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Justifying Electronic Banking Network Expansion Using Real Options Analysis

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JUSTIFYING ELECTRONIC BANKING NETWORK EXPANSION

USING REAL OPTIONS ANALYSIS

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Brief Biographies

Michel Benaroch is an Associate Professor of Information Systems in the School of Management, Syracuse University. His current research interests focus on knowledge modeling, evaluation of investments in information technology using option-pricing models, and intelligent decision support methods in Finance and Economics. He has published in a variety of outlets, including *Information Systems Research, IEEE Transactions on Knowledge and Data Engineering, International Journal of Human-Computer Interaction, Decision Sciences, International Journal of Economic Dynamics and Control, Decision Support Systems,* and *INFORMS Journal on Computing.* He was twice the recipient of the "Exceptional Research and Scholarship Award" at Syracuse University (1996 and 1998).

Robert J. Kauffman is an Associate Professor of Information Systems at the Carlson School of Management of the University of Minnesota. He specializes in research on financial information systems, evaluation of information technology investments and the adoption of new technologies. His papers have appeared in *Information Systems Research, MIS Quarterly, IEEE Transactions on Software Engineering, Decision Sciences, Electronic Markets, the Journal of Management Information Systems, Information and Software Technologies,* and elsewhere. He is a past co-chair of the Workshop on IS and Economics (1991 and 1998) and recently guest-edited special issues of *Communications of the ACM* and the *Journal of Organizational Computing and Electronic Commerce* on information systems research issues involving theoretical perspectives from economics and finance.

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Abstract

The application of real options analysis to information technology investment evaluation problems recently has been proposed in the IS literature by Dos Santos (1991), Kambil et al. (1993), Kumar (1996), Chalasani et al. (1997), and Taudes (1998). The research reported on in this paper illustrates the value of applying real options analysis in the context of a case study involving the deployment of point-of-sale (POS) debit services by the Yankee 24 shared electronic banking network of New England. In the course of so doing, the paper also attempts to operationalize real options analysis concepts by examining claimed strengths of this analysis approach and balancing them against methodological difficulties that this approach is believed to involve. The research employs a version of the Black-Scholes option-pricing model that is adjusted for risk-averse investors, showing how it is possible to obtain reliable values for Yankee 24's "investment timing option", even in the absence of a market to price it. To gather evidence for the existence of the timing option, basic scenario assumptions and the parameters of the adjusted Black-Scholes model, a structured interview format was developed. The results obtained using real options analysis enabled the network's senior management to identify conditions for which entry into the POS debit market would be profitable. These results also indicated that, in the absence of formal evaluation of the timing option, traditional approaches for evaluating information technology investments would have produced the wrong recommendations.

Keywords: Black-Scholes model, investment decisionmaking under uncertainty, electronic banking networks, POS debit systems, project investments, IT investment evaluation, option-pricing models, real options.

ISRL Categories: AK0101 Financial Models, AM Economic Theory, DB03 Finance, EF07 IS Investments, EI01 Evaluation Methods, EI225 Strategic Impacts, HB05 Banking IS, HB11 Financial IS.

JUSTIFYING ELECTRONIC BANKING NETWORK EXPANSION USING REAL OPTIONS ANALYSIS

"When you make an initial investment in a research project, you are paying an entry fee for a right … To me, all business decisions are options."
-- J. Lewent, CFO Merc & Co., in a Harvard Business Review Interview, (Nichols, 1994).

"I have become convinced that it is time to revisit the usefulness of NPV and to reconsider just how much stock we want to place in it. … For most investments, the usefulness of the NPV rule is severely limited. If modern finance is to have a practical and salutary impact on investment decisionmaking, it is now obligated to treat all major investment decisions as option pricing problems."
-- Stephen Ross, Yale University Sterling Professor of Economics and Finance, in a keynote speech to the 1994 Financial Management Association Annual Meeting.

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1. Introduction

The application of option pricing models (**OPM**) to information technology (**IT**) investment evaluation problems recently has been proposed in the information systems (**IS**) literature by Dos Santos (1991), Kambil et al. (1993), Kumar (1996), Chalasani et al. (1997), and Taudes (1998). These papers make a strong case for new methods, in addition to traditional net present value (**NPV**) or discounted cash flow (**DCF**) approaches, and especially in lieu of leaving hard decisions that senior managers face regarding IT investment to experienced intuition. Benaroch and Kauffman (1999) are the first to follow up on these proposals. They examine the theoretical basis for applying OPMs to IT investment evaluation as well as the range of evaluation situations where various OPMs can be applied in light of their underlying assumptions. Moreover, they illustrate the feasibility of using a specific OPM, the *Black-Scholes model*, to analyze a real deferral option on the deployment of point-of-sale (**POS**) debit services by the Yankee 24 shared electronic banking network of New England.

Yet, to date there has not been a study that truly tests the claimed strengths of OPMs in the context of IT evaluation problems, while balancing these strengths against the methodological difficulties that OPMs are believed to involve. The need for such a study is fueled by the expansion of work on real options along two fronts. On one front, the business world started to seriously attempt to apply OPMs. For example, in a Harvard Business Review interview, the Chief Financial Officer of Merck & Co., discusses ways her firm evaluates R&D projects intended to yield new drugs by applying OPMs to abandonment, growth and investment staging options embedded in these projects (Nichols, 1994). Trigeorgis (1996) provides other examples of how these models are applied to real-world business investments, including natural-resource mining projects involving deferral, abandonment, and expansion options.

Along another front, recent empirical studies have begun providing evidence in favor of using OPMs. In a survey of how financial officers deal with flexibility in capital appraisal, Busby and Pitts (1997, p. 169) found that "Very few decisionmakers seemed to be aware of real option research but, mostly, their intuitions agreed with the qualitative prescriptions of such work." Axel and Howell (1996) offer stronger results based on a laboratory study with 82 experienced managers from large British companies. The study found that managers unaided by OPMs tended to overvalue real options, although their valuations did not differ significantly from those produced by these models. While this study suggests that managers can decide in a manner analogous to OPMs without having learned these models, it also shows that the least overvaluation tendency was among managers from the oil and pharmaceutical industries, two industries already using real option models in capital budgeting. Overall, the study indicates that OPMs are adequate for formalizing managers' intuition, and that familiarity with these models can improve the valuation of investments involving options.

In this light, the present paper seeks to evaluate and operationalize relevant real options analysis concepts in the IS context. Relative to our earlier paper (Benaroch and Kauffman, 1999), the intended contribution of this paper is threefold.

1. We present the case study details behind Yankee 24's IT investment in POS debit services (the example in (Benaroch and Kauffman, 1999)), describe the structured interview used to obtain from Yankee 24's senior management evidence that enabled us to analyze this investment from a real options perspective, and subsequently use the analysis results to offer case study insights specific to electronic banking service deployment decision-making.
2. We put to a real test the claimed strengths and weaknesses of the Black-Scholes model, to show the pragmatic value of applying this model to realistic IT investment evaluation problems. We specifically focus on two traits of the model. One trait concerns the investor's risk preferences assumed. In (Benaroch and Kauffman, 1999) we explained the economic basis for the risk-neutral valuation (defined later) of the Black-Scholes model being valid in the context of IT investments embedding options, even in the absence of a market for IT investments. Yet, some researchers and practitioners continue to claim that this model would tend to overvalue options because decision-makers are usually

risk-averse. Subsequently, we investigate the extent to which this claim applies to the analysis results that the Black-Scholes model produces for our case, by adjusting these results for risk-averse investors. The second trait pertains to sensitivity analysis. In (Benaroch and Kauffman, 1999) we presented the Black-Scholes' partial derivatives as a powerful sensitivity analysis tool. We scrutinize this claim in the context of our case, showing that the use of partial derivative analysis must be largely supplemented by the use of conventional simulation-based sensitivity analysis.

3. We examine methodological issues involved in using OPMs. We discuss factors that must be carefully analyzed before an IT investment decision like the one we study can be cast as a real options analysis problem (what kind of option is involved, what is the option's underlying asset, where does the option come from and at what cost, etc.). We also assess the claim that the estimation of certain option parameters (e.g., variability of the option's underlying asset) involves major difficulties, and thus present practical guidelines that can help to alleviate those claimed difficulties.

The rest of this paper is organized as follows. Section 2 introduces the fundamentals of OPMs and then explains why these models can be applied to IT investments embedding options. Section 3 discusses preliminary case study details that enable the reader to understand the nature of Yankee 24's IT investment decision and the need to apply real options analysis to this decision. Section 4 analyzes Yankee 24's investment decision from a real options perspective. It outlines the structured interview we conducted with Yankee 24's senior executives in order to obtain details for framing the decision as a real deferral option and to elicit parameter values for the OPM used. It also presents the analysis results and examines the ability of partial derivative analysis concepts to deliver useful investment decisionmaking guidance. Finally, it offers a retrospective interpretation of why the recommendations that our real options analysis yielded would have been well suited to what actually happened in Yankee 24's markets. Section 5 concludes with a discussion of the primary contributions of this research, and revisits some methodological issues that warrant additional investigation.

2. Pricing Real IT Investment Options

We next review the concepts underlying real options analysis, and the fundamental models for analyzing project investment decisions involving real options. We also discuss the economic rationale underlying the use of option pricing models to the evaluation of IT investments embedding real options.

2.1. Value of Managerial Flexibility and Project Evaluation Methods

Research on real options seeks to address criticism concerning the inadequacy of traditional capital budgeting methods for evaluating a project that offers management the flexibility to take actions which can change traits of the project over time (Dixit and Pindyck, 1994). The term *flexibility* is "nothing more (or less) than a description of the options made available to management as part of the project" (Mason and Merton, 1985, p. 32). This flexibility adds value to the *passive NPV* of a project, where one has assumed that no in-project actions are possible to affect its expected value outcomes. It changes the probability distribution of project payoffs asymmetrically, by enhancing the upside potential or reducing the downside risk. This corresponds to the notion of an *active NPV*, whose expected value trajectory is controllable by management. Figure 1 illustrates these changes and provides examples of specific real options that cause them. Real options offering in-project flexibility are termed *operating options*. They differ from so-called *growth options* whose value stems from future investment opportunities that they open up. For more background information on real options from the capital budgeting literature, the reader can see Trigeorgis (1996), Amram and Kulatilaka (1999), and Dixit and Pindyck (1994).

Figure 1: Asymmetry of the probability distribution of project payoffs when real operating options are involved

Examples (left)

EXPAND: ability to scale up a project investment when market demand for products or services produced by the project appears to be building

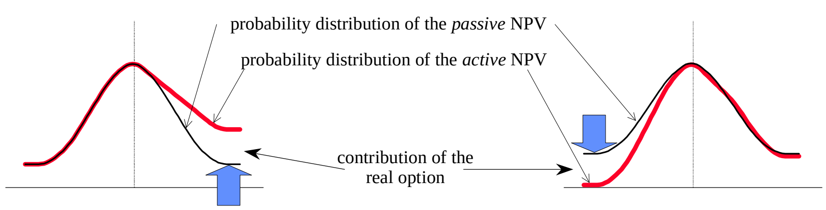
DEFERRAL: deferring a decision to invest in one IT instead of another (e.g., Windows vs. OS/2) may allow buying into emerging standards

Examples (right)

ABANDONMENT: ability to abandon an ongoing project investment and to direct salvageable resources to alternate more valuable uses

DEFERRAL: ability to defer a project until a new less costly technology is proven feasible, without losing the investment opportunity

LEASING: ability to outsource a project in order to "transfer" the risk of project failure



Option enhances the upside potential by possibly opening future project investment opportunities, thus pushing upwards the right tail of the probability distribution of the investment outcome

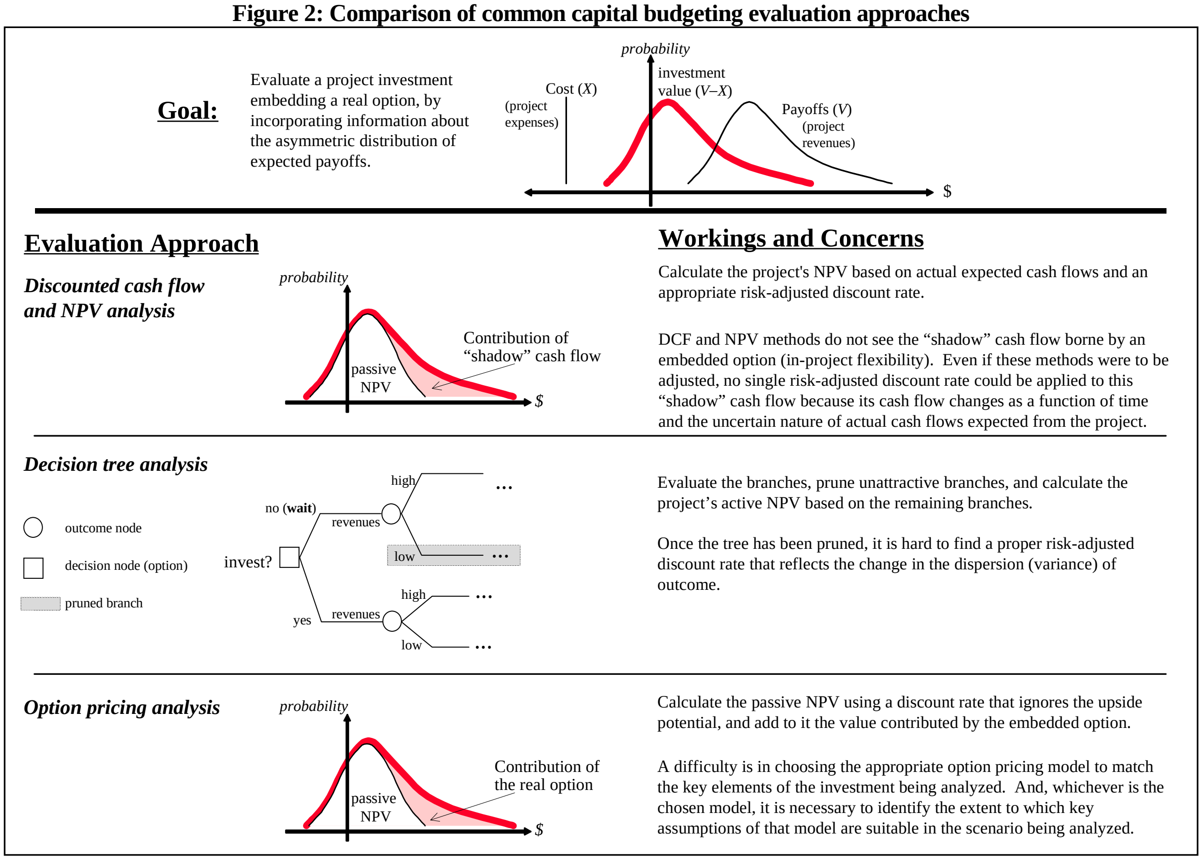
Option reduces the downside potential by possibly lowering the project's cost and/or failure risk, thus pushing downwards the left tail of the probability distribution of the investment outcome

Two approaches commonly used to evaluate investments are DCF (NPV) analysis and decision tree analysis (DTA) (see Figure 2). Besides the theoretical reasons for these approaches being inadequate for investments involving options (Benaroch and Kauffman, 1999), a pragmatic question is: why can't they be adapted to such investments?

The key problem with adapting DCF analysis is that it can evaluate only actual cash flows that a project is expected to yield. DCF analysis does not explicitly recognize that managerial flexibility has a value equivalent to a "shadow", non-actual cash flow. Such flexibility is borne by the presence of embedded options and it allows management to adjust traits of the investment (timing, scope, scale, etc.) to changing environmental conditions. Even if DCF analysis were to consider this shadow cash flow, or option value, risk-adjusted discounting remains a problem. Because the risk of an option is not the same as that of actual cash flows, and because this risk changes as a function of time and the uncertain size of actual cash flows, it is neither possible to predict the option risk nor find a risk-adjusted discount rate that applies to it.

DTA provides a significant conceptual improvement over the way DCF analysis handles options. A decision tree shows the expected project payoffs contingent on future in-project actions that management can take over time (e.g., abandon an operational project at time *t*, if the salvage value of resources used exceeds the payoffs arriving after *t*). As the tree represents each action as a decision node, corresponding to an option, evaluating the project requires working backward from the future to the present, to calculate how much the presence of these actions adds to the project value. This approach yields useful results only once poor tree branches are pruned. Pruning means finding out how embedded options alter the range of expected payoffs and then adjusting the discount rate to recognize the change in risk (or variability of payoffs). Unfortunately, DTA provides no direct basis for discount rate adjustment (Brealey and Myers, 1988, p. 228). Only with a proper modification involving an estimation of the investor's (management) utility function DTA could be adequately applied to projects embedding options (see [Smith and Nau, 1995] for details).

Figure 2: Comparison of common capital budgeting evaluation approaches



Real options analysis strives to complement the other two approaches, in light of the difficulties involved in adapting these approaches to investments embedding options. It looks at the active NPV of a project as the sum of the passive NPV and the value of embedded options. The intuition behind how it evaluates an embedded option resides in two factors. First, it models payoff contingencies using a probability distribution function (e.g., log-normal, binomial), enabling to translate the presence of an option into expectations of shifts in this distribution. Second, it replaces the actual probabilities of payoffs by risk-neutral (certainty-equivalent) probabilities, to facilitate discounting by the risk-free rate, instead of a risk-adjusted rate. This is equivalent to allowing an analyst to prune unattractive branches in a decision tree without having to worry about discount rate adjustment.[1] However, these factors raise two issues. The first

[1] In this sense, real options analysis is an adjusted version of decision tree analysis, involving a redistribution of probability masses such that risk is reallocated in a way that allows for discounting by the risk-free rate. This adjustment usually relies on economic arguments that permit for the appropriate discount rate to be extracted from market information, indirectly through revision of probabilities.

requires estimating the variability of uncertain payoffs and costs modeled using probability distributions. As to the other factor, the validity of discounting by the risk-free rate is questionable when options are not traded in a market. We return to these issues later, to show that they do not limit the applicability of real options analysis to IT options.

In the rest of this section we formalize real option pricing concepts based on prior work in finance. We focus in particular on deferral options, because the case study we present in Sections 3 and 4 involves a deferral option.

2.2. Option Pricing Concepts Applied to Real Deferral Options

The fundamental options are financial *calls* and *puts*. A *European call* (*put*) on some underlying asset, whose current value is *V*, gives its holder the right to buy (sell) the asset for an agreed exercise price, *X*, at a fixed expiration date, *T*. For instance, a "June 99 call" on IBM stock with a $75 strike price allows its holder to buy IBM shares for $75 on June 15, 1999. This call is worth exercising only if the value of an IBM share on June 15 exceeds $75, in which case it is said to be *in-the-money*. Thus, the terminal value of a call, or its value on expiration, C_T, is $\max(0, V_T - X)$, where V_T is the terminal value of the underlying asset. An *American option* is like a European option, but it can be exercised at any time t, $t \le T$. We next focus on European calls because they are simpler to understand, and later return to discuss American options.

The current value of a call, *C*, is partially determined by the volatility (variability) of the underlying asset's value, σ, and the length of time to its maturity, *T*. Before the option expires, *V* can go down only to zero (downside risk limit) or up to infinity (unlimited upside potential). This asymmetrical distribution of *V* means that, the higher σ is, the greater is the chance that V_T will exceed *X* for the call to end in-the-money, and the higher is the call value. Likewise, the longer is the time to expiration, *T*, the more chance there is that *V* will rise above *X*, so that the call will end in-the-money. So far we see that *C* depends on parameters *V*, *X*, *T*, and σ. We will see that *C* also depends on the risk-free interest rate.

For a firm facing a project embedding the right to defer investment, the analogy with a financial call is direct. The firm can get the value of the operational project via immediate investment, $V - X$, or hold on to the investment opportunity. This is akin to a call option to convert the opportunity into an operational project. The option (opportunity) offers the flexibility to defer conversion until circumstances turn most favorable, or to back out if they are not satisfactory. Its value corresponds to the active NPV, equaling the passive NPV plus the value of the deferral flexibility. The option parameters are: (1) the time to expiration, *T*, is the time that the opportunity can be deferred; (2) the underlying asset, *V*, is the present value of risky payoffs expected upon undertaking the investment; (3) the exercise price, *X*, is the irreversible cost of making the investment; and, (4) the volatility, σ, is the standard deviation of risky payoffs from the investment. When *V* can fluctuate, the unexercised option (opportunity) can be more valuable than immediate investment, $\max(V - X) > V - X$. The value of the option depends on how much the decision-maker expects to learn about the way the value of risky payoffs, *V*, will evolve due to changes that might occur within the firm or in its environment during deferral. The more uncertain is *V*, the more learning can take place during deferral, and the more valuable is the option. This is consistent with what the Finance theory postulates about the effect of σ, the variability of *V*, on the value of financial options.

Two basic models for pricing financial options are the binomial model and the Black-Scholes model (Hull, 1993). Because these models make similar assumptions and thus compute a similar option value for options maturing in a year or longer (Benaroch and Kauffman, 1999), we rely here only on the Black-Scholes model to price the option identified later in our case study. The Black-Scholes model is a closed-form formula that computes the price of a European call option for a risk-neutral investor.[2] It is written as:

$$C = V\,\mathrm{N}(d_1) - X\,e^{-r_f T}\,\mathrm{N}(d_2), \qquad d_1 = \frac{\ln(V/X) + (r_f + \sigma^2/2)T}{\sigma\sqrt{T}}, \qquad d_2 = d_1 - \sigma\sqrt{T}, \tag{1}$$

where $\mathrm{N}(\cdot)$ is the cumulative normal distribution, *V* is an underlying asset that is assumed to be log-normally distributed so as to reflect the asymmetric nature of payoffs from an investment embedding the option (Figure 1), σ is the volatility of *V*, *X* is the option's exercise price, *T* is the time to maturity, and r_f is the risk-free rate. This equation has a simple intuition. As $V_T - X$ is the call's terminal in-the-money value, $V - e^{-r_f T} X$ is the current in-the-money value. To cover the case that the call might be unattractive to exercise, *V* and *X* are weighted by the probabilities $\mathrm{N}(d_1)$ and $\mathrm{N}(d_2)$, respectively.

In light of the similarity of a deferral option to a financial option, we should be able to apply the Black-Scholes model to real IT options. Benaroch and Kauffman (1999) support this assertion by showing that the economic rational for the risk-neutrality assumption of the Black-Scholes model fits in the context of IT investment evaluation, even though many IT investments are not traded. However, recall that one goal of this paper is to examine the impact of adjusting the risk-neutral option value calculated by this model to the case of risk-averse investors. This examination is meant for address the

[2] The Black-Scholes model assumes that the option is priced for a risk-neutral investor (who is indifferent between an investment with a certain rate of return and an investment with an uncertain rate of return whose expected value matches that of the investment with the certain rate of return). Underlying this assumption is a requirement that *V* be an asset that is traded in a market that presents no arbitrage opportunities. Under this requirement it is possible to construct a portfolio of other traded assets that has the same risk as *V*, where return on the portfolio must equal the risk-free interest rate, r_f. This is why the Black-Scholes model treats the option value as a function of r_f.

claim that, because most decision-makers are risk-averse, risk-neutral valuation overvalues options embedded in non-traded investments. Trigeorgies (1996, p. 101) explains this claim as follows: Managers evaluating an investment that is subject to a firm- and/or industry-specific risk not shared by all market investors must discount the option value by a factor corresponding to the investment's unique risk. Analogously, if the asset underlying an option is not traded in limited supply by a large number of investors (so that demand for the asset exceeds supply), the asset's return rate, α, may fall below the equilibrium expected rate of return investors require from an equivalent-risk traded asset, α^*. The *rate of return shortfall*, $\delta = \alpha^* - \alpha$, necessitates an adjustment in the option valuation. A version of the Black-Scholes model that reflects this rate shortfall adjustment is:

$$C = Ve^{-\delta T}\,\mathrm{N}(d'_1) - X\,e^{-r_f T}\,\mathrm{N}(d'_2), \qquad d'_1 = \frac{\ln(V/X) + (r_f - \delta + \sigma^2/2)T}{\sigma\sqrt{T}}, \qquad d'_2 = d'_1 - \sigma\sqrt{T}, \tag{1'}$$

A simple conclusion follows. Risk-neutral valuation does not pose a roadblock to implementing real options analysis using the Black-Scholes model. Even for a non-traded underlying asset, we can apply risk-neutral valuation using the Black-Scholes model adjusted by an appropriate rate of return shortfall, δ.[3] Following one of our goals, we later check the impact of adjusting the Black-Scholes model by δ on the analysis results for the case study presented shortly.

2.3. Option-Based Decision Rule for Investment Timing

Having seen why it is reasonable to use the Black-Scholes model in the context of real IT options, the question that a firm must answer for a deferrable investment opportunity is: *For how long to postpone the investment up to T time periods?*

Economists study many variants of this kind of *investment-timing problem* (e.g., cyclical demand for goods to be produced by a deferrable project). They use different specialized solution approaches, many of which are isomorphic to the option-pricing approach (Bernanke, 1983). For example, McDonald and Siegel (1986) study the problem for the case of stochastic project costs, showing that under risk-neutrality and non-stochastic project costs their model reduces to the Black-Scholes model. Likewise, Smit and Ankum (1993) say that the general investment-timing problem *"is analogous to the timing of exercising of a call option"* (p. 242), and thus explain how the simplicity and clarity of real options analysis enables them to study the problem under various competitive market structures.

From a real options perspective, the intuition behind the evaluation principle for solving an investment-timing problem like the one we present shortly is as follows. Holding a deferrable investment opportunity is equivalent to holding an American call option. At any moment, the investor can own either the option (investment opportunity) or the asset obtained upon exercising the option (operational investment). The option parameters are: the present value of risky payoffs from the investment (V), the cost of making the investment (X), the standard deviation of risky payoffs (σ), the maximum deferral period (T), and the risk-free interest rate (r_f). Holding the option unexercised (postponing investment) for time t has two competing effects: V is lowered by the amount of foregone cash flows and market share lost to competition, and X is lowered because it is discounted during the deferral period, t. Depending on the magnitude of these two tendencies, the value of the option exercised at time t, C_t, can be higher or lower. If information arriving during deferral indicates that V is likely to exceed original estimates, investment can be justified by the rise in the payoff expected from investing; otherwise, the irreversible sunk cost (X) can be avoided by not investing, at a lose of only the cost of obtaining the deferral flexibility. Consequently, the following decision rule leads to the optimal investment strategy, given today's information set.

Decision Rule: *Where the maximum deferral time is T, make the investment (exercise the option) at time t^*, $0 \le t^* \le T$, for which the option, C_{t^*}, is positive and takes on its maximum value.*

$$C_{t^*} = \max_{t=0 \ldots T} C_t = V_t e^{-\delta t}\,\mathrm{N}(d'_1) - X\,e^{-r_f t}\,\mathrm{N}(d'_2), \tag{2}$$

where d'_1 and d'_2 are defined in equation (1'), and V_t equals V less the present value of foregone cash flows and market share lost to competition. Of course, this decision rule has to be reapplied every time new information arrives during the deferral period, to see how the optimal investment strategy might change in light of the new information.

Because the Black-Scholes model is suitable for pricing only European options, it is not directly applicable with a decision rule involving an American deferral option. However, we will see later a specific variant of the Black-Scholes model that can be directly applied with the above decision rule.

3. A Planning Retrospective for Point-of-Sale Debit at Yankee 24

In this section, we discuss the background of shared electronic banking services in relation to Yankee 24, to pave the way for our evaluation of an IT investment embedding a deferral option. We examine the investment scenario that Yankee 24 faced in determining whether to deploy POS debit services, and conclude by suggesting the elements of the scenario that make real options analysis a useful evaluation alternative.

3.1. Electronic Banking and Point-of-Sale Debit

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[3] This adjusted version of the Black-Scholes model is also used for risk-neutral investors when δ is termed the convenience yield. The *convenience yield* is a measure of the benefits realized from holding an asset (e.g., land) that are not realized by the holder of an option on that asset.

Electronic banking was instituted in the mid-1960s to facilitate the execution of financial transactions using credit cards. Due to the popularity of this service among consumers, retailers rapidly came to accept credit cards on an almost universal basis. This service was followed in the early 1970s by the deployment of automated teller machines (**ATMs**).

Later, a "middle ground" service emerged, combining the speed and ease of a credit card transaction for the consumer and the low risk of a credit or check-free transaction for the merchant. First Federal Savings of Lincoln, Nebraska was the first bank to install in 1972 ATM-like devices in supermarkets, enabling its depositors to use plastic cards to pay in the Hinky Dinky supermarket chain. The mechanism involved a book transfer at the bank, resulting in a debit to the purchaser's account and a credit to the merchant's account. This service became known as *point-of-sale (**POS**) debit*. Hinky Dinky's service was not very successful because it was confined to First Federal Saving's depositors. Retailers simply did not want to install systems with restricted availability to their broad spectrum of customers.

Since that time, there were more successful attempts to establish POS debit services. Around 1985, for example, four major banks in California collaborated to introduce the "InterLink" payment system. At the time, since these banks held about 50-60% of all checking accounts in California, retailers, and especially supermarkets, rapidly adopted the service. Around the same time, other shared ATM networks observed the emergence of this POS debit payment system, and began to consider its applicability to their own marketplaces.

3.2. Electronic Banking and POS Debit Services in New England

Yankee 24 (hereafter, Yankee), a regional shared electronic banking network, was established in 1983 by a small group of large banks in Connecticut to provide cost-effective services within Connecticut. Yankee grew to include more than 200 member firms. Many member firms deployed their own ATM hardware and software. Others outsourced all ATM transaction processing to the network. Charges for network services involved an initial membership fee and fees for all transactions processed through Yankee's switch. Despite its limited focus on Connecticut, by 1985 Yankee became the largest shared network in New England. Yankee subsequently expanded to the remainder of New England, experiencing 400% growth in transactions in 1987. By 1990, its ATM transaction volume had reached about 20 million per month. Table 1 provides additional information about Yankee and others among the largest regional shared electronic banking networks in the U.S. This information reveals four facts about the 1990 time frame. *First*, the West Coast had the largest number of POS terminals installed by STAR. *Second*, NYCE owned about 15% of the POS terminals in the North East, but none in the New England area. *Third*, Yankee as well had no POS terminals installed in New England. Finally, although Yankee is small in terms of the number of network cards it services, this number is still significant.

Table 1: Overview of the ten largest electronic banking networks in 1990 (source: Yankee 24)

Network Name	Date Formed	Ownership	Main Market	Network Membership Breakdown			Network Cards	ATMs Deployed (Monthly Transactions)	POS Debit Terminals (Monthly Transactions)
				Banks	S&Ls	Credit Unions			
NYCE	10/84	9 NYC banks	NY, PA, NJ and New England	298	133	91	16.5MM	9,504 (63.8MM)	1,639 (.7MM)
STAR	7/84	17 member firms	CA, NV, AZ, OR, HI, UT, WA	177	845	249	20.3MM	10,851 (61.6MM)	11,121 (1.4MM)
MAC	9/79	Core States Financial Corp.	PA, NJ, DE, NY, WV, MD	472	249	222	17.5MM	7,405 (48.3MM)	9,924 (.5MM)
Most	7/84	28 member firms	DC, VA, MD, TN, WV, DE, KY	264	73	98	7.7MM	4,029 (37.3MM)	872 (<.1MM)
Pulse	7/81	1,476 member firms	TX, OK, LA, NM, AR	1,162	129	185	8.5MM	5,110 (32.1MM)	3,247 (.5MM)
Money Station	4/83	7 member firms	OH, WV, KY, IN, MI, PA	220	126	154	4.9MM	2,998 (22.8MM)	507 (.1MM)
Yankee 24	8/83	740 member firms	CT, ME, MA, RI, NH, VT	370	95	275	4.8MM	3,891 (20.0MM)	not deployed
Honor	6/83	8 member firms	FL only	310	92	52	6.7MM	3,228 (19.4MM)	3,984 (.5MM)
Relay	6/82	27 member firms	NC, SC, VA, GA, FL, DC, MD	105	64	32	6.9MM	3,079 (19.0MM)	not deployed
Exchange/ Accel	6/73	40 member firms	WA, OR, ID, MT, AK, BC	81	31	137	4.8MM	2,960 (18.2MM)	484 (not available)

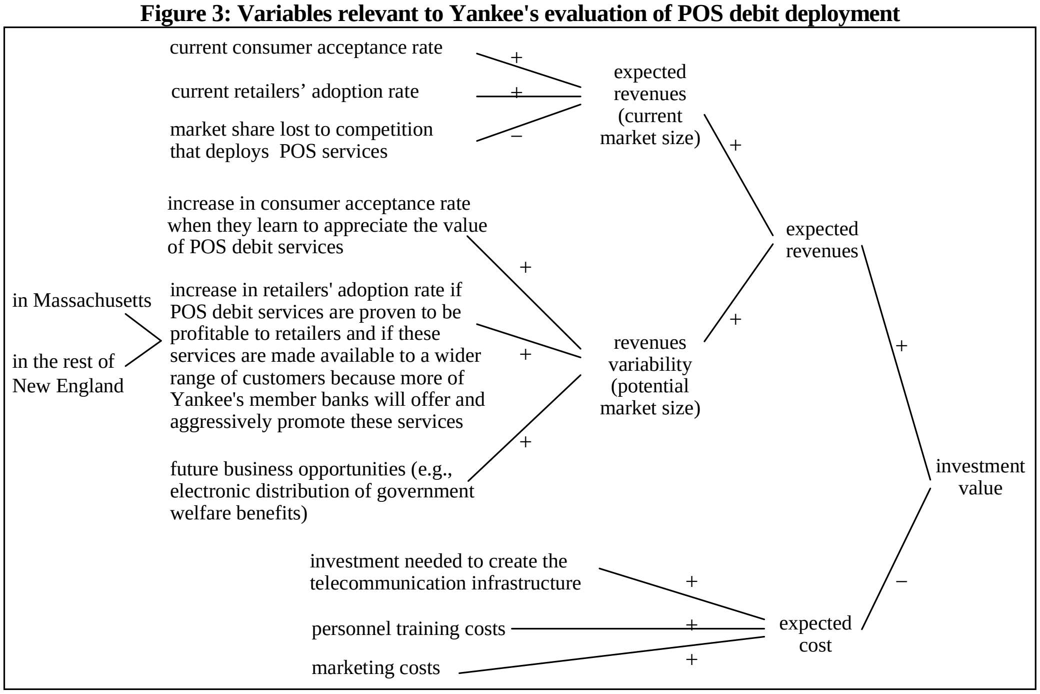
In 1987, Richard Yanak, Yankee's president, first considered supporting POS debit network services. Yanak's initial perception was that this investment in new infrastructure was risky. But, Yanak also viewed POS debit as a way for Yankee to expand its franchise in the market, increase its transactions volume and revenues, and thus increase the network's value to its member firms. In addition, one potential new business of interest was applying the POS debit payment system to the electronic distribution of food stamps and a host of government welfare benefits.

Given the strategic nature of a move into POS debit, Yanak began building a business case that would convince the board of directors to undertake this project. In Yanak's initial view, entering this market seemed workable because of its similarity to the ATM market, which was well understood by the board of directors. Both markets have resulted from societal change in consumer payments mechanisms, and the training concerns and technological infrastructure employed are similar. Yet, it was also clear to Yanak that the ATM and the POS debit markets would differ in important ways: in terms of acceptance rate, demographics, and investment risk.

3.3. POS Debit Service Startup Timing at Yankee: The Justification Issues

Entry into the POS debit business in 1987 was not without risk, although it was technically feasible, could have yielded revenues early on, and would have created entry barriers for competitors. Before making a decision, Yanak had to analyze a number of key variables and their relationships (see Figure 3).

Figure 3: Variables relevant to Yankee's evaluation of POS debit deployment



The expected revenues depended on the market acceptance rate, the market share lost to competition, and the extent to which these revenues might deviate up or down. Relative to the variability of revenues, while the expected revenues could turn out slightly worse than those generated in California until 1987, they could turn out to be much higher. For example, the consumer acceptance rate and the adoption rate by retailers might rise, and the government might decide at any time to start delivering welfare benefits electronically.

On the consumers' side, it was necessary to understand when sufficient customer demand for POS debit services would emerge. California offered a relevant analogy – the consumer acceptance rate was assumed to parallel the one in California until 1987. POS debit services were quite successful, as suggested by the number of terminals deployed and transaction volume processed by STAR, for example (Table 1). Still consumer acceptance was considered slow. Between 1985 and the end of 1991 about 10 million transactions were executed in California by a population base of 15 to 20 million card holders. While consumers were becoming aware of the benefits of using plastic cards at ATMs (e.g., to make bill payments), a clear call for POS debit services had not yet appeared in the market. Debit cards were initially less attractive to consumers than credit cards, since transfer of funds to the merchant was not postponed by the no-interest, end-of-the-month billing cycle. Nonetheless, network executives and industry consultants broadly believed that the adoption rate of POS debit services would parallel that of ATM services, albeit in a more compressed time frame. It took 15 to 20 years for ATM adoption to run its course; acceptance of POS debit services was expected to occur over a 5-8 year period.

Retailers' adoption rate is another revenue-related concern. Unlike in the ATM business where clients are bank depositors, Yankee's POS debit direct clients are retailers for which cash and checks (and less often, credit) are the primary payment vehicles. These retailers had to make substantial investments (e.g., in networking and training cashiers), unlike in the ATM world where the entire investment is borne by the banks. While this meant that the investment required by Yankee and its member banks would be relatively small, effectively shifting much of the risk of the rollout to the retailers, it caused many merchants to hesitate, resulting in spotty geographic coverage of POS debit services in California. Yankee faced another hindrance: a legislation in Massachusetts, which includes about 50% of the New England population, required retailers who participate in POS debit servicing to be subject to state banking department scrutiny. This meant that Massachusetts retailers might be slower to adopt POS debit services. Some would adopt early on. Others would wait until the prospect for a change in the law arose, as legislators begun to see the value of POS debit to consumers. And, some would wait until POS debit services proved profitable enough to justify being under state banking department scrutiny.

The primary retailers Yankee identified were supermarkets, gas stations, and convenience stores. More financial transactions are executed in supermarkets than in any other retail arena, and the majority of the transactions are paid in cash.

At the time, New England had about 100 supermarket chains, with the largest 21 selling nearly 75% of all groceries. Gas stations and convenience stores also used cash as the primary mode of payment. Yankee estimated that there were about 250,000 such retailers in New England who had the infrastructure in place to process credit card transactions electronically. This additional market was expected to exhibit a lower volume of transactions per merchant, though, in aggregate, it was large and would grow significantly.

On the cost side, Yankee had to consider the cost of creating the telecommunication infrastructure, personnel training costs, and advertising costs. These costs were expected to be relatively low, because the ATM infrastructure acts as a complementary asset to POS debit capabilities. (Additionally, the marginal operating costs per transaction were estimated at zero for the transactions volume expected over the time horizon considered.) Yet, Yankee's situation in New England posed some problems. *First*, the network was growing rapidly during 1987, as Yankee moved to expand its operations into other New England states. This required substantial financial resources not available to Yankee at the time, placing a strain on the small network management staff. *Second*, it seemed that member banks in New England would be reluctant participants in an early rollout of POS debit, given the marginal returns. They would balk at incurring the costs of planning and aggressively promoting the services to retailers who would use the POS debit services to garner the income. But in 1987 and 1988 the financial services industry throughout the region (and elsewhere) was under stress. Many banks were increasingly choosing to exit from non-core banking businesses (e.g., insurance, real estate, etc.) which posed risks that often led to real losses.

Although Yankee's senior management was convinced of the great potential of the POS debit market, their prevailing attitude was that 1987 was probably not the best time to enter this market. This view was supported by the fact that, in 1987, Yankee's principal potential competitor, New York Cash Exchange (NYCE) shared electronic banking network, had not yet signaled its intent to enter the POS debit market. Moreover, it would take NYCE at least three years to build up the necessary infrastructure. It was believed that Yankee could time the launch of POS debit services so as to get rapid acceptance by retailers and rapid growth in transaction volume, and to forestall the competition from making serious inroads into Yankee's potential merchant base.

Yanak concluded that: the longer Yankee waited to enter the POS debit market, the greater the chance that entry would pay off. While waiting too long could mean losing ground to the competition, it had the benefit of resolving some uncertainties. By waiting Yankee could see if the environment would become more favorable, and whether the POS debit experience in other regions of the U.S., such as Texas and Florida, would parallel California. Moreover, in the meantime, efforts could be made to lobby for a change in Massachusetts' law, encouraging more rapid adoption by retailers.

4. Debit Card Service Deployment Decisionmaking: A Real Option Perspective

In this section we apply real options analysis to Yankee's investment decision and assess claims concerning the main benefits and drawbacks of this analysis approach. We first discuss methodological issues involved in establishing the suitability of real options analysis to Yankee's situation and in eliciting relevant information for the analysis. We next explain how the primary findings of our analysis are derived as well as examine how sensitivity analysis capabilities can be used to supplement these findings. The primary analysis findings indicate two major conclusions: (1) immediate entry by Yankee into POS debit services involves a negative NPV, and (2) the value of the deferral option Yankee possessed suggests entry in three years. These conclusions agree with the actual decision that Yankee's senior executive made at the time based on "guesstimates". Finally, we discuss implications of these findings for Yankee's management.

4.1. Study Methodology Issues

Based on the preliminary case study details provided in the previous section, it seems that in 1987 Yankee had the flexibility to postpone the entry decision, akin to having a real *deferral option* on an investment opportunity. Provided that Yankee indeed possessed such an option, a real options approach would have brought ease and conceptual clarity to Yankee's investment analysis. Management's experience suggested that the expected payoffs from a POS debit rollout would be asymmetric, and their high potential variability would be the key to making the right decision. Hence, real options analysis could have helped to structure expectations about the future in a way that matched the thinking of Yankee's management. In the same spirit, it could have permitted conducting sensitivity analysis in a way that matches Yanak's intuition, by allowing to frame changes in expectations about payoff drivers in terms of the payoff variability that might be encountered (rather than in terms of changes in the possible payoff levels, their probability, and the respective discount rate used).

On this premise, our next step was to establish a structured interviewing format based on a strong questionnaire that would enable us to cast Yankee's investment decision as a real options analysis problem, identify a suitable option-pricing model, get all model parameters, obtain proprietary and public data, triangulate with different people in the firm, etc. The interview included two parts.

4.1.1. Part 1: Establishing the Existence of Yankee's Option

The first part of the interview gathered evidence needed to establish the existence of Yankee's deferral option and its nature. It included over 10 questions aimed at gauging the strategic importance of entering the POS debit market, the factors that allowed Yankee to wait, the factors that required Yankee to wait, and what Yankee expected to gain by deferring entry. The primary finding that emerged from this part can be summarized by the answers to three key questions.

One question is: what kind of option did Yankee possess? Yankee possessed an *American deferral option* on a *dividend paying asset*. The asset underlying this option is the potential stream of revenues from an investment opportunity that will materialize only once Yankee enters the POS debit market any time starting 1987, where the dividends are the revenues lost during the time Yankee deferred entry into this market.

Another question is: where did the option come from and at what cost? Unlike a financial option that is purchased for a cash fee, Yankee obtained its deferral option at no direct cost. Generally, a firm could obtain a deferral option at no cost if it faces no credible competitive threat of loosing the deferred investment opportunity (Dixit and Pindyck, 1994). This is clearly true in the case of a monopoly. In case of a duopoly, the option exists for the "leader" among two competitors who made indirect investments in building up over time managerial competencies, reputation, IT infrastructure, etc.; if there is no clear leader, both firms may have the option, but only the first mover would enjoy its full benefits. Yankee operated in a duopoly, where it maintained a leadership position because of prior investment in its ATM network infrastructure in New England. As this infrastructure acts as a complementary asset to POS debit capabilities, Yankee possessed most of the resources needed to enter the New England POS debit market in 1987. The only viable competitor, NYCE, did not show any intent to enter this market at that time, in part, because it lacked the necessary infrastructure in New England. Hence, as far as project valuation decision-making is concerned, Yankee's only option cost was the opportunity cost of delaying entry -- the revenues lost during the deferral period -- and a negligible opportunity cost borne by the slim risk of losing the investment opportunity to NYCE (which counter to expectations might act earlier than expected).

The third question is: where did Yankee's option value come from? The option value stemmed from Yankee's belief that it could resolve some of the uncertainties concerning acceptance of POS debit services. Yankee had the ability to wait and learn more about the investment, to be able to better assess it and subsequently avoid it if the expected revenues turned out to be unattractive. Yankee could passively observe how the POS debit business evolved in other parts of the country, and it could actively try to lower the risk of expected revenues (e.g., lobby for a change in Massachusetts' law).

4.1.2. Part 2: Choosing a Pricing Model and Eliciting Model Parameters

Upon precisely characterizing Yankee's deferral option, the second part of the structured interview aimed at eliciting relevant information for analyzing Yankee's situation from a real options perspective. In preparing the questions for this part, we had to sort out several methodological issues that would enable us to answer such questions as:

- What option-pricing model to use to evaluate Yankee's deferral option?
- What kinds of evidence would be needed to establish the primary assumptions for the analysis?
- How should we elicit relevant information concerning model parameters, especially concerning variances?
- How should we combine publicly available background information with interview information?

Starting with the choice of model, it was clear that the Black-Scholes model cannot be used directly because Yankee's deferral option is American and on a dividend paying asset. But, one variant of this model, called *Black's approximation*, is relatively simple and accurate in pricing such an option (Hull, 1993, p. 235). For the simplest case, Black's approximation assumes the existence of an American call that matures at time T, where the underlying asset pays a dividend D_t at time t, $0<t<T$. To find whether an early exercise at time t is more profitable, the Black-Scholes model is used to calculate the prices of European options that mature at T and t, denoted C_T^E and C_t^E, and then the American price is set to $\max(C_T^E, C_t^E)$. To compute C_t^E, the value of the underlying asset in Equation 1' must be V_t -- V less the foregone dividend D_t discounted for the period $T–t$. This procedure is easily extended for the case of Yankee, in which there are a number of dividends corresponding to the cash flows lost during a deferral period spanning time 0 to time t. Respectively, looking for the optimal deferral period in Yankee's case requires solving Equation 2 for $C_{t^*}^A$, namely:

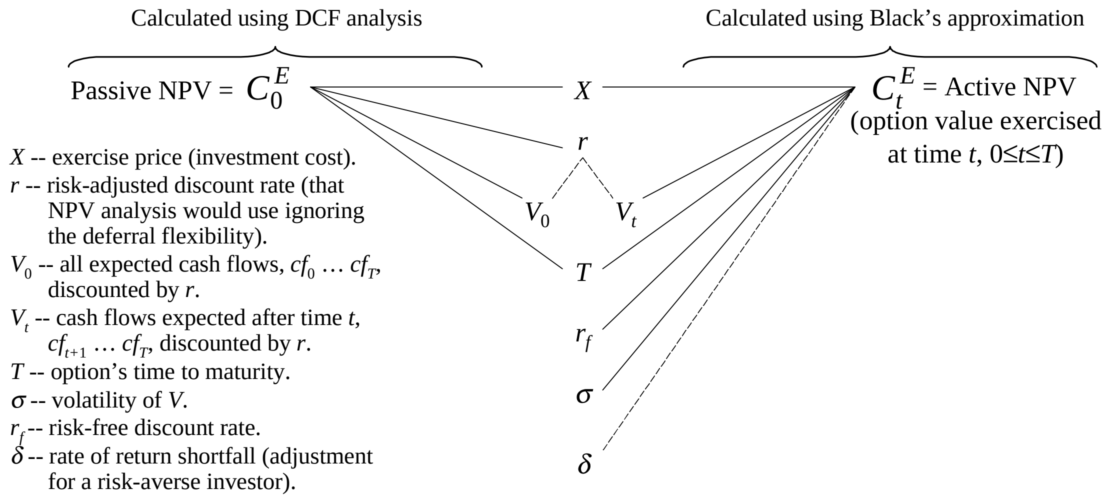
$$\begin{aligned} C_{t^*}^A &= \max_{t=0\ldots T}(\max(C_t^E, C_T^E)) \\ &= \max_{t=0\ldots T}(\max((V_t e^{-\delta t}\,\mathrm{N}(d'_1) - X\,e^{-r_f t}\mathrm{N}(d'_2)), (V_T e^{-\delta T}\,\mathrm{N}(d'_1) - X\,e^{-r_f T}\mathrm{N}(d'_2)))) \end{aligned} \quad \textbf{(3)}$$

In this equation, d'_1 and d'_2 are defined in equation 1', and V_t is defined as:

$$V_t = \mathrm{PV}(cf_0 \ldots cf_T, r) - \mathrm{PV}(cf_0 \ldots cf_t, r) = \mathrm{PV}(cf_{t+1} \ldots cf_T, r), \quad \textbf{(4)}$$

where cf_i denotes the cash flow expected at time i and r is the risk-adjusted discount rate (that DCF analysis would use ignoring the deferral flexibility). As Equation 3 and Figure 4 show, compared to DCF analysis, Black's approximation also involves one trivial parameter -- r_f -- and two more difficult to estimate parameters -- σ and δ.

Figure 4: parameters used for investment evaluation using Black's Approximation



We next had to reveal information for estimating the model parameters, assuming that the actual entry would occur any time after mid 1987. We first focused on the parameters involved in the DCF analysis preceding real options analysis -- X, V, r, and T (see Figure 4). The findings that emerged from the interview are stated in terms of the major assumptions that Yankee made, as listed in Appendix A and briefly summarized below.

On the cost side, there were two dimensions of entry. First, in terms of X, Yankee's initial investment in the technical implementation would be relatively small -- around \$400,000 -- compared to a non-participant in the ATM network business in New England. Second, a periodic (operational) discretionary marketing expense on POS debit promotion would be relatively low -- about \$40,000 a year -- until resources were shifted away from promoting ATM services, once stable growth had been achieved.

Eliciting information for estimating V involved questions concerning estimates of expected revenues and the basis for those estimates. According to Yanak, the New England POS debit market was considered similar to the California market (but smaller). Based on this assumption, all estimates of expected revenues and their growth rate were produced. Yanak felt that, starting from scratch, Yankee's POS debit transactions volume would grow over a 5-year term to about 50 million per year in 1992, where each transaction would generate about 10¢. This contrasts with a 1992 volume of about 40 million ATM transactions, built up over a 10-year period.

The next parameter was the rate, r, for discounting costs and revenues. Yankee's management agreed that, ignoring the embedded deferral flexibility, the risk characteristics of investing in POS debit services are similar to those of other electronic banking investments. Thus, to compute the passive NPV, we could use a discount rate of r=12%, which approximates the rate used for capital budgeting of other electronic banking investments at the time.

Finally, as to the investment time horizon, T, the following emerged. First, Yankee looked at the period between January of 1987 and June of 1992, corresponding to a 5½ years analysis horizon. Second, from the moment Yankee enters the POS debit market, it takes one year to begin servicing customers and for revenues to start arriving. This implies a maximal deferral period is four years -- from January of 1987 until January of 1991.

As seen in Figure 4, real options analysis (using Black's approximation) requires information concerning three additional parameters -- r_f, σ, and δ. Of these parameters, only the last two are hard to estimate.

To elicit information for estimating σ, we asked about the distribution of revenues (i.e., normal, skewed to the high or the low side), the perceived variance of potential revenues (if there were any) linked to uncertainties that might be resolved, the range of the potential revenues on the high and low ends, etc. Considering only direct quantifiable revenues, the answers to such questions would have permitted us to precisely estimate σ using schemes like the ones summarized in Appendix B. However, we also had to consider future potential revenues from business opportunities that were not perceived to exist in 1987 but could be spawned by growth options embedded in Yankee's investment; for example, the possibility that state governments would start using electronic payments to deliver welfare benefits was one indication of how large the non-tangible benefits could be. While information about such non-tangible benefits helped us to better understand Yanak's gut feelings about the POS debit business, it was not sufficient to enable us to quantify these benefits and precisely estimate σ. Yanak nonetheless was able to say that, given the possible size of indirect revenues as well as uncertainties linked to the direct revenues (Figure 3), and especially the one concerning the Massachusetts market, the variability of expected revenues could be as high as 100%. Eventually, because we could elicit quantifiable estimates only for direct revenues, we decided to try the following approach: first use 50% as an initial plausible value for σ, and then use sensitivity analysis to see if the analysis results are robust to changes of σ within the lower and upper bounds Yankee's management assigned to σ. Only if the analysis results turned out not to be robust to changes in σ would we be forced to find new ways to elicit more information for precisely estimating σ. This approach made sense because it enabled us to proceed and get a sense for the potentially significant impact of non-quantifiable revenues.

As to δ, the rate shortfall adjustment for risk-aversion, this parameter is even more difficult to estimate than σ. In principle, one way to estimate δ is based on the utility function of Yankee's management. However, given our goal, we felt it was not necessary to estimate δ for one reason. Since the options theory from Finance shows that the value of call options is relatively insensitive to changes in discount rates (Cox and Rubinstein, 1985), our intuition suggested that sensitivity analysis is a good way to check whether the results of risk-neutral valuation are sufficiently robust to cover the case of a risk-averse decision-maker. The analysis results reported shortly confirmed our intuition.

4.2. Analysis Results

With the above information, we were ready to apply real options analysis to the investment decision Yankee faced in 1987. The analysis results for immediate entry in 1987 can be summarized based on the figures calculated using DCF analysis (see Appendix A). The passive NPV is negative (–\$76,767), so immediate entry is not worthwhile. Moreover, what-if sensitivity analysis results show that the passive NPV remains negative even when the discount rate, r, drops from 12% to 8%. This result suggests that, even using a lower discount rate that "artificially" reflects a lower investment risk due to the upside potential of revenues, immediate entry is not worthwhile.

This brings up the key question Yankee faced: *How long should entry into the POS debit market be postponed*? We emphasize that this question is relevant even for a positive passive NPV. For instance, when the discount rate drops to 7%, to equal the risk-free rate, the passive NPV becomes positive at \$7,069, suggesting that immediate entry is worthwhile. Even if 7% were a realistic discount rate, r, the real options analysis results we present next clearly show that deferring entry is more worthwhile. The same holds if a positive NPV is obtained as a result of expanding the analysis horizon (beyond the original 5½ years horizon) to account for additional positive cash flows expected past June 1992.

For a deferred entry, we used the same assumptions, except that the investment is made any time between mid 1987 and early 1991. The same time horizon of 5½ years is used to reflect that the analysis is performed for the 1987 time frame as well. We calculated the option value for different exercise dates ranging from zero to four years at six-month intervals. The upper part of Table 2 shows the results computed using Black's approximation, assuming risk-neutrality (with δ=0%). These results can be summarized as follows.

- The value of the deferral option exercised at maturity T=4, as if it were a European option, is C_T^E = \$65,300;
- For deferrals between 1½ to 3½ years, the value of the option, C_t^E, as if it were European and it could be exercised at any time $t<T$, is greater than C_T^E.
- The value of Yankee's American deferral option is C_t^A = \$152,955. This value corresponds to the optimal deferral time of t=3, at which $\max(C_T^E, C_t^E)$ reaches its maximum for any $t \le T$.

Table 2: optimal investment time and sensitivity analysis data

t (length of deferral period in years)	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**
Calendar time	**Jan. 87**	**July 87**	**Jan. 88**	**July 88**	**Jan. 89**	**July 89**	**Jan. 90**	**July 90**	**Jan. 91**
Black-Scholes Parameter Values									
V_t (V_0 less revenues lost during waiting)	\$323,233	\$342,216	\$360,083	\$376,230	\$389,207	\$395,566	\$387,166	\$344,813	\$223,295
X_t (discounted investment cost, X_0)	\$400,000	\$393,179	\$386,473	\$379,883	\$373,404	\$367,036	\$360,777	\$354,625	\$348,577
$V_t - X_t$	(\$76,767)	(\$50,963)	(\$26,391)	(\$3,652)	\$15,803	\$28,530	\$26,389	(\$9,812)	(\$125,281)
Risk-Neutral Valuation -- Black's Approximation Results for δ=0%									
C_T^E (option maturing at T)	\$65,300								
C_t^E (option maturing at t)	\$0	\$32,024	\$66,093	\$96,830	\$123,786	\$144,565	\$152,955	\$134,873	\$65,300
Max(C_T^E , C_t^E)	\$65,300	\$65,300	\$66,093	\$96,830	\$123,786	\$144,565	**\$152,955**	\$134,873	\$65,300
Recommended deferral time (years)		0.5	1.0	1.5	2.0	2.5	**3.0**	3.5	4.0
Risk-Averse Valuation -- Black's Approximation Results (of Max(C_T, C_t)) **for $0 \le \delta \le r_f$.**									
δ (rate of return shortfall)									
0%	\$65,300	\$65,300	\$66,093	\$96,830	\$123,786	\$144,565	**\$152,955**	\$134,873	\$65,300
4%	\$47,228	\$47,228	\$65,868	\$96,418	\$123,164	\$143,721	\$151,892	\$133,643	\$64,223
7%	\$36,656	\$36,656	\$65,408	\$95,570	\$121,877	\$141,967	\$149,684	\$131,115	\$62,119
What-If Analysis Results (for Max(C_T , C_t))									
r (discount rate for calculating V_t)									
7%	\$119,108	\$119,108	\$120,839	\$156,110	\$186,092	\$208,795	\$217,870	\$198,158	\$119,108
10%	\$84,139	\$84,139	\$84,932	\$117,765	\$146,085	\$167,723	\$176,433	\$157,693	\$84,139
12%	\$65,300	\$65,300	\$66,093	\$96,830	\$123,786	\$144,565	**\$152,955**	\$134,873	\$65,300
σ (volatility of expected revenues)									
10%	\$0	\$457	\$9,070	\$27,161	\$47,747	\$64,253	**\$67,803**	\$43,562	\$1,467
40%	\$0	\$22,613	\$51,884	\$79,573	\$104,369	\$123,562	**\$130,857**	\$112,586	\$47,617
49%	\$0	\$31,073	\$64,679	\$95,117	\$121,859	\$142,481	**\$150,769**	\$132,682	\$63,550

50%	$0	$32,024	$66,093	$96,830	$123,786	$144,565	**$152,955**	$134,873	$65,300
51%	$0	$32,977	$67,506	$98,540	$125,709	$146,643	**$155,135**	$137,055	$67,044
60%	$0	$41,608	$80,140	$113,785	$142,824	$165,104	**$174,428**	$156,255	$82,446
100%	$0	$80,041	$133,992	$177,401	$213,036	$239,523	**$250,579**	$230,032	$141,348
***X*$_t$** (technical investment cost)									
$100,000	$223,233	$245,658	$266,937	$286,556	$303,029	**$312,898**	$308,118	$269,955	$156,212
$200,000	$123,233	$151,095	$179,182	$204,771	$226,529	$241,388	**$241,916**	$210,894	$112,640
$399,999	$0	$32,024	$66,093	$96,830	$123,786	$144,565	**$152,956**	$134,874	$65,300
$400,000	$0	$32,024	$66,093	$96,830	$123,786	$144,565	**$152,955**	$134,873	$65,300
$400,001	$0	$32,024	$66,093	$96,830	$123,786	$144,564	**$152,955**	$134,873	$65,300
$700,000	$0	$1,739	$13,606	$32,321	$53,229	$72,392	**$83,943**	$76,690	$34,276
Market Size Relative to that of California									
20%	$0	$5,791	$23,860	$45,408	$66,844	$85,182	**$95,282**	$86,566	$41,521
25%	$0	$32,024	$66,093	$96,830	$123,786	$144,565	**$152,955**	$134,873	$65,300
30%	$15,087	$84,490	$126,533	$161,771	$191,228	$212,347	**$217,459**	$188,644	$92,547

Assumptions

1. V_t — option's underlying asset calculated as the present value of net revenues arriving after Yankee enters the POS debit market at any time point t, $0 \le t \le 4$.
2. X_t — option's exercise price calculated as the present value of the technical investment cost outlay (of $400,000) Yankee would make to enter the POS debit market at the any time point t, $0 \le t \le 4$.
3. σ — volatility of expected revenues is 50%.
4. T — maximum deferral period is 4 years, from early 1987 to early 1991.
5. r_f — 7% annual risk-free interest rate.
6. δ — 0% rate of return shortfall adjustment for a risk-averse investor. (What-if analysis results are shown for $0 \le \delta \le r_f$.)

These results suggest two conclusions, *contingent on the information Yankee had at the time*. First, it is beneficial for Yankee not to wait 4 years to enter the POS debit market, so long as the roll out occurs after the end of the first year, because $C_T^E < C_t^E$ for $1<t<4$. Second, optimal deferral time is 3 years, because $C_3^A = \$152{,}955 > C_t^A$ for all $t \ne 3$.[4] The logic behind these conclusions is simple. Recall from Section 2.3 that, for certain expected values of V the values of the investment opportunity (option) and the operational project (underlying asset) would be equal, and so a risk-neutral firm would be indifferent between holding either. By the same token, profit maximizing decisions taken on behalf of the firm's shareholders would prompt it to undertake the investment opportunity at that point in time at which the investment opportunity -- in this case, the American deferral option -- takes on its maximum value. Alternately, as the deferral option in effect enabled Yankee to "buy" information for resolving uncertainties prior to undertaking the investment opportunity, at a cost equaling the revenues lost during deferral, it is best to convert the opportunity into an operational project (i.e., exercise the option) at the time point where the cost of information Yankee could buy exceeds the value of this information.

To see the impact of assuming risk-aversion, we included in Table 2 what-if analysis results for the rate of return shortfall, δ, changing from 0% to 7%, it upper limit equaling r_f. These results show that, for a deferral time longer than half a year, the recommendation still holds because the option value drops by less than 2% when δ goes to its upper limit. Such a small change in the option value is explained by the relative insensitivity of call options to a change in discount rates (Cox and Rubinstein, 1985). This crucial observation indicates that the recommendation produced based on risk-neutral valuation is robust enough to cover the case of risk-averse decision-makers in Yankee's case (and probably other cases).

For reasons explained shortly, Table 2 includes other results based on conventional simulation-based sensitivity analysis. These results, which reflect changes in one parameter at a time, show that the recommendation to postpone entry for 3 years is robust to changes in key parameters. It holds for the discount rate (used to calculate V_t) changing from 12% to 7%, for the variability of revenues changing from 10% to 100%, for a New England market size that is between 20% and 30% of that in California, and for an investment cost between $200,000 and $700,000. Only when the investment cost is as low as $100,000 does the analysis suggest postponing entry for just 2½ years.

4.3. Additional Sensitivity Analysis

Our next step was to analyze partial derivatives in the context of the Black-Scholes model, to see what additional useful results can be obtained for Yankee's situation and to assess Benaroch and Kauffman's (1999) claim that these derivatives offer simple and powerful sensitivity analysis capabilities. These derivatives measure the sensitivity of a call option to changes in volatility (σ), the value of the underlying investment asset (V), the cost to exercise the option (X), the option's time decay as expiration nears (t), and changes in the risk-free rate (r_f):

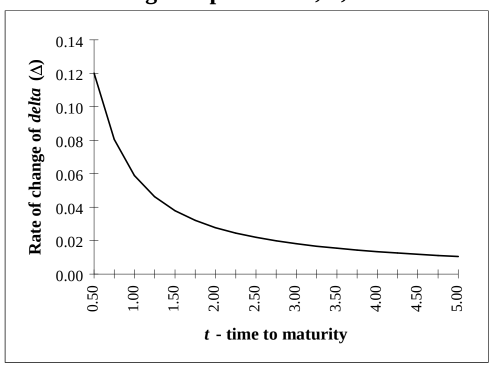
$$vega = \Lambda = \frac{\partial C}{\partial \sigma}, \quad delta = \Delta = \frac{\partial C}{\partial V}, \quad xi = \Xi = \frac{\partial C}{\partial X}, \quad theta = \Theta = \frac{\partial C}{\partial t}, \quad rho = \rho = \frac{\partial C}{\partial r_f}. \qquad \textbf{(2)}$$

[4] A conventional NPV-like analysis would suggest that the optimal deferral time is 2½ years, because $V_t - X_t$ reaches its maximum value for t=2½. However, such an analysis would be misleading because the (12%) discount rate used is not adjusted to reflect the upside potential of revenues.

On the positive side, these derivatives do help to answer some questions regarding the effect of changes in model parameters on the value of the investment opportunity. For example, based on ideas discussed in (McGrath, 1997), one question could be: what is the maximum pre-investment Yankee should be willing to make to ensure that σ won't drop by 1% (e.g., due to a lower chance for regulatory changes in Massachusetts in the lack of lobbying)? This question could be answered using *vega*, Λ, which tells us by how much the option (investment opportunity) value changes as a result of a 1% change in σ, the variance of expected revenues. In our case, (assuming t=3, V=\$387,166 for a New England market 25% the size of California's, X=\$400,000, and σ=50%), Λ=218,284 means that an increase in σ from 50% to 51% increases the net value of the deferred investment option by \$2,183. (This is confirmed by what-if simulation results in Table 2.)

We also found that additional useful results can be obtained based on plots of certain derivatives, although these plots would be produced as part of an open-ended investigation of the decision situation. For example, the plot in Figure 5 can help to explain why Yankee's management considered waiting three years, instead of two or four years. We speculate that, after about 3 years, the expected value of the underlying POS debit network asset would grow more slowly than the value of foregone revenues in the absence of POS debit roll out.

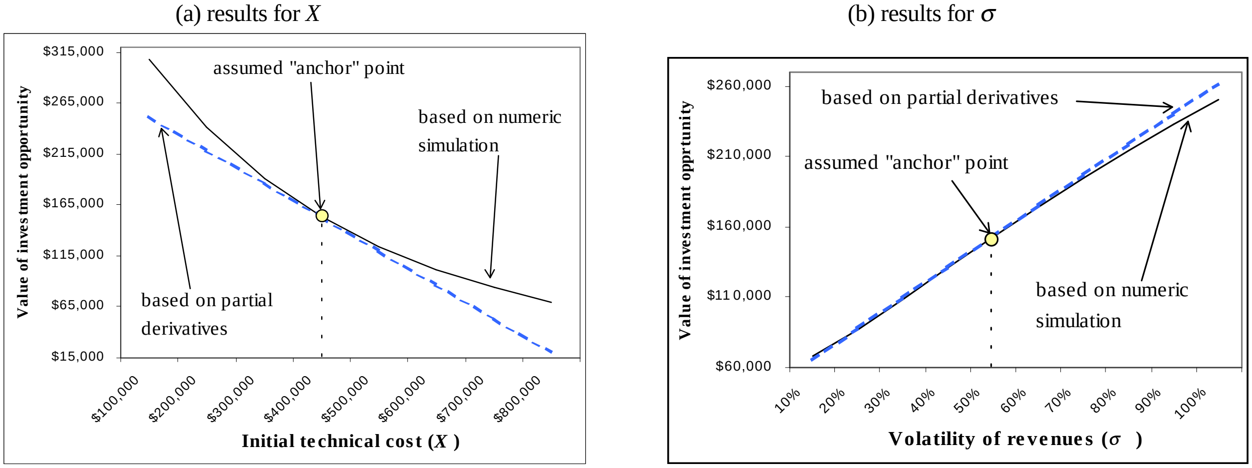
Figure 5: rate of change of option delta, Δ, as a function of time to maturity, *t*



On the negative side, upon further probing into the use of these derivatives in Yankee's case, we identified two weaknesses that make these derivatives of limited value. One weakness is their ability to yield valid answers only for questions involving a small change in one parameter. Like with what-if analysis, we must assume a specific anchor point (e.g., t=3, V=\$387,166 for a New England market 25% the size of California's, X=\$400,000, σ=50%, and δ=0%). Now, because the derivatives are not linear in their variables, they provide reliable answers only in the immediate vicinity of this anchor point. As Figure 6 illustrates, the degree of non-linearity can vary and thus impact the size of error made based on linear extrapolation. For a change of X from \$400K to \$500K, extrapolation based on *xi*, Ξ, would predict a drop of \$33,214 in the investment opportunity value, which deviates by more than 14% from the \$29,100 drop predicted by numeric simulation. (Note that Ξ=–0.33 means that a \$1 increase in the cost to enter the POS debit market would cause only a \$0.33 net decline in the investment opportunity value, as confirmed by what-if results in Table 2.) In the case of σ, for a change from 50% to 60%, extrapolation based on Λ would predict an increase of \$21,828 in the investment opportunity value, and deviate by only 1.66% from the \$21,472 increase predicted by numeric simulation. However, note that the dashed graph in Figure 6b becomes highly non-linear under different assumed parameter values (e.g., δ>0).

Figure 6: sensitivity analysis results obtained using derivative-based extrapolation and using numeric simulation

(a) results for X (b) results for σ



When it is not possible to assume an anchor point with a high degree of certainty, the last observation has implications on simulation-based sensitivity analysis as well. In Yankee's situation, choosing an initial plausible value of

50% for σ amounts to choosing an uncertain anchor point. In such cases, conducting what-if analysis with respect to two or three parameters at a time might reveal that the analysis results change for parameter values corresponding to points not in the proximity of the assumed anchor point. Indeed, in Yankee's case we found that certain parameter values lead to results that slightly deviate from the results reported in Table 2. For example, compared to the earlier recommendation reported based on the assumed anchor point (i.e., sigma=50%), when X=\$200K and δ=5%, the recommendation no longer hold when σ is below 15%. Overall, not being able to choose an anchor point with certainty (e.g., due to parameter estimation difficulties) requires putting more effort into sensitivity analysis.

Another weakness of partial derivative analysis is that it can provide answers only for parameters that plug directly into the Black-Scholes model. For example, a question that could be really interesting to Yankee is: what would happen if the assumed New England market size relative to California's market was 1% larger? There is no way to answer this question using derivative analysis. Since V depends on the market size relative to California, *delta* with a value of Δ=0.738 would only tell us that a \$1 increase in V causes a \$0.74 net increase in the value of the investment opportunity. Some additional computation is needed to produce the result necessary to answer the above question. A somewhat similar observation applies to *ro*, ρ. In our case, ρ=398,567 suggests that a ±%1 change in the risk-free interest rate, r_f, changes the investment opportunity (option) value by ±\$3,985, only ±2.3% of its original value. However, even here we must caution the reader with respect to the reliability of this result. In Yankee's case, ρ is not useful by itself because we cannot express V (and X) as explicit functions of r_f. Since C_t^A depends on V_t, by knowing ρ alone we cannot say anything about how C_t^A would change; a change in r_f would also mean changing the discount rate r (of 12%) used to estimate V_t based on the cash flows arriving after entry into the POS debit market (see Figure 4). Hence, here again, some form of what-if simulation seems more appropriate.

Finally, we checked if the Black-Scholes model also supports break-even analysis, following the claim that it can derive analytically values for volatility that are consistent with a given investment opportunity value (Benaroch and Kauffman, 1999). Formally, the *implied volatility*, σ', is the variance of the underlying asset that is consistent with (or implied by) the other variables, including the observed market value of the option. Assuming that σ is unknown and that all other parameters, including the option value, are given, one should be able to compute the Black-Scholes implied volatility. However, when we applied this concept to Yankee's case (using Excel's goal-seeking capabilities), some interesting questions arose. Specifically, by setting the investment opportunity value to zero, we hoped to find the minimum volatility level below which deferral need not be considered. But, to find this minimum level in the context of Black's approximation, should we set to zero the value of the American option (C_T^A) or the European option (C_T^E)? and for what time point t, $0<t\leq4$? Setting $C_T^E = 0$ yields an implied volatility that we could not interpret when the option is American. By contrast, setting $C_T^A = 0$ for the optimal deferral time recommended (of t=3) surprisingly yielded a negative implied volatility, suggesting a possible idiosyncrasy of the Black-Scholes model with respect to computing implied volatility under certain parameter values. We concluded that the ability to calculate implied volatility using the Black-Scholes model is of no value in Yankee's case (and probably other non-trivial cases).

In summary, our experience with Yankee's case suggests that Black-Scholes' derivatives cannot easily reproduce the results produced using simulation-based sensitivity analysis. Nevertheless, we must emphasize that even simulation-based results are obtained as an integral part of real options analysis. More precisely, it is the fact that the Black-Scholes model is a closed-from formula that allows to obtain simulation-based sensitivity analysis results with minimal effort (compared to, say, the binomial method). Our overall conclusion is that the ability of Black-Scholes model and its variants (e.g., Black's approximation) to usefully support sensitivity analysis cannot be discarded or ignored.

4.4. Discussion

How should the option pricing analysis results be interpreted in Yankee's case? The results indicate that an early entry into the POS debit market is not worthwhile, and that a rational recommendation would be to defer entry for a period of three years. Of course, this recommendation is based solely on the information Yankee had at the time of the analysis in 1987. Any new information arriving with the occurrence of events or changes during the recommended deferral period would require repeating the analysis to see whether and how the recommendation has to be revised.

What is the key benefit from using real options analysis *in Yankee's case*? The key benefit is that this analysis generates reliable results, regardless of whether the passive NPV is negative or positive and regardless of the decision-maker's assumed risk preferences. Moreover, even if the NPV decision rule were to be revised to choose a deferral period that maximizes the passive NPV, the results would still be faulty (see footnote 4). In this regard, a comment is warranted regarding the 5½ years analysis horizon Yankee used. As has been argued before (e.g., Trigeorgis, 1996), a firm can almost arbitrarily choose to shorten or lengthen the analysis horizon, and thus effect the size and the sign of the passive NPV. Yankee's case shows that real options analysis yields more reliable results independent of the exact analysis horizon considered. This benefit generally comes at the cost of having to estimate additional parameters. Estimating these parameters for Yankee's case did not overly complicate the analysis, its results or their interpretation, largely because real options analysis provides for an easier derivation of meaningful sensitivity analysis results and their interpretation. However, we recognize that this might not be the situation in more complicated cases.

In light of the above discussion, we feel that applying real options analysis to Yankee's case is well justified -- the results of our analysis can explain rationally the actual actions taken by Yankee. Ultimately, largely based on intuition and experience, it was decided that Yankee would defer entry into the market for POS debit services. Yankee made the move in 1989, hoping to have the POS debit service operational by early 1990, and it was very successful in that regard. Yanak thought that the timing was nearly optimal for three reasons. *First*, the uncertainty as to the acceptance rate of POS debit services seemed significantly lower, since by 1989 dramatic growth had begun to occur in California's POS debit market. *Second*, Yankee's ATM business had reached a mature stage, freeing up resources to push POS debit. *Third*, and most important, however, was an unexpected event in mid-1989. The Food Market Institute, the primary trade association for the grocery business, released a study that clearly demonstrated the benefits of POS debit transactions. The study said that for retailers the average transaction cost per sale was 0.82% of the sale value for POS debit, in contrast to 1.2% for checks and 2.1% for cash. (Checks involve depository handling costs and risk that the writer has insufficient funds; cash is subject to mishandling and pilfering, and must be physically moved from the supermarket to the bank by secure means.) The results of this study became the primary tool in educating retailers.[5]

Yanak went to Yankee's board of directors in early 1989, arguing in favor of rapid entry into POS debit. Yanak's strategy was to go after the largest 21 supermarket chains in New England first. By mid-1990 Yankee had one commitment from, Hannaford Brothers, one of the largest supermarket chains which decided to pilot the service in nine supermarkets in Maine and New Hampshire. It took about seven months to get the technology in place, and the service was operational in early 1991. Yankee's second major sign-up was Stop & Shop, the largest convenience store chain in New England. Stop & Shop chose to pilot POS debit in Rhode Island in order to assist Yankee in its efforts to persuade legislators that POS debit was a service in the public interest. It was hoped that this would result in a change of the law in Massachusetts that was a serious inhibitor to an earlier rollout. Since than, Yankee has been largely successful in getting the major supermarket retailers. In 1995, it had about 40 supermarket chains signed, out of the 100 operating in New England.

The growth has been phenomenal, from no POS debit terminals in 1990 to about 27,000 terminals in early 1993. That contrasts with a total of about 4,000 network ATMs, built up since 1984. The business volume grew rapidly, and is expected to continue for the next few years. Estimates for 1996 were for more than 40 million transactions per year.

5. Conclusion and Future Research

The present paper illustrates the value of applying real options analysis to an IT investment embedding a real operating option. The major conclusion of our study is that real options analysis provides a powerful complementary approach for evaluating real-world IT investments like the one in Yankee 24's case. Real options analysis proved suitable for structuring senior management's view of the strategic value of an investment involving an option, enabling a logical and intuitive interpretation of the analysis results. Moreover, it facilitates conducting sensitivity analysis which helps to probe and subsequently to understand the nature of an investment in terms that match the way a manager thinks about the problem.

Beyond just illustrating the value of real options analysis, our study also investigated several methodological issues that had to be addressed in the context of Yankee's case. We feel that our experience with respect to these issues can help to make the use of real options analysis more practical for senior managers.

One methodological issue, which arose when our interviewees had some difficulty expressing the variability of expected project payoffs as a single number, σ, is the need to develop ways to estimate this number. In Yankee's case, instead of precisely estimating σ, we used an approach that leads us to make our first recommendation.

> **Recommendation 1**: When it is difficult to obtain a precise estimate of σ (e.g., because of non-tangible benefits), start with an initial plausible estimate of σ and use sensitivity analysis to see if and how the analysis results change within the estimated lower and upper bounds of σ.

This approach worked well in Yankee's case, although it required putting more effort into sensitivity analysis (see reasons in Section 4.3). However, are there situations were this approach will not work? Or, is it possible to structure the approach better so that it would fit a wide range of situations? We referred to alternative estimation schemes in Appendix B. Can such schemes lead to more useful results? If so, under which circumstances should each scheme be used? More generally, thinking of variability as just another word for risk brings to mind Clemons (1991), who showed that IT managers deal with risk of various forms (functionality risk, project risk, market risk, etc.). Would linking the variability of expected payoffs to specific sources of risks present in a target investment simplify the estimation task?

Another important methodological issue we examined pertains to the notion of risk-neutral valuation. Since the introduction of the real options approach in the IS literature, the risk-neutral valuation of this approach has been criticized as

[5] While this event may suggest that σ (variability of revenues) could pick at some time point, we assumed a constant σ because the information available to Yankee at the time of analysis did not indicate the possible occurrence of this or any similar event.

being inadequate for options on non-traded investments (e.g., Kauffman et al., 1993, p. 588). Elsewhere we offered economic arguments that address this criticism (Benaroch and Kauffman, 1999). Here we used a version of the Black-Scholes model that adjusts for risk-aversion by discounting the value of an option by the so-called *rate of return shortfall*, δ. While δ is another difficult to estimate parameter, our experience in Yankee's case suggests the following recommendation.

> **Recommendation 2**: If you don't subscribe to risk-neutral valuation, and thus have to estimate the rate of return shortfall, δ, first calculate a risk-neutral option value using the Black-Scholes model, and then use sensitivity analysis with the adjusted Black-Scholes model to see how robust is the option value with respect to δ.

In Yankee's case, even when δ is at its upper limit, corresponding to the case of a very risk-averse investor, the adjusted model computes an option value that is only 2% lower than the value computed using risk-neutral valuation. Such a small drop in the option value is usually not enough to change the investment decision suggested by risk-neutral valuation. This conclusion is consistent with what the Finance literature postulates about the sensitivity of options to discount rates.

To summarize the estimation issues, a pragmatic message from our study is that the lack of exact parameter estimates is not always crucial. Only when the calculated value of an investment (plus embedded options) is marginally positive are precise parameter estimates necessary. Sensitivity analysis, which is always needed for real-world decision problems, is an effective way to obtain useful and reliable results in the absence of exact parameter estimates.

Relative to sensitivity analysis, another methodological issue we studied, our experience with the Black-Scholes model in Yankee's case suggests the following. Whereas partial derivative analysis seems to be of little value in supporting sensitivity analysis, the closed-from of this model permits to easily generate useful what-if sensitivity analysis results. This suggests the next recommendation.

> **Recommendation 3**: For sensitivity analysis purposes, it is more useful to rely on numeric, simulation-based analysis capabilities than on the capabilities associated with Black-Scholes' partial derivatives.

We must admit that, knowing that partial derivative analysis is much used in the investment arena leaves us with the question: is there a way to make partial derivative analysis more useful in the context of IT capital investments?

Our experience with the Yankee case also helped to surface other important methodological issues relevant to investments that are more complex than the one we presented. Such investments typically embed multiple cascading (compound) options. For example, for some projects, it is possible to stage the investment, and defer some of the stages, and abandon the project before all stages are completed, etc. Evaluating such projects requires guidelines for dealing with two related complexities.

One set of guidelines should help to recognize the options potentially present in an investment. Our experience indicates the need for a taxonomy of real IT options that identifies the exact assumptions, conditions and prerequisites underlying the existence of each option type. Using such a taxonomy, it should be possible to develop structured questionnaires that can help an analyst to identify readily all the options that might be involved in a given situation, and obtain the evidence necessary to establish the existence of a few central ones.

Another set of guidelines should help to identify which of the options potentially present in an investment ought to be brought into existence through additional investment. These guidelines must consider that the cost of creating an option, keeping it alive and exercising it could exceed the value that the option adds to the investment. This is especially true when the value of a compound option involving a series of cascading options is smaller than the sum of values of the individual options (see [Trigeorgis, 1996] for details). In this sense, identifying which options are worth creating also requires using an option-pricing model that is intuitive, flexible, and does not require managers to understand all of the mechanics of pricing complex options. So far the IS literature on IT options has examined three models: the binomial, the Black-Scholes, and the asset-for-asset exchange models. The Finance literature offers other models for different types of real options (Hull, 1993). In Yankee's case, the choice of model was relatively straightforward. But, when the investment is more complex, identifying the right model to employ requires mapping characteristics of the specific IT option being analyzed to the assumptions that each model makes (Benaroch and Kauffman, 1999).

In conclusion, we invite the reader to consider the strengths of real options analysis in a variety of IT investment contexts. To this end, we illustrated how the Black-Scholes model can be applied in the case of an IT investment option, and we explored the power of its sensitivity analysis capabilities as an interpretative mechanism for the results. We also encourage the reader to consider pursuing some of the issues we identified so that option-pricing concepts and models become more useful and accessible to IT practitioners and researchers.

Appendix A: DCF Analysis for Yankee 24's Immediate Entry

The data gathered using our structured interview with Yankee 24's senior management (see Section 4.1) suggests the following assumptions concerning the parameters involved in an immediate entry into the POS debit services market:

1. The POS debit transaction volume expected in New England is estimated based on the experience in California, assuming that the POS debit New England market is 25% the size of the market in California,
   - Until the end of 1991 the total number of POS debit transactions in California was around 12 million, and by the end of 1992 the number of transactions per month rose to 10 million. These figures imply a 16% per month growth rate in transaction volume in California between 1985 and 1992, consistent with expert estimates of the growth rate expected between 1993 and 1996. To obtain the periodic transaction volume in New England, we applied this growth rate to a base of 2,500,000 transactions for December 1992, based on the 10,000,000 figure in California. The base figure is discounted back by the 16% growth rate per month, and the monthly transaction volumes are aggregated.
2. The revenue per transaction is 10¢.
3. The operational marketing cost is estimated at $40,000 a year.
4. The initial technical investment cost is estimated at $400,000.
5. The discount rate, *r*, used to compute the passive NPV (ignoring the deferral flexibility) is 12%,
6. The analysis horizon is 5½ years, from early 1987 until (and including) early 1992.
7. The time it takes to begin servicing customers (and receiving revenues) once an entry decision is made is one year.

Based on these assumptions, Table A.1 shows the (passive) NPV we calculated for Yankee 24's immediate entry.

Table A.1: passive NPV analysis of Yankee's immediate entry into POS debit services

Year - Month	Number of Transactions	Operational Revenues	Operational Costs	Net Revenues	Investment Cost	Cash Flows
Jan. 87	0	$0	$0	$0	$400,000	($400,000)
July 87	0	$0	$0	$0	$0	$0
Jan. 88	3,532	$353	$20,000	($19,647)	$0	($19,647)
July 88	8,606	$861	$20,000	($19,139)	$0	($19,139)
Jan. 89	20,969	$2,097	$20,000	($17,903)	$0	($17,903)
July 89	51,088	$5,109	$20,000	($14,891)	$0	($14,891)
Jan. 90	124,470	$12,447	$20,000	($7,553)	$0	($7,553)
July 90	303,258	$30,326	$20,000	$10,326	$0	$10,326
Jan. 91	738,857	$73,886	$20,000	$53,886	$0	$53,886
July 91	1,800,149	$180,015	$20,000	$160,015	$0	$160,015
Jan. 92	4,385,877	$438,588	$20,000	$418,588	$0	$418,588
						NPV: ($76,767)

Appendix B: Plausible Schemes for Estimating σ

Option-pricing models represent the uncertain payoffs expected from an investment, *V*, using a probability distribution, and this requires having an estimate of the variability of *V*, σ. To this end, the recent literature on real options discusses several schemes for estimating σ based on market data (e.g., Luehrman, 1998; Amram and Kulatilaka, 1999). Here we summarize only a few of the more basic schemes that can be used to estimate σ:

(1) Supposing that an estimate of *V* is available, a subjective prediction that *V* will deviate by ±Δ% means that Δ is σ in percent terms (Brealey & Myers, 1988, p. 497). This scheme is straightforward, but somewhat naïve. Management would rarely be able to directly come up with an adequate estimate of ±Δ%.

(2) Assuming that multiple sets of contingent cash flows exist, each with different subjective probabilities, let V_i be set *i* of predicted payoffs. By computing a separate internal rate of return (IRR) for each V_i, σ can be the standard deviation of the computed IRRs (Copeland & Weston, 1988, p. 426). Compared to the first scheme, this scheme forces management to take an extra step that could make the estimate of σ more reliable.

(3) If we know the probability distribution of the expected project revenues and we can specify mathematically the functional relationships between input and output variables, a monte-carlo simulation can be used to estimate σ (Luehrman, 1998). Thus, since the variance associated with the present value of expected cash flows captures the uncertainty due to multiple possible future outcomes, a monte-carlo simulation of the future outcomes can establish σ. As a variation of the second scheme, this scheme forces management to probe deeper into the uncertain nature of *V* in order to produce an even more reliable estimate of σ.

(4) Where *S* is the price of a "twin security" – a traded security that has the same risk characteristics as (i.e., is perfectly or highly correlated with) the project under consideration – both *V* and *S* have the same rate of return and volatility. Thus, σ can be estimated as the variability of the rate of return on *S*. This scheme is readily applicable in two cases. One is when there is a publicly traded firm whose primary revenue generating services (e.g., ATM services, Internet advertising) parallel the services that the target project would yield to generate payoffs. Another cases is when the primary risk in the target project is due to reliance on a risky IT that is the main product sold by a traded firm (e.g., CASE tools, multimedia tools).

(5) Where the sources of project value uncertainty have been recognized (technical risk, competition risk, etc.), we propose that σ can be plausibly broken down into its components. If r_i is one of the risks contributing to the uncertainty of *V* and $\sigma(r_i)$ denotes the direct contribution of r_i to the variance of *V*, then σ can be estimated as:

$$\sigma(V) = \sum_{i,j=1}^{m}\left[\sigma(r_i) - \mathrm{cov}(r_i, r_j)_{i \neq j}\right]$$

When risks are not correlated, this equation becomes a simple sum of independent elements contributing to the variability of *V*, where each element can be estimated using one of the above schemes. This scheme is logical, but it remains to be seen whether it is easy to apply in practice.

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