$$\underset{I}{\text{Max}}\begin{bmatrix} \frac{1}{2} s^2 V^2 F_{VV} + \frac{1}{2} b^2 IK\, F_{KK} + \frac{1}{2} \tilde{a}^2 K^2 F_{KK} + \tilde{n}_{VK}\, s\, \tilde{a} VKF_{VK} + \left(m_V - \text{ç}_V \right) V F_V \\ -\left(I - d\,K - \text{ç}_K \right) F_K - (r_f + l)\, F - I = 0 \end{bmatrix} \tag{7}$$

Equation (7) is a linear function of I. Therefore, the optimal investment policy will be either to set I=0 or to set I=I_m depending whether the slope of the corresponding line is positive or negative:

$$I = \begin{cases} I_m & \text{if } \frac{1}{2}\beta^2 KF_{KK} - F_K - 1 \geq 0 \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

As a result, Eq. (7) has a free boundary along the line of critical asset values V*(K) such that I=Im when the asset value is greater than V*(K) and 0 otherwise.

Equation (7) is subject to the following boundary conditions:

$$F(V,0) = V \tag{9}$$

$$F(0,K) = 0 \tag{10}$$

$$\lim_{K \to \infty} F(V,K) = 0 \tag{11}$$

Equation (9) indicates that at the end of the project (K=0) we obtain the underlying asset V. Equation (10) 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 (11) indicates that when the remaining costs are very large the value of waiting decreases asymptotically to zero.

3.4 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}:

$$NPV(V,K) = V_{PV} - K_{PV} \tag{12}$$

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 Eq. (3) by setting K=0 when the project is completed and assuming that there is no uncertainty ($\beta=\gamma=0$):

$$D = \frac{1}{\delta}\ln\left(1-\delta\frac{K}{I_m}\right) \tag{13}$$

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:

$$D^* = \frac{1}{\delta}\ln\left(1-\delta\frac{K}{I_m-\eta_K}\right) \tag{14}$$

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:

$$\mathrm{V(D)} = V(0)\, e^{\,m_V D^*} \tag{15}$$

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:

$$V_{PV} = V(0)\; e^{-(r_f + l + h_V - m_V)D^*} \tag{16}$$

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:

$$K_{PV} = E_o\left[\int_0^{D^*} I_m e^{-(r_f+\lambda)}\,\mathrm{d}t\right] = \frac{I_m}{r_f+\lambda}\left[1-e^{-(r_f+\lambda)D^*}\right] \tag{17}$$

Note that the same result for the NPV of the project can be obtained directly by solving Eq. (7) 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) gives the value of the *option* that the organization has for *waiting* before investing in the IT asset and the *option* to *stop investing* if conditions deteriorate. Table 1 shows the different situations that may be encountered in an IT development project. Whenever the difference between F(V,K) and NPV(V,K) is positive and 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(C,t) > 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

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

3.5 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 Expected Costs	0 to 10 million		Range of Expected Asset Value	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 (Eq. (7)) using an iterative procedure known as *successive over relaxation* (Press, Teukolsky 1992, p. 854). For this purpose, the (V,K) space is represented by means of a grid of points and partial derivates are approximated using finite differences. An starting solution is obtained by computing the NPV(V,K) at each point of the grid and by determining an initial boundary V*(K). At each iteration, the algorithm computes the value of condition (8) $\frac{1}{2}\beta^2 KF_{KK} - F_K - 1$ for each point of the grid to determine if I is set to zero or to its maximum value Im. This information is used to compute the matrix of coefficients for the corresponding linear system of equations that is derived from the finite differences. A new solution is then obtained by solving these equations taking into consideration the residuals and the boundary conditions of Eqs. (9), (10) and (11). This new solution is combined with the values corresponding to the previous solution and the algorithm proceeds to the next iteration. The procedure continues until convergence is obtained.

Figure 3 shows the values of the investment opportunity F(V,K) for different values of variables V and K. For a given expected cost of completion K, the project becomes more attractive when the value of the asset V increases. This is similar to what we encounter when we value a project by the conventional NPV as the difference between these two values (V-K). However, in contrast with NPV, the value of the investment opportunity is not a straight line but asymptotically decreases to zero when V is reduced.

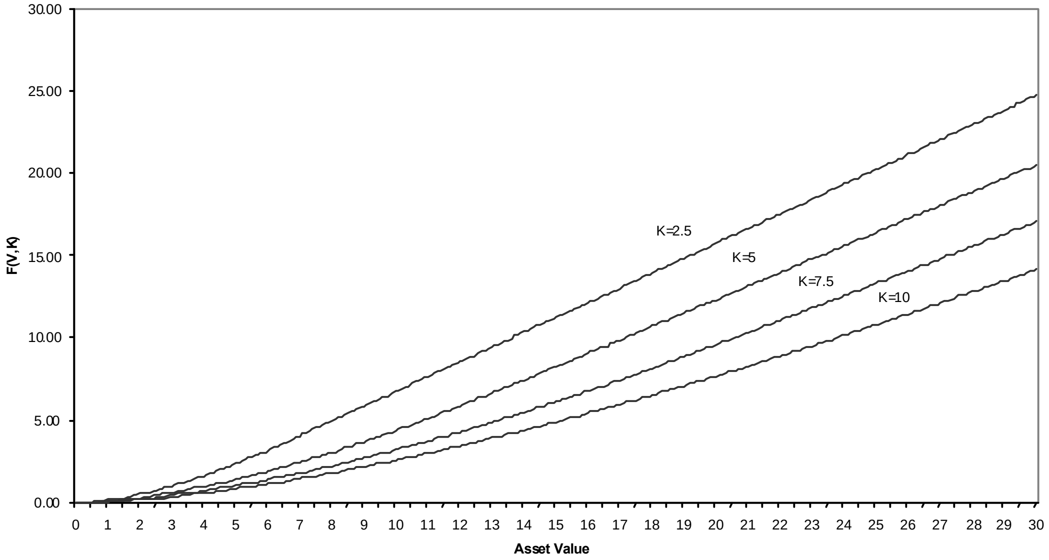

Figure 3. Value of the Investment Opportunity for the Example Development Project (Base Case)

Figure 4 shows the impacts 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).

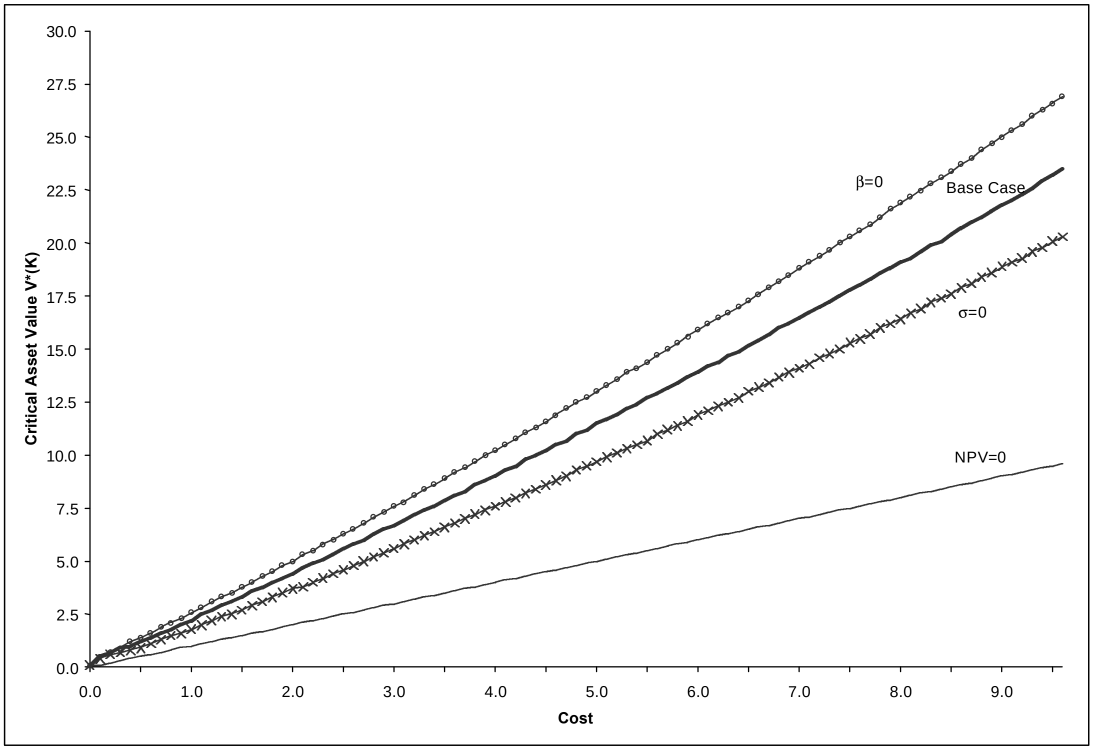

Figure 4. Impacts of Uncertainties in Critical Asset Values for the Example Development Project

Figure 5 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.

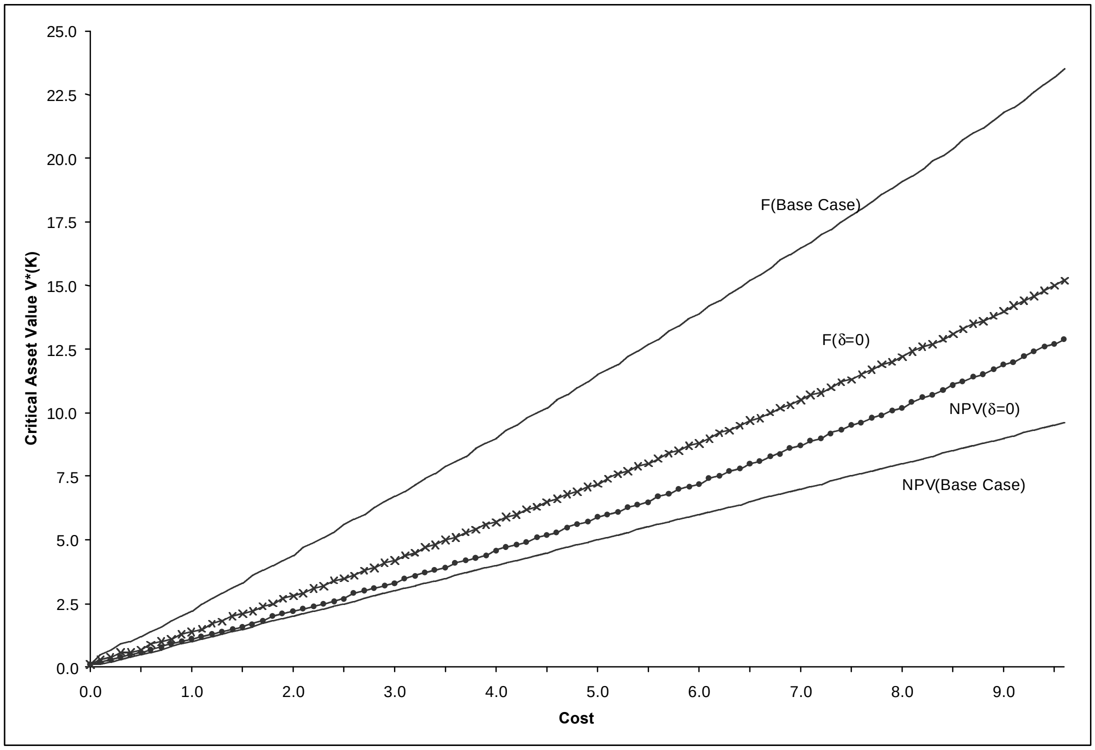

Figure 5. Impact of Cost Decay (δ) in Critical Asset Values for Example Development Project

Figure 6 shows the difference between the value of the investment opportunity determined by the model F(V,K) and the conventional NPV(V,K) for a situation in which the expected completion cost of the project K is equal to 5. Note that the value of keeping the option alive (i.e., waiting) is higher when the expected asset value is close to the expected completion cost. In this region, it is better to wait to see if the project becomes more attractive before investing or deciding to abandon it. When V is substantially larger than K, waiting becomes less attractive and there is a point in which we should exercise the option to invest (F=NPV).

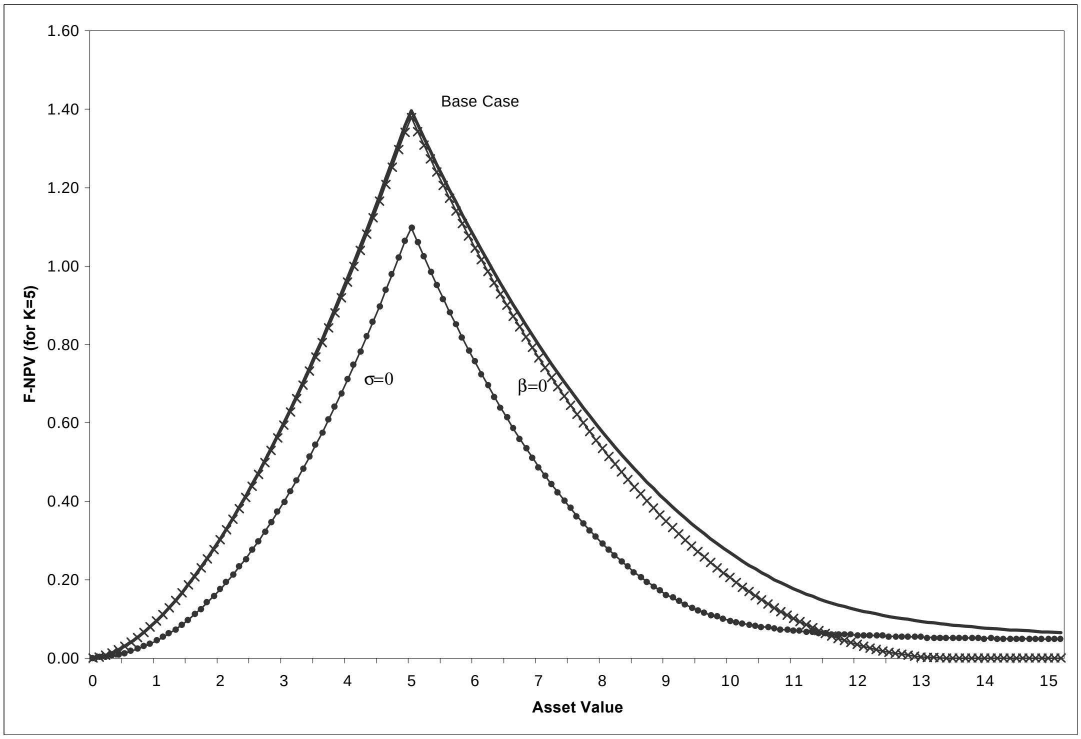

Figure 6. Value of Waiting for the Example Development Project (K=5)

4 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). Certainly, there might be changes in operating costs that are incorporated into the stochastic cash flows (C). However, most of the investment takes place in a particular point of time. In the model, it is assumed that the investment K 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 K and C and determine when it is convenient to acquire the IT asset.

4.1 Cost Uncertainty

The cost of acquiring the IT asset (K) is assumed to evolve according to the following expression:

$$\mathrm{d}K = \delta K\,\mathrm{d}t + \gamma K \mathrm{dw} \tag{18}$$

As in the valuation model for IT development projects, the term (δ K dt) with $\delta < 0$ describes the drop in cost experienced by some IT assets through time. However, in this case we have removed the two terms associated with the *technical uncertainty* of the project ($\beta(IK)^{1/2}$) and with the investment over time (-I dt) of our previous model since no development process is taking place. Therefore, the expected cost of the IT asset only changes in response to an exogenous drop in price and to random changes in input labor costs.

4.2 Cash flow Uncertainty

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

$$\mathrm{d}C = \alpha\, C\,\mathrm{d}t + \phi\, C\,\mathrm{dx} \tag{19}$$

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 (X) that might be correlated with the market portfolio (or aggregate wealth) as well as with the stochastic process associated with the costs (W).

4.3 Value of the IT Asset

The value of the IT asset at a particular time $0 \le t \le T$ 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:

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

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

$$\mathrm{d}C = (\alpha - \eta_C)\, C\,\mathrm{d}t + \phi\, C\, \mathrm{dx}^* = \alpha^* C\,\mathrm{d}t + \phi\, C\, \mathrm{dx}^*$$

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

$$V(C,t) = \frac{C}{r_f - \alpha^*}\left[1 - e^{-(r_f - \alpha^*)(T-t)}\right] \tag{20}$$

If T→∞, this expression leads to the well known formula for the present value of an infinite stream of cash flows compounded continuously and growing at a rate * (for $\alpha^* < r_f$):

$$V(C,t) = \frac{C}{r_f - \alpha^*}$$

When T is infinite, the value of the asset would not be affected if we delay the decision to invest. However, in cases in which T is finite, V(C,t) decreases as t approaches T.

Note that these expressions for V(C,t) do not depend on the uncertainty in the cash flows (ϕ). Only the expected value of the cash flows is important for computing the value of the corresponding asset.

4.4 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 d*F*:

$$dF = \frac{\partial F}{\partial t}dt + \frac{\partial F}{\partial C}dC + \frac{\partial F}{\partial K}dK + \frac{1}{2}\frac{\partial^2 F}{\partial C^2}dC^2 + \frac{1}{2}\frac{\partial^2 F}{\partial K^2}dK^2 + \frac{1}{2}\frac{\partial^2 F}{\partial C\,\partial K}dC\,dK \tag{21}$$

In this case we have introduced the partial derivative of F with respect to time because its value depends on how close we are from the end of the life period of the technology. The longer the period in which we expect to receive C(t), the more attractive the project becomes. As a result, two investment opportunities with the same expected cost and cash flows, but with different lives, will have different values.

The Bellman equation of optimality (Pindyck 1993) becomes:

$$r_f F = \frac{1}{dt} E_Q\left[dF\right] \tag{22}$$

where E_Q denotes expected value under the risk neutral measure. By substituting Eqs. (18), (19) and (21) into Eq. (22), the following second order parabolic differential equation is obtained:

$$\frac{1}{2}\phi^2 C^2 F_{CC} + \frac{1}{2}\text{ã}^2 K^2 F_{KK} + \text{ñ}_{CK}\,\phi\,\text{ã} CKF_{CK} + (\text{á} - \text{ç}_C) CF_C + \\ (\delta - \text{ç}_K) KF_K + F_t - r_f F = 0 \tag{23}$$

The solution to Eq. (23) must satisfy the following boundary conditions:

$$F(C,K,T) = 0 \tag{24}$$

$$F(C,K,t) \geq \max\{0, V(C,t) - K(t)\} \tag{25}$$

Equation (24) 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 (25) 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.

4.5 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,K,t):

$$NPV(C,K,t) = V(C,t) - K(t) \tag{26}$$

The traditional criteria for project evaluation indicates that whenever NPV > 0, the firm should invest in the project. Conversely, when the cost of the IT asset is greater than the expected present discounted value of the stream of future differential cash flows, it is better not to acquire the IT asset. However, due to the volatility of the costs and cash flows this criteria might be wrong. In some situations, it is wrong to invest even if the expected NPV is positive. Again, the difference between the value of the investment opportunity, F(C,K,t), and expected Net Present Value, NPV(C,K,t), gives the value of the *option* that the organization has for *waiting* before investing in the IT asset.

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,K,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. There is no reason for abandoning the project, since the investment opportunity will be available during the whole interval.

Table 3. Optimal Decisions for IT Acquisition Projects under Uncertainty

Expected 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
$NPV(C,K,t) = 0$	$F(C,K,t) > NPV(C,K,t)$	+	Wait (if possible) or indifferent (if waiting is not allowed)
$NPV(C,K,t) < 0$	$F(C,K,t) > 0$	+	Wait (if possible) or do not acquire the asset (if waiting is not allowed)

4.6 Example of an IT Acquisition Project

Suppose that an organization is evaluating whether to modernize its manufacturing process by acquiring a new generation of programmable automation machines whose technology is expected to be supported by the supplier for the next ten years. Following Kelley's model, the firm expects to reduce its unit production hours, currently representing 3.75 million dollars per year, by an average 40% or 1.5 million dollars per year. However, the value of the expected cash flows changes stochastically over time and so does the cost of the machines. Currently, the machines cost an estimate of 5 million dollars but their price drops an average of 20% per year. Using the parameters shown in Table 4, 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, for different cash flows and costs.

Table 4. Parameters for the Example IT Acquisition Project (Base Case)

Cost Parameters			*Cash flow Parameters*		
Range of Expected Costs	0 to 10 million		Range of Expected Cash flows	0 to 3 million per year	
Input Costs Uncertainty	γ	0.1	Drift in Cash flow Value	α	-0.05
Rate of Cost Change	δ	-0.2	Cash flow Uncertainty	ϕ	0.2
Adjustment for Risk in Costs	η_K	0	Risk premium on Cash flow Value	η_C	0.02
Other Parameters			Time to Maturity	T	10 years
Risk-free rate	r_f	0.06	Correlation between C and K	ρ_{CK}	0.0

We solved the second order parabollic equation of the model (Eq. (23)) using the *alternating direction implicit* method (Press, Teukolsky 1992, p. 847). For each time slice t, a (V,K) grid of points is formed and partial derivates are approximated using finite differences. First, the solution for time t=T is obtained by using the boundary condition of Eq. (24). Then, the algorithm proceeds backwards in time, solving the corresponding linear system of equations that is derived from the finite differences for each of the time slices.

Figure 7 shows the impact of uncertainty in the computation of the critical cash flow values C*(K,t) that are needed to make the investment immediately at a particular time t<T. Similar to what we found earlier, uncertainties make the decision to invest immediately less attractive (i.e., there is a value in waiting). Therefore, higher critical asset cash flows are required in order to acquire the IT asset. However, instead of having a single threshold for a given cost, critical cash flow values increase as we approach the end of the period in which the technology is considered to be effective.

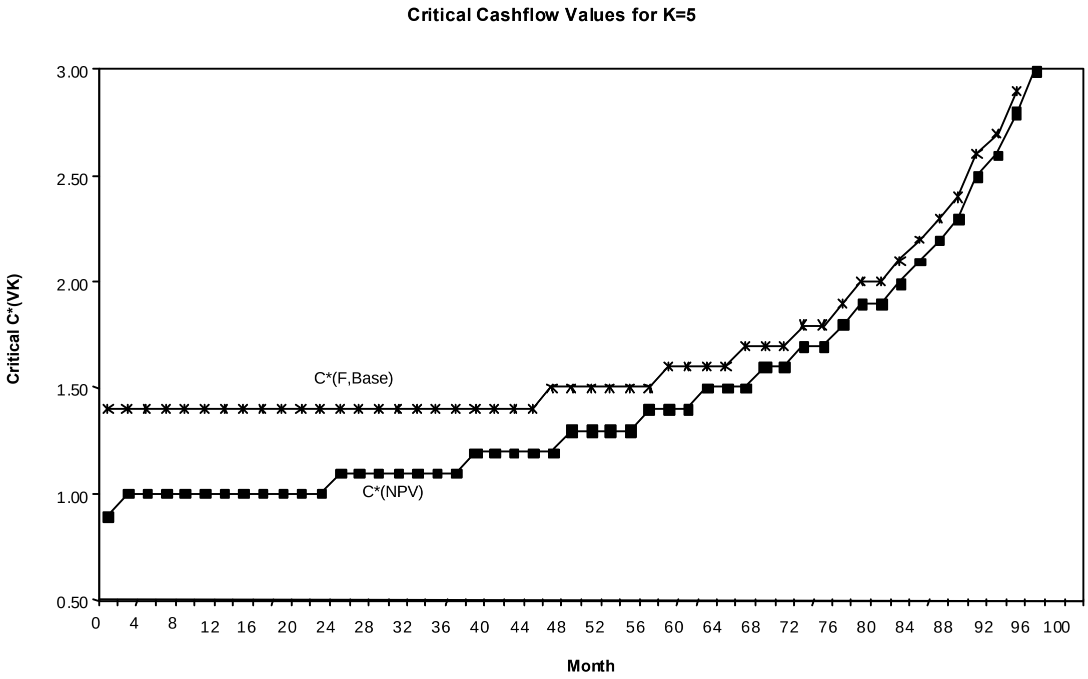

Figure 7. Impacts of Uncertainties and Time in Critical Asset Values for the Example Acquisition Project

Figure 8 shows the impacts of uncertainties in F(C,K,t) and NPV(C,K,t) for the example acquisition project when the expected cost is 5 million and the decision to invest is analyzed in month 60. The critical value in which NPV=0 is (solving for C in Eq. (20)):

$$C^*(5,60) = 5 * \frac{(0.06-(-0.05-0.02))}{(1-e^{-(0.06-(-0.05-0.02))(120-60)/12})} = 1.36$$

For smaller values of C, NPV is negative and the value of the investment opportunity F(C,K,t) asymptotically approaches zero. For higher values of C, F asymptotically approaches NPV and there is a point in which the difference between both methods is zero (critical cash flows). Note that the difference between F and NPV is higher under uncertainty and smaller when no decay in costs is experienced over time.

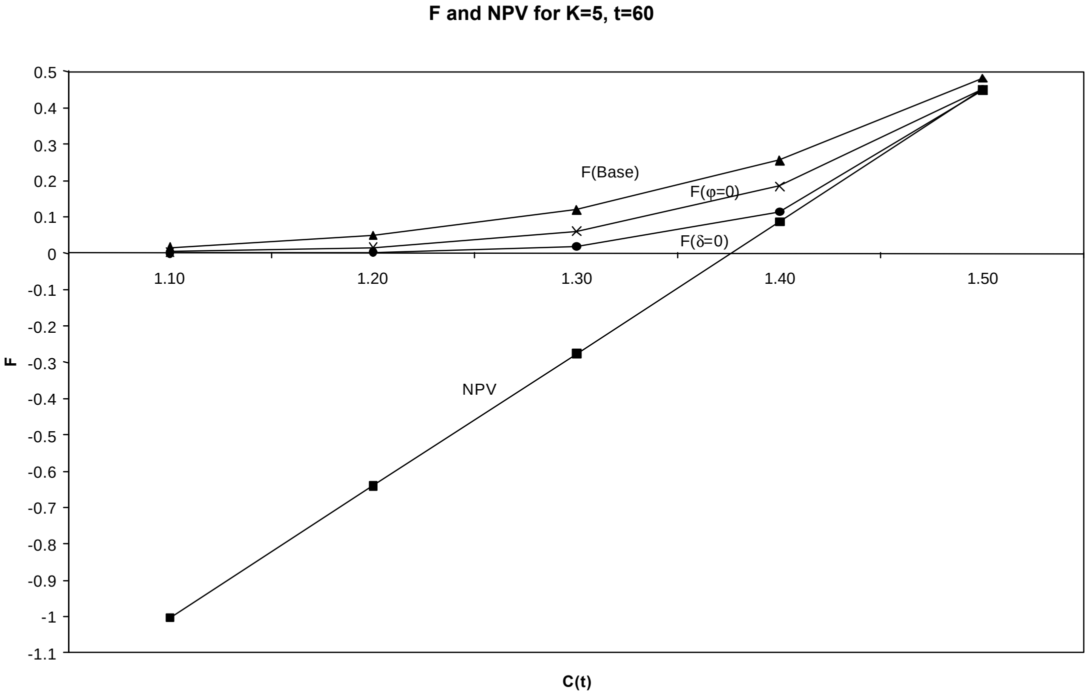

Figure 8. Impacts of Uncertainties in the Value of the Investment Opportunity and NPV for the Example Acquisition Project (t= 60 month, K=5 million)

Figure 9 shows the difference between both valuation methods when NPV is positive for various values of K at the end of the first year. In this case, the decision maker should wait even though the NPV criteria would suggest to acquire the IT asset immediately. For instance, for C=1.0 million, K=5 million and t=12 months, NPV= 0.279 but F=0.715 and the difference option to wait is worth 0.436 or $436,000 dollars. Note that the value of waiting is greater for higher values of K.

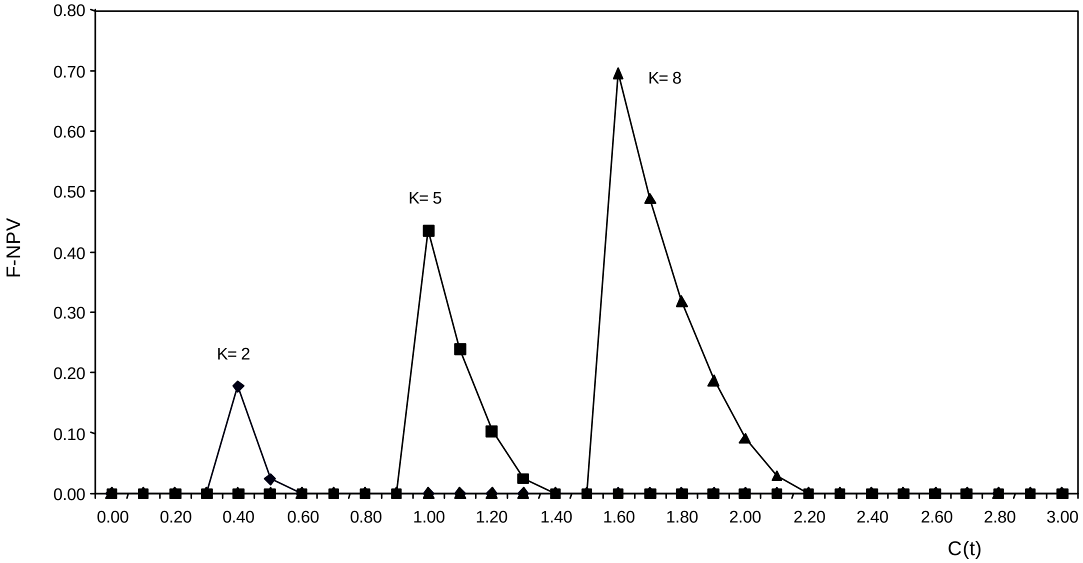

Figure 9. Difference between the Value of the Investment opportunity and NPV (> 0) for the Example Acquisition Project for various Costs (t= 12)

Figure 10 shows the impact of cash flow uncertainty in the middle curve of Figure 9. The higher the uncertainty, the more valuable it becomes to wait before buying the IT asset. A similar situation occurs with respect to uncertainly in the costs. Finally, Figure 11 shows the variation of the option to wait for a pair of C and K over time. For K=2 or 5, the option value of waiting when t is close to zero is zero, since it is optimal to invest immediately. As we move forward in time, we reach a point in which the option value of waiting becomes positive because NPV gets closer to zero. Then, the option value of waiting decreases asymptotically to zero as t approaches T and NPV becomes increasingly negative. Note that at early times the option value is zero because it is optimal to invest immediately, but at times close to maturity the option value is zero because both the NPV and F are zero and it will never be optimal to invest.

For K=8 we should not invest immediately when t=0 because the option value of waiting is positive. Then, as we move forward in time, this value decreases and reaches a value close to zero as t approaches T.

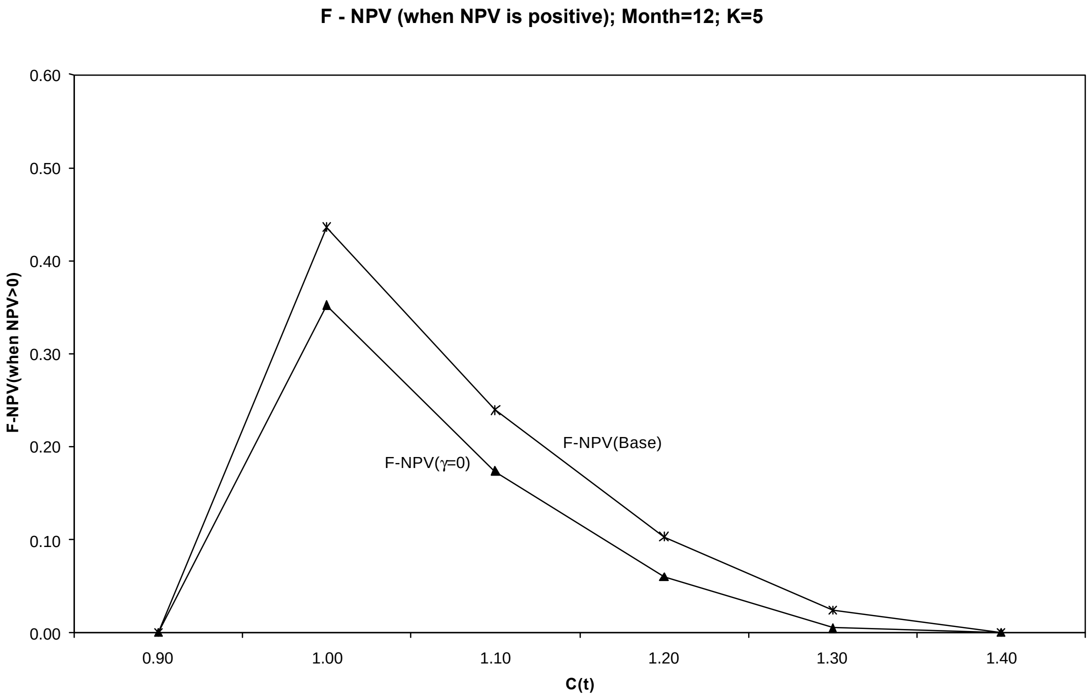

Figure 10. Impacts of Uncertainties in the Difference between the Value of the Investment opportunity and NPV (> 0) for the Example Acquisition Project (t= 12, K=5 million)

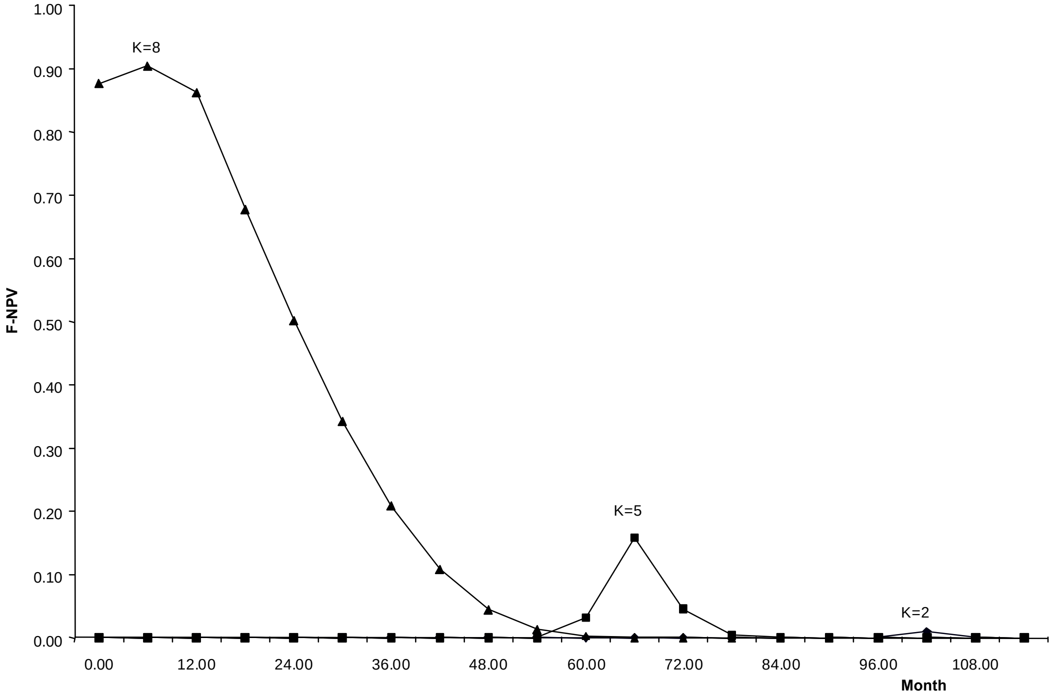

Figure 11. Impacts of Uncertainties in the Difference between the Value of the Investment opportunity and NPV (> 0) for the Example Acquisition Project (C=1.5 million)

5 Valuating the Yankee 24 Project

Benaroch and Kauffman (1999) used a Black-Scholes approximation (Hull 1997, p. 252) to evaluate a 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 the IT Acquisition model developed in Section 4 to this real world problem using the data provided in the Benaroch and Kauffman article.

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 as soon as it starts operations. Finally, the time horizon of the project was considered to be five years and a half.

Table 5. 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 12 shows a first approximation of 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 considerations were made:

- The operational marketing costs were added to the initial investment. Since the operation cost per year is constant, we modified Eq. (18) to include a constant decay in cost rather than a proportional decay. Therefore, the cost of acquiring the IT asset (K) will evolve according to following expression:

$$\mathrm{d}K = \delta \mathrm{d}t + \gamma K \mathrm{dw} \tag{27}$$

where δ is the marketing operational cost per year (δ = -\$ 40,000) and γ is the volatility of the costs. Since these are assumed to be 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, the value of the asset V(C,t) becomes:

$$V(C,t) = \frac{C}{r_f - \alpha^*}\left[e^{-(r_f - \alpha^*)\tau} - e^{-(r_f - \alpha^*)(T-t)}\right] \tag{28}$$

where $\alpha^* = (\alpha - \eta_C)$ and τ = 1 year. Note that this expression reduces to Eq. (20) when cash flows start to be received immediately (τ = 0).

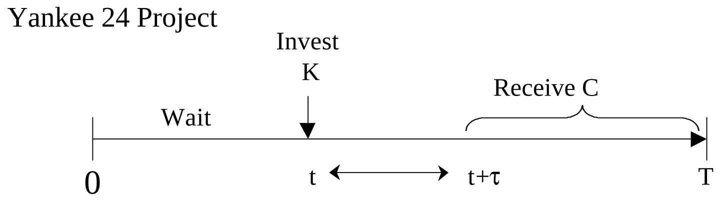

Figure 12: Conceptualization of the Yankee 24 Project as an IT Acquisition Project

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 6 summarizes the parameters for the base case of the Yankee 24 project. Even though the original example considered the costs to be constant, we will 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 6. Parameters for the Yankee 24 Project (Base Case)

Cost Parameters			*Cash flow Parameters*		
Range of Expected Costs	0 to $ 600,000		Range of Expected 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 7 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. 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. Once again, note that only for Jul-90 the expected rate of the cash flows is above the corresponding critical value.

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 7 only displays the results of the valuation for the expected costs at the expected cash flow rates at the beginning of each semester. As we move forward in time, however, Yankee 24 might encounter that it needs to update the previous values of these variables used for the initial valuation of the project. However, as long as the parameters of Table 6 remain constant, there is no need to solve again the partial differential equation. Management would only need to check the values of F and NPV for the actual values of C and K to determine what the optimal decision would be (wait, invest or abandon).

Table 7. 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.

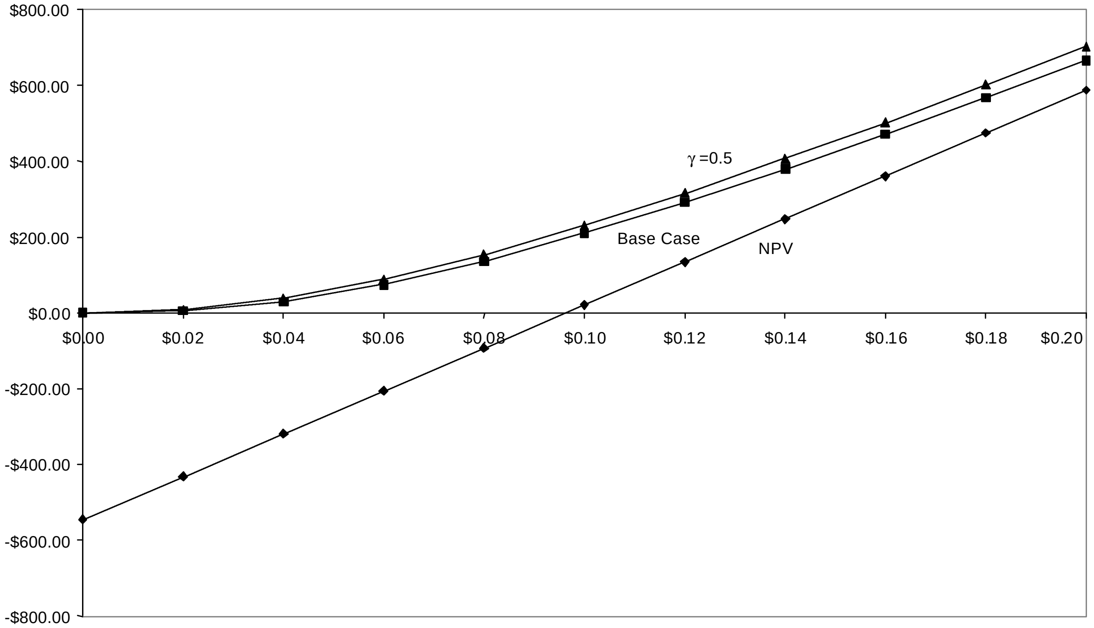

Figure 13. Impact of Cost Uncertainty in the Value of the Investment Opportunity and NPV for the Yankee 24 Project (t= 0, K(0)=$546) (thousands)

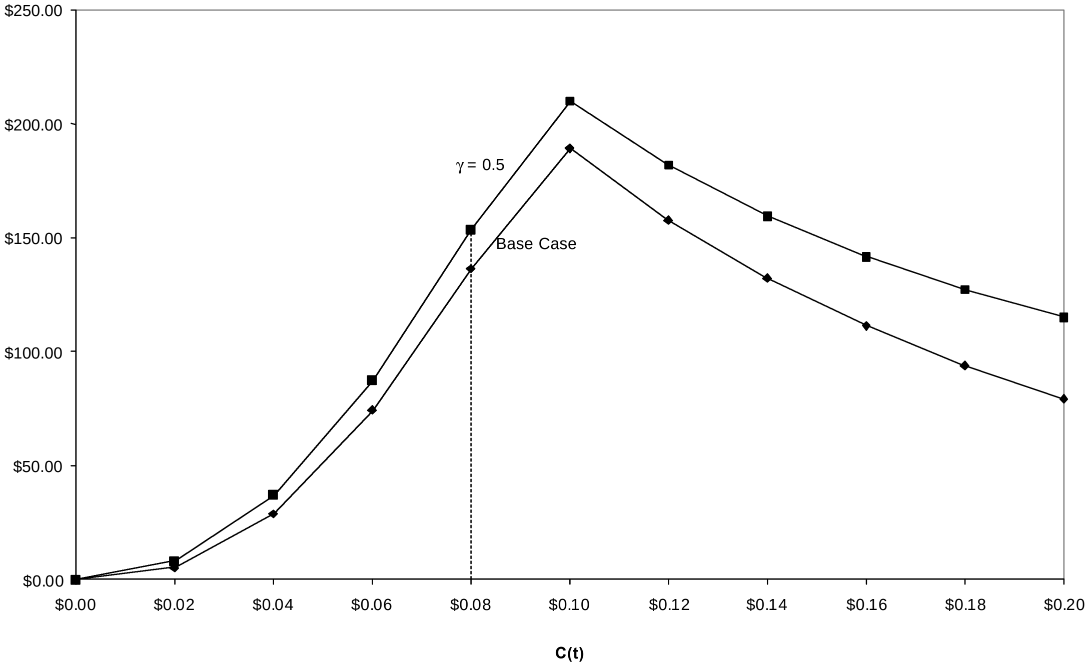

Figure 14. Impact of Cost Uncertainty in the Difference between the Value of the Investment opportunity and NPV (> 0) for the Example Acquisition Project (t= 0, K(0)=546) (thousands)

6 Summary and Conclusions

In this paper we developed 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. In contrast with previous work, both models take into consideration the particular decay in costs experienced by some IT assets over time.

Both models 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.

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 5, we can easily adapt the acquisition model for this purpose.

The models described in the paper represent a formal scientific approach for evaluating investments in projects characterized by high degree of uncertainty in the different variables associated with them These models could act as the building blocks of more comprehensive frameworks that extend the scope of our work. An interesting extension would be to model the process of sequential investments in substituting technologies. 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.

The next step will be to take a specific case of IT investment and estimate all the parameters needed for the valuation. This implementation stage is not trivial and will be the subject of our future research.

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