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Managing Information Technology Investment Risk: A Real Options Perspective

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Abstract

Past information systems research on real options has focused mainly on evaluating information technology (**IT**) investments that embed a single, a-priori known option. However, since real options are not inherent in any IT investment, they usually must be planned and intentionally embedded in a target IT investment in order to control various investment-specific risks, just like financial risk management uses carefully chosen options to actively manage investment risks. Moreover, when an IT investment involves multiple risks, there could be numerous ways to reconfigure the investment using different series of cascading (compound) options. In this light, we present an approach for managing IT investment risk that helps to rationally choose which options to deliberately embed in an investment so as to optimally control the balance between risk and reward. We also illustrate how the approach is applied to an IT investment entailing the establishment of an Internet sales channel.

Key words: IT investments, IT investment evaluation, IT investment management, IT investment risk, option-pricing models, real options, risk management.

1. Introduction

Clemons and Weber [10] have recognized early on the role that real options (deferral, piloting, outsourcing, abandonment, etc.) could play in managing information technology (**IT**) investment risk:

> "A number of forms of risks arise in undertaking [strategic] IT programs. … These risks need to be recognized, and in some cases, the risks can be hedged, through out-sourcing and joint development, or by investing sequentially and scaling the project up or down as uncertainties become resolved." (p. 21)

They also illustrate how certain investments have, or could have, been configured to manage risk using real options.

> "The initial versions of Merrill's Cash Management Account and McKesson's Economost were initially rolled out as prototype versions […]. When market response permitted more precise and accurate estimation of their impact, these prototypes were replaced by full implementations. … In the early 1980s, Manufacturers Hanover built GEONET, a $300 million international X.25-based telecommunication network […]. Actual volumes reached only 50 percent of the estimates, well below capacity, and well below the level needed for recovery of the system's cost. And yet, since virtually all of the technology was acquired from a third-party provider of packet-switching services, it is likely that initial capacity could have been leased. Necessary expertise would have been acquired, and the bank could have begun conversion of existing applications as well as development of new applications to exploit packet-switching technology. This, too, is equivalent to a call option: if demand had materialized, the bank would have been in a position to respond rapidly with its own network." (p. 22)

With the growing acceptance of real options analysis (**ROA**) as a modern approach to investment analysis [2,14,32], several information systems (**IS**) researchers have tried to apply ROA to IT investment decision-making. Early proposals were put forth by Dos Santos [15] and Kambil et al. [19]. More recent IS work operationalizes these proposals. For example, Benaroch and Kauffman [3] examine the theoretical foundations of ROA and their relevance to IT investments. Additionally, several published case studies use ROA: to analyze the growth opportunities that prototyping yields relative to the launching of a new IT infrastructure [33], to study an IT investment in document image processing and workflow management [23], to determine the optimal timing of IT investment in point-of-sale debit card services [4], and to justify an IT platform adoption decision to upgrade from SAP/R2 to SAP/R3 [31].

There is one notable characteristic of this IS research. All the work cited above considers only IT investments that embed a single a-priori known option. That is, only once the option embedded in a target IT investment has been recognized, does this work use ROA to evaluation the recognized option. In practice, however, real options are not inherent in any IT investment. Rather, they usually must be planned and intentionally embedded in a target IT investment so as to enable a beneficial configuring of the investment. Additionally, as we show shortly, optimally configuring an IT investment may require embedding in the investment a series of cascading (compound) options that are difficult to value. These two complexities remain to be addressed by IS research on real options.

This paper presents an approach that uses ROA to actively configure IT investments for the purpose of managing the balance between their value and risk. More precisely, building on the notion that real options can control IT investment risk [10], the approach uses ROA to decide on how to optimally configure an IT investment by creating the set of options that maximally contributes to that investment value. Before we proceed, we must distinguish between two classes of real IT options: *operating* options that allow to flexibly change investment configuration features (timing, scale, scope, etc.), and *strategic growth* options that spawn new investment opportunities. The approach we present focuses on the use of operating options; however, we discuss the issues involved in extending the approach to growth options as well.

The rest of the paper is organized as follows. Section 2 motivates the need for the proposed approach by looking at the modeling and valuation issues involved in optimally configuring a realistic Internet-based IT investment example. Section 3 reviews the links between three fundamental concepts underlying our approach: risk, operating options, and risk management. Section 4 presents the approach along with a detailed illustration of how it is applied to the Internet-based investment example. Section 5 discusses strengths and limitations of the approach as well as presents key questions for future research. Section 6 offers some concluding remarks.

2. Sample Investment Situation

2.1. Modeling and Evaluating an "Internet Sales Channel" Investment

Consider the following investment scenario.

> A firm is contemplating the creation of a new Internet Sales-Channel (shortly, ISC). The ISC investment opportunity entails supporting sales of products A and B via the Internet. This includes enabling e-shoppers to obtain product information, to order products and pay for them, and to track their orders. The initial technological solution considered involves developing a front-end application using HTML scripts and linking it to legacy sales processing systems in the back office.

A common approach to modeling and evaluating the ISC investment is decision tree analysis (DTA). When the investment payoffs (V) and/or costs (I) are uncertain, the decision tree would include chance nodes reflecting two or more probabilistic payoff and/or cost scenarios. This would imply that the distributions of V and/or I have a non-zero variance. To reflect managerial flexibility, the tree could embody decision nodes that enable management to prune poor tree branches so as to avoid bad outcomes and/or enhance good outcomes. Thus, whereas uncertainty affects the expected investment value by widening the distributions of V and/or I, decision nodes beneficially change these distributions asymmetrically (see Figure 1).

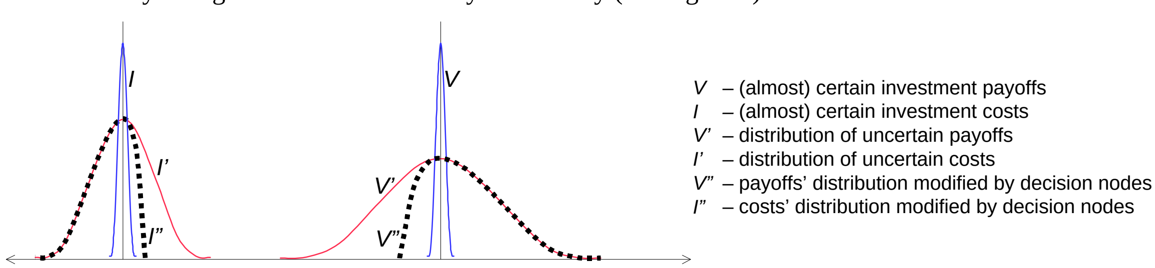

Figure 1: effects of uncertainty and decision nodes on the distribution of investment value

To illustrate, consider two of the uncertainties potentially present in the ISC investment and the forms of managerial flexibility they could call for. One uncertainty is about the level of demand that the new Internet sales channel can generate. Low demand could make it non-economical to undertake the investment or to keep it operational, and high demand could present opportunities to expand the range of initially planned e-services. Another uncertainty is due to the potential for "channel conflict". Parties (e.g., sales force) holding the view that the Internet sales channel might cannibalize existing sales channels could mislead the IS staff to produce an inadequate application. To control these uncertainties, several decision nodes can be used to reconfigure the investment. One alternative is to defer investment, say for up to *n* time periods (months, years, etc.). Deferral can resolve demand uncertainty by allowing to wait-and-see how demand for comparable e-offerings is building up elsewhere. Another alternative is to invest in a smaller scale pilot effort. This would help to learn what the actual demand could be and whether the Internet sales channel would indeed cannibalize existing sales channels. A third alternative is to invest fully and then scale the investment up or down. Scaling down means contracting operations (e.g., disabling personalization features) in response to low demand, and scaling up means expanding operations (e.g., selling additional products) in case of high demand. Each of these three alternatives and their hybrids corresponds to a different way to configure the investment.

Two things follow from the ISC example. First, as we consider more uncertainties (competition, technical complexity, etc.), the number of investment configurations enabled by different forms of managerial flexibility (abandonment, outsourcing, etc.) grows unproportionally fast. Second, since different configurations could allow managing the same uncertainties differently, some configurations are bound to be more valuable than others.

2.2. Key Modeling and Valuation Questions

How can we optimally configure an IT investment in light of its uncertainties? This question raises issues concerning the way DTA is used to model and evaluate an investment.

Relative to modeling, the question is how to identify all relevant investment configurations? In principle, a decision tree that maps out all plausible investment outcomes, as well as all the decision nodes that permit choosing which outcomes to avoid and/or enhance, is a "complete" tree that embeds all possible investment configurations. Any branch going through all decision nodes between the root and leaves is a configuration. But, how do we develop such a complete tree? Because DTA does not provide a systematic way to develop such a tree, how can we be sure that we identified all relevant decision nodes and where they ought to be inserted in the tree? This concern is magnified by the tendency of a decision tree to grow very fast as we consider more uncertainties and the various forms of managerial flexibility that they call for, especially when entire subtrees originating in time-sensitive decision nodes (e.g., deferral for up to *n* periods) must be duplicated in different parts of the tree.

Valuation wise, even if we have a complete decision tree, how do we choose the most valuable investment configuration? Choosing the most valuable configuration requires using a dynamic rollback valuation procedure that determines what choices to make at each decision node in order to maximize the expected investment value.[1] This valuation procedure suffers one problem that has been extensively discussed and illustrated in the capital budgeting literature (e.g., [32]): it is difficult to find a suitable risk-adjusted discount rate when managerial flexibility is involved. During tree evaluation, poor tree branches are pruned, changing the dispersion (or risk) of expected outcomes and, in turn, complicating the estimation of a proper risk-adjusted discount rate. In essence, DTA seeks to compute the *active* net present value (NPV), NPV^A, of an investment:

$$NPV^A = NPV^P + \text{value of managerial flexibility}, \qquad \textbf{(1)}$$

where NPV^P, the *passive* NPV, is what traditional NPV analysis measures (i.e., NPV analysis ignores the value of managerial flexibility on the premise that it is an intangible cash flow). However, DTA cannot treat managerial flexibility as a separately measurable value element. An enhancement of DTA that avoids this complication has been developed, but it is non-trivial and requires estimating the investor's utility function [29].

2.3. The Real Options Analysis (ROA) View

ROA is an increasingly popular alternative approach that offers two important benefits relative to the modeling and valuation of capital investments. ROA equates managerial flexibility with real options: the real options embedded in

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[1] In DTA, since a decision at any stage can be optimal only if all subsequent decisions are themselves optimal, the optimal initial decision is determined by starting from the end of the tree and working backwards. This dynamic programming, roll-back procedure involves determining at each stage, as we move backwards, the expected risk-adjusted NPV by discounting all the NPV values calculated at the previous stage and multiplying them with their respective probabilities of occurrence and then summing up.

an investment permit management to apply rational interventions that favorably change traits of the investment (timing, scale, scope, etc.) as uncertainties unfold. (Appendix A reviews fundamental option concepts.)

The most widely documented benefit of ROA is more correct valuation (compared to traditional capital budgeting techniques like NPV analysis and DTA), as illustrated by several IS case studies (e.g., [4], [31]). Unlike DTA, ROA computes the value of embedded options (managerial flexibility) separately and then adds it to the NPV^P. Conceptually, standard ROA can be seen as an adjusted version of DTA. ROA computes the value of embedded options as follows: it replaces the subjective probabilities associated with cash flow contingencies by certainty-equivalent probabilities, and then discounts the value of options by the risk-free (not risk-adjusted) rate.[2] Although in some cases ROA and DTA give similar valuation results, it has been shown that DTA generally tends to be off the more the investment is uncertain, sometimes by as much as a factor of two [11]. However, despite this benefit of ROA, evaluating investments embedding multiple interacting options, not just one option, remains a non-trivial endeavor.

The other benefit of ROA is in investment modeling. One aspect of this benefit is obvious in the way ROA models risk factors that cause a decision tree to grow fast: all cash flow contingencies are modeled using an explicit probability distribution (e.g., binomial, log-normal), and decision nodes that must be duplicated (e.g., flexible deferral) are modeled as American options (see Appendix A). There is another important aspect of the modeling benefit – ROA enables managing capital investment risk through a rational choice of which real options to deliberately embed in an investment so as to beneficially configure the investment. This idea contrasts with the way ROA is typically used to evaluate real options that are a-priori known to be embedded in an investment. Rather, this idea parallels the way financial risk management uses carefully chosen options to actively manage the risk specific to each financial investment. Unfortunately, this aspect of the modeling benefit of ROA has been discussed only implicitly in the ROA literature, and it was never operationalized or practically illustrated.

In sum, despite these modeling and valuation benefits of ROA, IT managers remain without answers to questions that are central to the ability to optimally configure an IT investment:

- How to systematically identify the "shadow" options that an IT investment could potentially embed?
- Which of these shadow options can and ought to be created and embedded in the investment?
- What viable investment configurations are yielded using different subsets of the identified shadow options?
- How to find out which of these viable configurations maximizes value?

2.4. Expanding ROA to the Management of IT Investment Risk

The present paper develops an approach that addresses exactly the questions listed above. The need for such an approach arises on two grounds. The ROA literature at large offers no explicit answers to these questions. More importantly, even if it were to address these questions, it is likely to overlook certain unique traits of IT investments.

In other words, there are some gaps between what ROA currently offers and what is needed to effectively configure (model and evaluate) real-world IT investments. The main gaps can be summarized as follows.

1. The ROA literature typically looks at a subset of the risks effecting IT investments. It mostly looks at financial risk (e.g., interest rate and foreign exchange uncertainty), exogenous market risk (e.g., price and demand uncertainty), and cost risk (e.g., technical and inputs uncertainty) [14]. Typical IT investments involve several additional risks (functionality risk, organizational risk, etc.), as we shall see shortly.
2. ROA typically considers no more than two sources of risk at a time. Applying ROA to an investment that is subject to more than one risk usually requires formulating a custom-tailored analytical valuation model reflecting those risks. However, developing such analytical models for situations involving more than two risks is infeasible,

[2] ROA redistributes probability masses such that risk is reallocated in a way that allows for risk-free discounting. This adjustment is based on economic arguments that permit extracting the appropriate discount rate from market information (through revision of probabilities). Although this adjustment is originally intended for options on traded assets, three arguments are made in support of applying it to real options on non-traded assets as well. First, in capital budgeting, whether an investment is traded or not, the goal is to determine how much its cash flows contribute to the market value of the investing firm, and so a firm seeking to maximize its shareholders' value may use risk-free discounting to evaluate real options [26, 3]. Relatedly, Amram and Kulatilaka [2] argue that the risk-free discounting issue is becoming less critical: as more investment risks are nowadays being scrutinized by the financial markets (shareholders), decision-makers can draw on financial market techniques, benchmarks and information in order to align their investment decisions with those of the market. Finally, even if one rejects these arguments for investments that are subject to firm-specific risks not shared by all firms, discounting the value of a real option by a factor reflecting the risk unique to an investment (i.e., for a risk-averse investing firm) lowers the option value only marginally [4]. This result is due to the relative insensitivity of options to discount rates [18].

as Amram and Kulatilaka [2, p. 110] explain: "the computational complexity increases as more sources of uncertainty are added. Most numerical solutions to the pde [partial differential equation] can handle just two sources of uncertainty." Since typical IT investments could be exposed to more than two risks, it is necessary to find other ways to model and evaluate such investments. We present later one alternative way that gets around the need to formulate complex custom-tailored analytical models.

3. Real options are not inherent in IT investments. Rather, specific options often must be carefully planned and intentionally created in order to configure an investment in a way that permits controlling the risks specific to that investment. Yet, the ROA literature offers no explicit guidance as to why and how the risks specific to each investment are the key to identifying which particular options ought to be embedded in that investment. Our forthcoming analysis of the role of options in managing investment risk offers new insights into this issue.

4. The valuation of complex options remains a difficult endeavor. As IT investments could be exposed to multiple risks, they may need to be configured using a series of cascading (compound) options. Standard valuation models (e.g., Black-Scholes model) ignore the fact that the value of individual options in a series of cascading options may be lowered or enhanced by interactions with other options. Yet, custom-tailoring a separate valuation model for each viable investment configuration is not practical, especially when more than two risks are involved [2]. There are general lattice models that simplify the valuation of cascading options, however, some of these have not yet found their way into the IS literature. We later present the log-transformed binomial model [32] as one example.

As indicated in the above summary of gaps between what ROA currently offers and what is needed to configure real-world IT investments, the next sections discuss several steps that move us closer towards closing these gaps. Building on these steps, Section 4 presents an approach that helps managers to address the question: *How to use real options to optimally configure an IT investment*? Because concepts like risk, operating options and risk management are at the core of this approach, understanding these concepts is an important prerequisite.

3. IT Risks, IT Options, and Risk Management

In this section, we discuss the links between IT risks and real IT options. We start by reviewing the risks effecting IT investments. Then, we examine why the risks present in an IT investment help to recognize which specific options should be embedded in the investment for the purpose of value maximization. Finally, we explain how different options permit controlling different IT investment risks.

3.1. Common IT Risks

Over the years two streams of IS research identified different forms of IT investment risk. The major stream includes mainly work concerned with ways to control software development cost (e.g., [1,27,12,5,21]). As such, this work focuses only on risks arising in software development. Recently, Lyytinen et al. [25] classified the risks identified by this body of work using the socio-technical model of organizational change. This model views organizations as multivariate systems consisting of four interacting components – task, structure, actor, and technology – which can easily be mapped to well-known elements of software development. Because this model focuses on components internal to the firm, the risks in Lyytinen et al.'s classification can be generally referred to as firm-specific risks related to software development practices. Relative to the lifecycle of an IT investment, these risks apply mainly to the building stage.

The second stream of research focuses more on IT investment risks arising outside the scope of software development (e.g., [22,10,9,20,13]). This body of work looks at organizations as open systems operating within an environment that can effect or be effected by the enterprise, a view that is especially relevant in the context of strategic IT applications. Respectively, this work identifies additional forms of risk that can generally be referred to as competitive risks and market risks. Several of these additional risks parallel some of the risks included in Lyytine et al.'s (1998) classification, although they are at a higher level of granularity. More importantly, relative to the lifecycle of an IT investment, some of these additional risks arise at the recognition stage, before software development commences (e.g., unacceptable financial exposure), and some arise at the operation stage, once development is completed and the application becomes operational (e.g., regulatory actions).

Table 1 offers a high-level synthesis of the central forms of IT investment risks identified by both research streams. As suggested earlier, these forms of risk can be placed into three categories.

- *Firm-specific risks* are due to uncertain endogenous factors. They could be the result of uncertainty about the ability of the firm to fully fund a long-term capital-intensive investment, the adequacy of the firm's development capabilities to a target investment, the fit of the target application with various organizational units, etc. These factors affect the ability of the investing firm to successfully realize an investment opportunity.

- *Competition risks* are the result of uncertainty about whether a competitor will make a preemptive move, or simply copy the investment and improve on it. These risks give rise to the possibility that the investing firm might loss part or all of the investment opportunity.
- *Market risks* are due to uncertain exogenous factors that affect every firm considering the same investment. These risks could be the result of uncertainty about customer demand for the products or services a target investment yields, potential regulatory changes, unproven capabilities of a target technology, the emergence of a cheaper or superior substitute technology, and so on. These factors can affect the ability of the investing firm to obtain the payoffs expected from a realized investment opportunity.

Risk Category	***Risk Area***	**Add to variability of**	
		Payoffs	**Costs**
Firm-specific risks	*Monetary* – the firm cannot afford the investment; the financial exposure may not be acceptable and/or the projected investment costs may not remain in line with the projected investment benefits.	+	+
	Project – the target application is too large or too complex, the IS staff's technical skills may be inadequate or it may lack experience with a target IT, or the firm's existing IT infrastructure may be inadequate.	+	+
	Functionality – the firm may build the application right according to the required specifications, but still fail to realize the anticipated benefits because the requirements are wrong to begin with.	+	+
	Organizational (political) – the IT application can be undermined by vested interests of people in the firm, or it may be adopted too slowly by people in the firm.	+	+
Competitive risks	*Competition* – competitors could take an unanticipated preemptive action or simply respond by developing a better application.	+	
Market risks	*Environmental* – unanticipated favorable or infavorable reaction of bodies that can effect or be effected by the application; these reactions could come from regulatory bodies, customers, vendors and business partners.	+	+
	Systemic – the IT application may so dramatically change the environment (i.e., market or industry) that the expected benefits vanish.	+	
	Technological – the technology used to develop the application may be immature (e.g., no experience exists with it), or the application could become obsolete with the introduction of a new superior technology.	+	+

Table 1: key risks inherent in IT investments and their impact on investment payoffs and costs

The right columns in Table 1 indicate the effect of each form of risk on the variability (uncertainty) of investment payoffs and costs. Firm-specific risks apply to all kinds of IT investments, and they affect both the expected payoffs and expected costs. However, these days their impact on expected payoffs is generally stronger. Increasingly, IT investments, and especially strategic ones, aim at producing innovative product, service and inter-organizational capabilities. Obtaining the payoffs expected from such capabilities depends primarily on market acceptance (by customers, vendors, etc.) and sometimes on the first-mover effect. Since firm-specific risks increase the possibility of failure to deliver promised capabilities on a target date, such a failure could erode the first-mover advantage and/or lead to market rejection, even if the capabilities are re-introduced later in an improved form [13]. This observation applies to a lesser degree to investments that produce capabilities for internal use, although these capabilities could also fail to deliver the expected payoffs (i.e., cost reductions) because of organizational and/or architectural misfit (e.g., reengineering projects [7]). The other two risk categories, competition risks and market risks, apply especially to strategic IT investments and, therefore, they impact the variability of payoffs more than the variability of costs [10, 20].

3.2. Real IT Options and Risk Management

IS research on real options recognizes that IT investments can embed various types of real options, including: *defer*, *stage*, *explore*, *alter operating scale*, *abandon*, *lease*, *outsource*, and *growth*. Table 2 defines these options in a way that highlights saddle conceptual differences between them. When looking at these options from a pure valuation perspective, some of the options can be considered identical because these conceptual differences can be ignored (e.g., the outsource and the lease options are essentially special cases of the abandon option). However, the conceptual differences between these options are important from a perspective that is also concerned with using options to beneficially configure IT investments, the perspective taken by the approach we present in Section 4. For example, a decision to embed an outsource option as opposed to an abandon option may have critical business implications. Our forthcoming analysis of how each of the options in Table 2 permits controlling risk further clarifies the importance of the conceptual differences between seemingly similar options.

Option	Investment Features (and References to Examples in the IS literature)
Defer	IT investment with expected payoffs and costs *V* and *I*, respectively, can be postpone for up to *T* time periods (years) in order to learn about the potential investment outcomes before committing to the investment [4].
Stage (Stop-Resume)	IT investment is realized (implemented) as a series of *m* development stages involving cost outlays $I_1,\ldots, I_m$ (to be made at times $t_1,\ldots, t_m$), where implementation could be shutdown temporarily and resumed, or even abandoned (killed) in midstream, and the investment payoffs *V* arrive only after all implementation stages were completed.
Explore (Pilot / Prototype)	IT investment can be realized on a prototype/pilot scale whose expected payoffs and cost are V_p and I_p, respectively, and, if the prototype/pilot is successful, the investment can be scaled up by making a follow-up investment whose expected payoffs and cost are V_F and I_F, respectively [10, 19, 23, 17]. Thus, unlike the *stage* option, the *prototype/pilot* option could generate payoffs (i.e., $V_p \geq 0$)
Alter Scale *Scale-up* (expand) *Scale-down* (contract)	IT investment operating scope can be expanded or contracted, depending on observed conditions, with the extreme case of shutting down operations temporarily and restarting when conditions become favorable [23]. Changes in operating scope could be achieved by changing the output rate (e.g., number of transactions processed per unit time) or the total length of time the investment is kept alive. The *scale-up* option could be important when choosing to build "production" capacity in excess of the uncertain expected demand; it offers the flexibility to produce more output per unit time. The *scale-down* option could be important when choosing among alternative realization technologies with different ratios of variable to fixed costs; building an application with higher operational (maintenance) costs relative to initial development costs offers the flexibility to shorten the application life and contract the application scale by reducing operational (maintenance) expenditures.
Abandon (switch-use)	A realized (operational) IT investment can be abandoned permanently if conditions worsen severely, so that its salvageable resources could be sold or put to more valuable uses [10, 17]. The abandonment flexibility is important, for example, when choosing among alternative realization technologies with different "purchase-cost" to "resell-cost" ratios.
Outsource	IT investment realization can be sub-contracted to a third party in order to transfer the risk of cost overrun, schedule overrun or complete failure of an in-house realization effort. This option can sometimes be likened to a *stage* option (e.g., in the case of software development [28]), expect that breaking an outsourcing contract in midstream could carry a cancellation penalty.
Lease	IT investment realization resources can be leased (instead of purchased), and if information arriving during the investment life indicates that the expected payoffs are too low, the investment can be killed by failing to make the next lease payment in order to save the resources' residual value [10]. Unlike in the *abandon* option, abandoned resources could have insufficient salvage value to the investing firm (but not to the leasing firm), and breaking a lease usually carries a penalty.
Compound	IT investment involves two or more of the above options, where the value of an earlier option can be affected by the value of later options or vice-versa [33].
(Strategic) Growth	IT investment yields capabilities that open up future investment opportunities as well as permits the firm to respond quickly to competitive or regulatory threats [33, 31]. Unlike with the *stage* option and *explore* option, a *strategic growth* option may have an underlying asset (the payoffs expected from future investment opportunities) that is different from the asset (current investment) that spawns it in the first place.

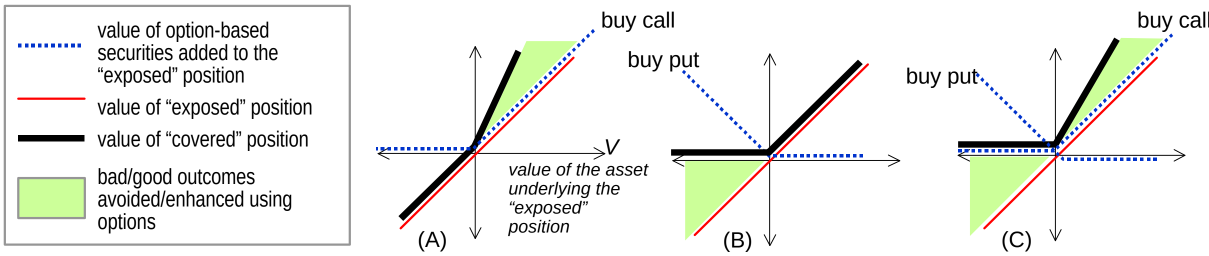
Table 2: types of real options that could be embedded in IT investments

To understand the role that these options play in relation to capital investment risk, it is useful to look at the role that financial options play in managing financial investment risk. Financial risk management is about designing investment positions that protect the investor against losses due to, and/or generate profits from exploiting, well-defined risks [18].[3] In option-based risk management, given an "exposed" position containing underlying asset *V* (e.g., stock), options on *V* are purchased and/or sold and then added to the exposed position in order to form a "covered" position. Figures 2A and 2B show the payoff functions of the most basic covered positions created by buying a call or a put option on *V* (ignoring option cost). These covered positions control risk by canceling out bad, or they leverage opportunities by enhancing good, fluctuations in *V*. Other covered positions are created: by selling a call option, by selling a put option, or by simultaneously buying and selling multiple calls and puts (e.g., see Figure 2C). The way options in all covered positions work is this – the buyer and the seller of an option on *V* hold different beliefs about the direction and size of future fluctuations in *V*, and so they create a side-bet on the future value of *V* by trading the option. In this sense, options are vehicles for trading specific risks across investors that perceive those risks differently.

The analogy with managing capital investment risk is apparent, except for one important difference. The value of an exposed financial position parallels the (passive) NPV^P of a capital investment, the options added to the exposed position parallel real options embedded in the investment, and the value of the covered position parallels

[3] Traditional risk management seeks to protect a financial position against the devaluation effects of risk (e.g., changes in interest rates). Under this view, actions (trades) that increase the risk of a position are considered speculative. In recent years, however, it has been recognized that economically sound actions (trades) can sometimes increase the expected return on a position by more than the risk they add to the position. Consequently, risk management is now broadly viewed as a way to control the balance between the risk and return characteristics of a position.

the (active) NPV^A of the investment. However, with capital investments, risk can be managed mostly "internally", through exploitation of operating options that are already owned and embedded in the investment. Only the outsource option and the lease option allow trading risk with other parties.



(A) Add to the exposed position a purchased call option that can enhance good, but is insensitive to bad, fluctuations in *V*.
(B) Add to the position a purchased put option that can cancel out bad, but is insensitive to good, fluctuations in *V*.
(C) Add a simple options combination of a purchased call and a purchased put that can cancel out bad fluctuations and enhances good fluctuations in *V*.

Figure 2: fundamental option-based risk management strategies

To illustrate how embedded options control risk, consider the way the defer option and the expand option alter the value profile of an investment with uncertain payoffs. Based on equation (1), if $NPV^P = V - I$, where V and I are the investment payoffs and costs, respectively, we can derive the payoff function characterizing the value that an option adds to the NPV^A. In the case of an investment embedding a deferral option, if the option is exercised immediately, the investment's NPV^A has the form $\max(V - I, 0)$ [32]. Since we can also write this NPV^A as

$$NPV^A = (V - I) + \textit{defer}\text{ option} = \max(V - I, 0), \qquad \textbf{(2)}$$

the payoff function characterizing the value of the deferral option can be written as

$$\textit{defer}\text{ option} = \max(V - I, 0) - (V - I) = \max(0, I - V). \qquad \textbf{(3)}$$

This payoff function resembles that of a purchased put option (see Appendix A). In relation to DTA, we can say that a deferral option allows cutting out tree branches for which $I > V$ (see Figure 3A), similar to the effect of a financial put in Figure 2B. In case of the expand option, its payoff function has a different form. Where I_e is the cost of expanding an investment by e%, the investment's NPV^A is

$$NPV^A = (V - I) + \max(eV - I_e, 0) = (V - I) + \textit{expand option}, \qquad \textbf{(4)}$$

and the payoff function characterizing the value of the expand option can be written as

$$\textit{expand option} = \max(eV - I_e, 0). \qquad \textbf{(5)}$$

This payoff function resembles that of a purchased call option (see Appendix A). In relation to DTA, we can say that an expand option allows exploiting tree branches for which $eV > I_e$ (see Figure 3E), similar to the effect of a financial call in Figure 2A. In both cases, real options control risk by favorably changing the probability distribution of V.

Applying the same derivation to the other options in Table 2 leads to a surprising insight: *except for the expand option, all operating options alter the value profile of an investment embedding no options the same way that purchased put options alter the value profile of an exposed financial position* (see Figure 3). This insight may seem inconsistent with the way numerous ROA researchers liken certain real options to call options.[4] In effect, these researchers probably mean to say that investments embedding those options, as opposed to the options themselves, can be likened to call options. Because buying a put option amounts to buying insurance against bad investment outcomes, adding a purchased put option to an exposed position produces a covered position whose payoff function resembles that of a call option, consistent with what is seen in Figures 2B and 2A. The above insight has a more important implication. It gives rise to a principle central to the approach we present shortly, namely: the specific risks effecting an investment can drive the recognition of which options to embed in the investment. This principle applies even to the expand option, for which risk can be defined as "failure to react to favorable outco

[4] In the ROA literature, it is common to think of real options as business opportunities, and hence to sometimes wrongly characterize certain options as call options. For example, with respect to the *defer* option, several authors write: "The option to defer is thus analogous to an American call option" [32, p. 10]; "Option to wait … is analogous to a call option." [19, p. 8]; and "the option to wait-to-invest is analogous to an American call option" [23, p. 8]. Likewise, relative to the *explore* option, other authors write: "pilot project can be likened to acquiring a single perid call option" [19, p. 170].

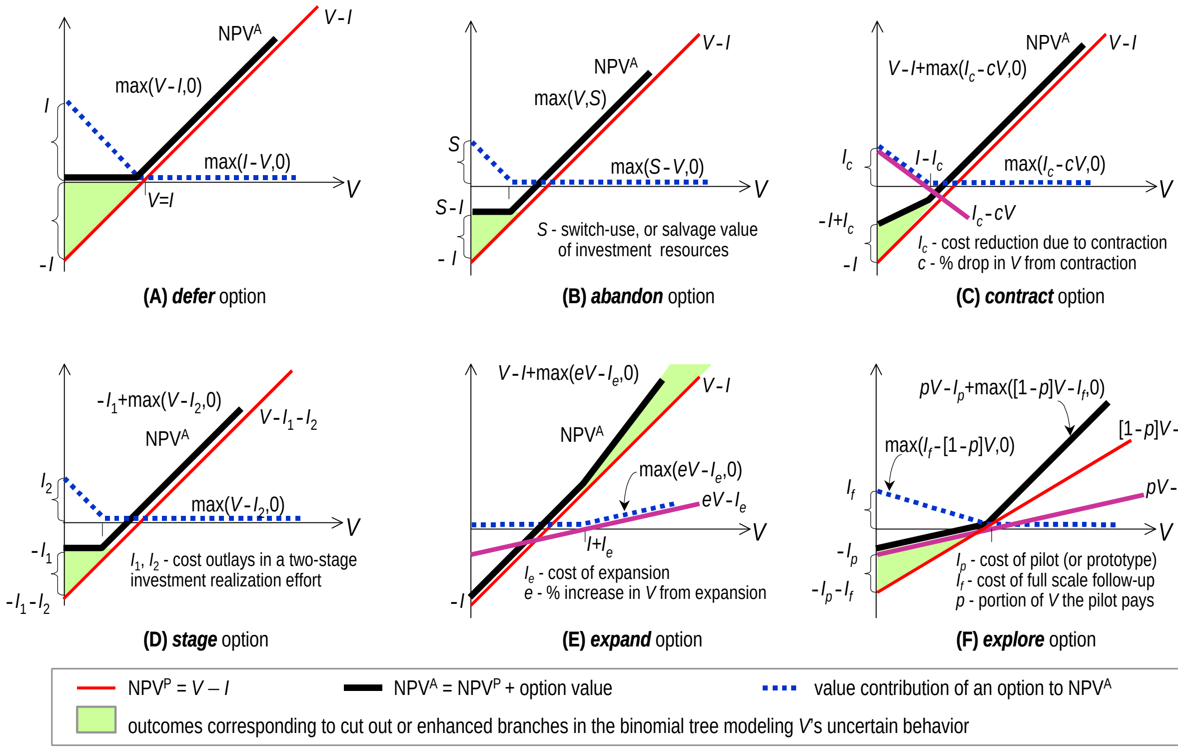
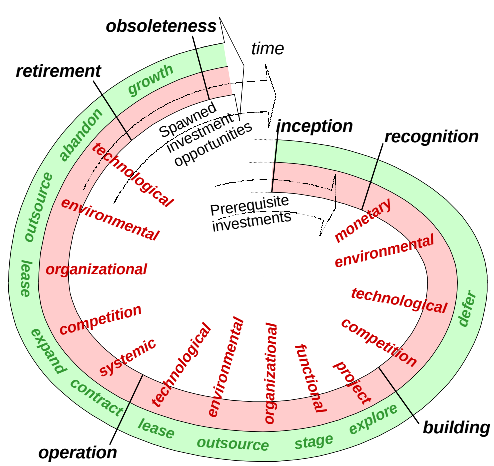


Figure 3: graphical depiction of how different operating options effect the (active) NPV^A

3.3. IT Risks-Options Mapping

Operationalizing the concept that risk can drive the recognition of which options should be embedded in the investment requires reliance on some sort of a mapping of risks to options that can control them. We develop such a mapping based on the notion that different stages in the investment lifecycle give rise to different IT risks, and that different operating options are relevant at different stages in the investment lifecycle (see Figure 4).



Stages in the investment lifecycle:

- *Inception* -- investment exists as an implicit opportunity that was probably facilitated by earlier investments.
- *Recognition* -- investment is seen as a viable opportunity.
- *Building* -- investment opportunity is realized.
- *Operation* -- investment is operational and produces direct, measurable payoffs.
- *Retirement* -- investment continues to produce indirect payoffs, in the form of spawned investment opportunities that build on the technological assets and capabilities it has yielded.
- *Obsolescence* -- assets and capabilities yielded by the investment become obsolete.

Figure 4: types of IT investment risks and real options mapped onto the investment lifecycle

Each type of operating option essentially enables the deployment of specific responses to threats and/or enhancement steps, under one of four investment modes.

1. **Defer investment** to learn about risk in the investment recognition stage. If we don't know how serious some risk is, the option to *defer* investment permits learning about the risk by acquiring information passively (observe competitor moves, review emerging ITs, monitor regulatory actions, etc.) or actively (conduct market surveys, lobby for regulatory changes, etc.). Such *learning-by-waiting* helps to resolve market risk, competition risk, and organizational risk. Apparently, the greater the risk, the more learning can take place, and the more valuable is the deferral option. This is consistent with what the finance theory postulates about the effect of uncertainty on the value of financial options (see Appendix A).

2. **Partial investment** with active risk exploration in the building stage. If we don't know how serious some risk is, investing on a smaller scale permits to actively explore it. Three options facilitate *learning-by-doing*, that is, enable gathering information about the firm's technological and organizational ability to realize the investment successfully. The option to *stage* investment supports learning via a sequential development effort, and the options to *pilot* and *prototype* support learning through the production of a scaled down operational investment. The last two options compress the investment lifecycle, thus allowing to learn early how competitors, customers, regulatory bodies and internal parties will react to the investment initiative. Put another way, these options permit market risk, development risk and organizational risk to be transferred to earlier parts of the full-scaled investment lifecycle. Similarly, the *stage* option divides the investment realization effort into parts, thus permitting to transfer risk across parts within the building stage. For example, implementing the riskiest parts of the realization effort as early as possible helps to reveal up-front whether the entire realization effort can be completed successfully (e.g., within schedule and budget).

3. **Full investment** with reduction of the expected monetary impact of risk in the building and operation stages. Here, options help to lower the value consequences of risk and/or the probability of its occurrence. An example of the former is the option to *lease* development resources, which protects against development and market risks by allowing to kill an investment in midstream and save the residual cost of investment resources. A way to lower the probability of risk occurrence is the option to *outsource* development. This option lowers the risk of development failure by subcontracting (part or all of) the realization effort to a third party that has the necessary development capabilities and experience. In essence, both these options permit *transferring risk* (partially or fully) to a third party.

4. **Dis-investment/Re-investment** with risk avoidance in the operation stage. If we accept the fact that some risk cannot be actively controlled, two options offer contingency plans for the case it will occur. The option to *abandon* operations allows redirecting resources if competition, market or organizational risks materialize. The option to *alter scale* allows contracting (partially disinvest) or expanding (reinvest) the operational investment in response to unfolding market and organizational uncertainties.

Based on the logic of these investment modes, the mapping of specific risks to specific options that control them can be refined to fit any class of IT investments. We show one such detailed mapping in Section 4.2.

4. Option-Based Approach to Managing IT Investment Risk

The approach we present next helps to address the question: *What shadow options potentially embedded in an IT investment can and ought to be created so as to configure the investment in a way that maximize its* NPV^A? Like with most methodologies, the value of our approach arises from the fusion of the simple risk and option concepts we just discussed, especially since these concepts have received little attention in the literature. When applied together, these concepts enable management to control the balance between risk and reward.

Our approach involves four main steps that must be repeated over time (see Figure 5). These four steps help to best configure an investment under the information set available initially, but as time passes they must be re-applied in case that some risks get resolved or new risks surface. In what follows, we explain these steps and illustrate them in the context of the Internet Sales Channel (ISC) investment.

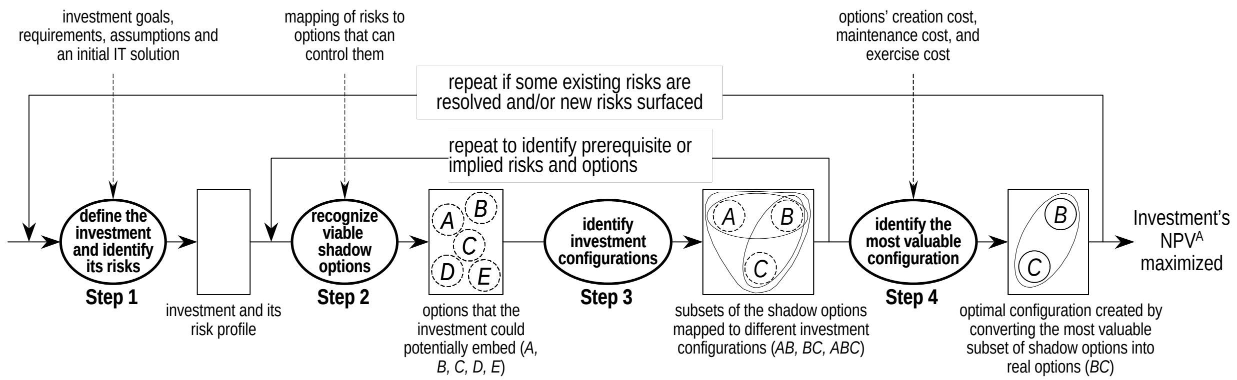


Figure 5: steps in the option-based approach to managing IT investment risk

4.1. Step 1: Define the Investment and its Risks

The first step entails defining the investment goals and requirements, identifying an initial IT solution, stating investment assumptions (economic, technological, organizational, etc.), and revealing the investment risks in light of the assumptions. These activities should be carried out relative to each of the stages in the investment lifecycle. Additionally, it is useful to specify for each identified risk whether it affects the investment payoffs and/or costs.

ISC Illustration

Table 3 summarizes the result of applying the first step to the ISC investment. The risks in this investment fall into three areas. One is environmental risk. There is much uncertainty about the expected customer demand. Another is firm-specific capability risk. There is uncertainty about the responsiveness of linkages with back office sales processing systems under high e-shoppers volume, and there is organizational and functionality uncertainty due to the potential for "channel conflict". The last area is competition risk. For simplicity of exposition we assume that all these risks affect only the expected investment payoffs, not costs. Even the firm-specific risks make only the payoffs uncertain. If the firm announces and advertises the new sales channel and the development fails or just gets delayed, the firm might not be able to reap the full payoffs from this channel once it is introduced at a later time.

Stage & Goals	Key Risks / Opportunities
Recognition: establish an ISC for products A and B, where e-shoppers can get product information, place orders, pay for orders, and track orders	• *Environmental* (E1) – low customer demand could mean it might not be economical to let the investment live past the recognition stage
Building: the initial IT solution involves developing a front-end application using HTML scripts and then linking it to legacy sales processing systems in the back office	• *Project* (P1) – IS staff lacks experience with linking Web applications to legacy sales systems (poorly implemented linkages may slow down the application response time) • *Organizational* (O1) / *functionality* (F1) – due to the potential for "channel conflict" (i.e., the new ISC cannibalizing existing sales channels), some parties (e.g., sales force) may not cooperate in providing system requirements or even provide faulty requirements, resulting in poor application functionality
Operation: support e-sales of products A and B	• *Environmental* (E1) – low customer demand could make it non economical to let the investment live long • *Environmental* (E2) – high (above expectations) customer demand presents an opportunity to expand the ISC investment, but implementation using HTML scripts could make expansion infeasible or too costly • *Environmental* (E3) – too high customer demand could result in an inability of the back office ISs to handle the extra processing load presented by e-shoppers • *Competition* (C1) – competitors could react by launching an improved application, and thus erode the extra demand generated produced by the new ISC

Table 3: first step of the approach applied to the ISC investment

4.2. Step 2: Recognize Shadow Options

The second step proceeds to recognize shadow options that the investment could embed, based on the identified investment risks. Following the discussion in Section 3.3, Table 4 shows the main sources of common IT risks mapped to specific operating options that can control them (e.g., technological risk (T2) could be controlled by the defer, the lease and the abandon options). Finally, as seen in Figure 6, it may be necessary to reiterate this step, because mapping some risks to certain options can raise new risks. For example, while outsourcing can help control project risk (P1), it may raise new co-development risks (contractual risk, subcontractor compatibility risk, etc.).

			Investment Lifecycle Stage	Recognition	Building				Operation		
	Risk Area		Risk (Opportunity) Driver / Option	*Defer*	*Stage*	*Explore*	*Outsource Develpm't*	*Lease*	*Abandon (switch-use)*	*Contract*	*Expand*
Firm-Specific Risks	*Monetary (Financial)*	**M1**	firm cannot afford the project (unacceptable financial exposure)	+		+	+	+			
		M2	costs may not remain in line with projected benefits	+	+	+	+	+	+	+	
	Project	**P1**	staff lacks needed technical skills	+	+	+	+	+			
		P2	project is too large or too complex		+	+	+	+			
		P3	inadequate infrastructure for implementation		+	+			+	+	
	Functionality	**F1**	wrong design (eg, analysis failed to assess correct requirements)		+	+	+	+	+		
		F2	problematic requirements (stability, completeness, etc.)		+	+			+		
	Organizational	**O1**	uncooperative internal parties	+	+	+			+		
		O2	parties slow to adopt the application		+	+			+	+	
	Competition	**C1**	competition's response eliminates the firm's advantage	+	+	+		+	+	+	
		C2	competition acts before the firm	+		+					
Market Risks	*Environmental*	**E1**	low customer demand, with inability to pull out of market	+	+	+	+	+	+	+	
		E2	demand exceeds expectations (follow-up opportunities exist)	+		+					+
		E3	too high customer response may overwhelm the application	+		+		+	+	+	+
		E4	customers may (bypass) develop their own solutions	+		+			+	+	
		E5	unanticipated action of regulatory bodies	+				+	+		
	Systemic	**S1**	environment changed requirements (expected benefits vanish)			+			+		
	Technological	**T1**	application may be infeasible with the technologies considered		+	+	+	+	+		
		T2	the introduction of a new superior implementation technology may render the application obsolete	+				+	+		
		T3	the implementation technologies considered may be immature	+		+	+		+		

Table 4: IT investment risks mapped to operating options that could mitigate them
(Cells painted in gray correspond to risks and options relevant to the ISC investment.)

Option	Key necessary and sufficient existence conditions
Defer	• investment opportunity is not "now-or-never" • investing firm is operating as a monopoly, or it is not exposed to a serious competitive preemption threat • deferral can resolve some uncertainties
Stage development	• full-scale development effort is decomposable into a series of steps that can be performed one at a time • certain steps in the development effort are more risky than others • series of development steps can be performed non-linearly, with the most risky steps moved at early or as late as possible in the building stage
Explore (pilot / prototype)	• investment can be made operational at a reduced scope of a pilot / prototype • pilot / prototype can be developed using existing resources at a fraction of the full-scale investment cost (i.e., relatively minor investment in resources is needed) • some risks can be investigated without making the full-scale investment • killing an operational pilot / prototype carries no reputation, competitive or regulatory consequences
Expand / Contract	• it is possible to increase / lower the investment "output" rate per unit time or to lengthen / shorten the investment life • implementation with higher / lower maintenance costs relative to initial development costs is viable – this feature allows to lengthen / shorten the investment life or to expand / contract the operating scale by increasing / lowering maintenance expenditures • implementation with higher / lower variable operating costs relative to the fixed operating costs is viable • expanding / contracting the scope or scale of capabilities the investment yields can increase the investment payoffs / lower the operating (maintenance) expenditures or improve the capabilities' quality
Abandon	• alternative implementations exists with different "acquisition"-cost to "resell"-cost ratios • investment resources have alternate uses • it is possible to kill the operational investment without sever regulatory, competitive or reputation consequences
Outsource development	• investment does not involve core (or strategic) business processes and capabilities • third parties with different investment-realization (development) risk profiles exist
Lease	• some investment resources can be leased (hardware, networking, software, etc) • third parties with different resource-ownership risk profiles exist (i.e., they are willing to offer cancelable lease contracts because the salvage value of leased resources is greater for them than for the firm)

Table 5: conditions that must be met for shadow options to be viable

The recognized shadow options must be examined carefully. Table 4 might map a particular risk to certain options that can control it, but not every investment exposed to that risk would necessarily embed all those options. Some recognized options would be immediately viable if they are already embedded in the target investment (e.g., the development technology considered by the initial IT solution might already support flexible expansion). Other recognized shadow options are viable only if they can be first converted into real options, usually by making a small pre-investment cost outlay. For example, the option to outsource development can become real only if we solicit and evaluate outsourcing vendor proposals and then identify a suitable proposal. In other words, not every recognized shadow option is necessarily viable. For example, Table 4 could suggest the abandon option as a way to control market risk, but regulatory constraints could prohibit killing the target investment shortly after it becomes operational. Table 5 lists key conditions that must be met in order for operating options of different types to be viable. These conditions are anchored in the logic underlying the four investment modes discussed in Section 3.3 (defer investment, invest partially, etc.) and in the investment context. Note that these conditions exclude option-cost and option-value considerations; these considerations are treated in step 4.

ISC Illustration (continued)

The gray cells in Table 4 show the shadow options recognized in the ISC investment. The options are: defer, stage, explore, outsource, contract, expand, and abandon. However, examination of the existence conditions (Table 5) for these shadow options reveals that the outsource option is not viable. Outsourcing could help to control project risk (P1), but it is not viable because back office sales processing systems are linked to core business processes and because the spawning of growth options into future E-Commerce opportunities could be suppressed. (We postpone discussion of such growth options to Section 5.2.)

4.3. Step 3: Design Alternative Investment Configurations

The third step entails identifying alternative ways to configure the investment using different subsets of the recognized (viable) shadow options, and then assessing risk tradeoffs between the identified configurations. It may seem that the number of possible configurations could be large. However, many implausible configurations usually can be ruled out based on three simple principles.

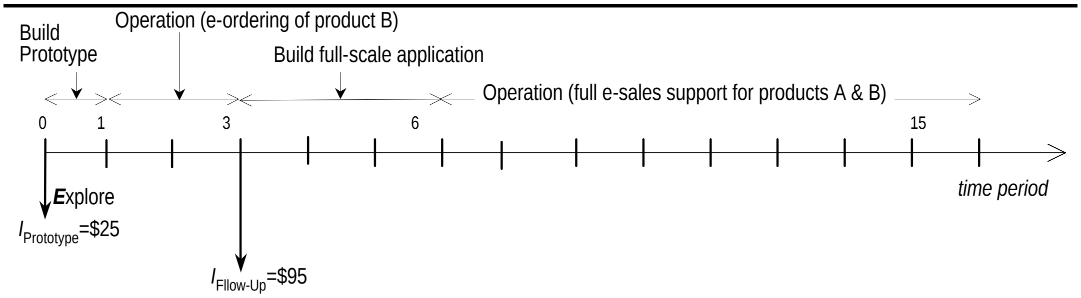
1. The order of options in a configuration must correspond to the order in which the options arise in the investment lifecycle (e.g., an abandonment option cannot precede a deferral option).
2. The options in a configuration must be able to co-exist (e.g., the options to defer and outsource may be each viable today, but the option to outsource today a deferrable (and cancelable) investment may or may not be viable).
3. Only configurations involving maximal subsets of shadow (viable) options are worth considering; such configurations are of equal or greater value than configurations involving non-maximal subsets of shadow options (e.g., instead of considering two separate configurations, one embedding a deferral option and one embedding a staging option, consider a configuration embedding both options).

Two reasons suggest that different plausible configurations could present risk tradeoffs. Each configuration might allow controlling only a subset of the risks present. Moreover, a configuration that reduces one risk might at the same time increase another risk (e.g., deferral lowers market risk but increases competition risk). Simple tabulation of the risks that each identified configuration lowers or increases can reveal such risk tradeoffs. In step 4, the quantitative valuation of configurations can assess the identified risk tradeoffs in monetary terms.

ISC Illustration (continued)

Based on the results of steps 1 and 2, we next illustrate plausible investment configurations that represent two extremes. One configuration includes one of the recognized shadow options, whereas the other includes five of these options.

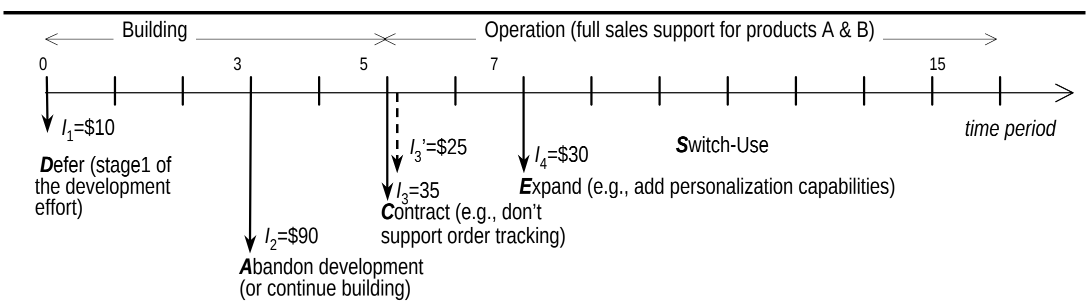
The first configuration considers only the *explore* option, which entails building a prototype that supports only e-ordering of product B (see Figure 6). Building the prototype and keeping it operational for two time periods would help to: (1) resolve demand risks E1, E2 and E3, by allowing to learn in practice what the actual volume of e-shoppers is going to be; (2) mitigate project risk P1, as it would be possible to test the response time of implemented linkages with legacy sales systems under varying loads; (3) reduce organizational risk O1 by permitting non-cooperative parties to find out how many e-shoppers are totally new customers; (4) control functionality risk F1 through an evolutionary convergence towards the application's desired functionality; and, (5) hedge competition risk C1 by allowing to find out upfront what the competition's reaction might be. Overall, by the third time period, resolution of uncertainties concerning demand and application response-time would enable management to decide whether to contract or expand the set of e-services initially planned for the full-scale implementation.



1. The ***explore*** option involves developing a prototype, followed by a contingent full-scale implementation.
   a. Cost outlay $I_{Prototype}$ is used to build a prototype that supports only the e-ordering of product B.
   b. If the prototype "succeeds", cost outlay $I_{Follow\text{-}up}$ would be used to develop the full-blown ISC application.

Figure 6: a configuration involving only one of the shadow (viable) options that the ISC investment can embed

The second configuration considers five of the recognized shadow options (see Figure 7). One option is to *stage* the investment into three cost outlays. The first outlay would be used to implement and test linkages with legacy sales systems. It would allow resolving risks P1 and E3, which concern the response time of those linkages under extreme demand patterns. Upon completion of this stage, if risks P1 and E3 are not resolved, construction could be shutdown by foregoing the subsequent cost outlays. The second option is to *defer* the first cost outlay for up to two time periods (assuming that longer deferral would significantly increase the risk of competitive preemption). Deferral permits learning about the levels of demand experienced by other firms with a comparable Internet sales channel, in support of resolving risks E1 and E2. Deferral could also provide the time to get the cooperation of all parties so as to reduce risks O1 and F1. A third option is to *contract* the investment at time period 5 by lowering the third planned cost outlay, also in support of hedging risks E1 and E3. A fourth option, relevant in case of high demand, is to *expand* the investment at time period 7 by making a fourth cost outlay. This option could control demand risk E2, as long as the application is implemented using a technology (e.g., Java) that provides the necessary expansion flexibility. (We ignore for now future investment opportunities spawned by growth options.) Last is the *switch-use* option, which would help to control competition risk C1 by allowing to kill the operational investment and to redirect its resources to alternate uses (e.g., Intranet applications). This option can be exercised any time between time period 7 and 15.



1. The ***stage*** option permits realizing the investment using three sequential cost outlays.
   a. Outlay I_1, which is ***deferrable*** for up to two periods, is used to build and test linkages with legacy sales systems.
   b. Outlay I_2, which is used to build the front-end Web functionality using Java, could be forgone if stage 1 fails. In such a case, development can be abandoned, with no recovery of I_1 (I_2=$70 if HTML scripts are used instead.)
   c. Outlay I_3, which is used to add order tracking features and to complete the building stage, could be lowered to I_3' if the outcome of stages 1 and 2 requires to ***contract*** the initially planned scope of operations by 25%.
2. The ***expand*** option permits scaling up operations by 50%, by making a fourth cost outlay, I_4. This option assumes that the application is developed using Java.
3. The ***switch-use*** option permits to shutdown operations and to reuse the investment resources elsewhere. The investment salvage value is 50% of the cumulative investment costs (i.e., it "jumps" upward 50% of each cost outlay incurred), and it declines exponentially at a rate of 10% per time period between cost outlays.

Figure 7: a configuration involving five of the shadow options that the ISC investment can embed

These two investment configurations involve one risk tradeoff. Staging development cannot control competition risk C1, because the firm would not be able to know how competitors would react before the investment becomes operational (upon making all three cost outlays). By contrast, because prototyping is viable only if implemented using HTML scripts (i.e., no time is taken to build Java skills), it could constrain future expansion and follow-up opportunities presented by high actual demand (risk E2).

4.4. Step 4: Evaluate Options and Investment Configurations

Given viable investment configurations, this step finds the most valuable configuration. To see how, it is useful to revisit the parallel between our approach and DTA. Conceptually, steps 1 through 3 construct a decision tree that encompasses every plausible form of managerial flexibility. Starting with a "plain" decision tree reflecting the NPV^P, and given the risks present at each stage in the investment lifecycle, we track through the tree and use Table 4 to suggest which decision nodes (or options) can (re)configure the investment in ways that suppress and/or enhance poor and/or good outcomes. Each path through this tree includes a different subset of these decision nodes (options), corresponding to one viable configuration. In this sense, each configuration can be seen as an independent investment involving its own assumptions about payoffs, costs, and flexibility afforded by options it embeds. Respectively, by calculating the NPV^A of every configuration separately, we can identify the one having the highest NPV^A.

Recall that ROA computes NPV^A as the sum of the NPV^P and the net value of embedded options. Computing the net value of embedded options requires considering two things.

- Option cost. To decide if it is worth bringing a shadow option into existence, we must weight its value against the costs of converting it into a real option. This cost can come in the form of: cash flows or market share lost during deferral, time involved in soliciting and evaluating leasing or outsourcing vendor proposals, extra cost of using a newer technology that has a higher switch-use value in case of abandonment, extra cost of using a more versatile technology that offers expansion flexibility, etc.
- Value additivity. IT investments that are subject to multiple risks may need to be configured using compound options, or a series of cascading options (e.g., see Figure 7). Because of interactions among the options embedded in the same investment, the individual options can contribute value in a substitutive, additive or complementary way. By substitutive, additive and complementary we mean that the value of compound option AB is smaller than, equal to, or greater than the sum of values of option A and option B, respectively. Trigeorgis [32] offers a formal discussion of the factors affecting the (non)additivity of options. The intuition can be explained in relation to DTA: there could be some overlap between tree branches that different put options cut out and/or different call options enhance. In this sense, since most real options are put options (see Section 3.2), it is more likely that the incremental value of each additional embedded option would be smaller than its isolated value, and this value would tend to get smaller as more options are present.

	Only *V* is uncertain	***V* and *I* are uncertain**
Investment embeds a simple option	Black-Scholes and binomial models [18, 3].	Asset-for-asset exchange model [18, 15].
Investment embeds compound options	Log-transformed binomial model [32].	Expanded log-transformed binomial model [16]. Asset-for-asset exchange model adapted for sequential opportunities [8, 30].

Table 6: sample option valuation models classified by investment traits

In this light, the question is which option valuation model can measure the value of embedded options. The answer depends primarily on whether the option involved is simple or compound and on whether the investment payoffs (V) and costs (I) are certain or stochastic. Table 6 shows a sample of valuation models classified along these two dimensions. If only V is uncertain, like in the ISC example and other IT investments, the log-transformed binomial model is appealing because it simplifies the valuation of compound options. This model can be easily applied using spreadsheets (see Appendix B). Additionally, it is intuitive because it can be seen as a natural extension of DTA (as we show shortly in the context of the ISC investment).

All the valuation models in Table 6 require estimating several parameters (see Appendix A). These parameters are: (1) V – expected investment payoffs; (2) I – expected investment costs; (3) r_f – risk-free interest rate; (4) T – option's time to maturity; (5) s_V – volatility (standard deviation) of V; (6) s_I – volatility of I; and, (7) r_{VI} – correlation coefficient between V and I. Parameters V and I are the expected cash inflows and outflows discounted at a risk-adjusted rate that ignores managerial flexibility, just like in standard NPV analysis. Parameter r_f is readily observable. Parameter T is needed for every one of the options embedded in a configuration, and it follows from the definition of each option. The last three parameters are more challenging. The literature offers a number of estimation schemes for these parameters [4, 2, 24]. Some schemes are subjective, some rely on proprietary information (e.g., past development cost data), and some are based on public market data. In addition to these schemes, we suggest a new estimation scheme that naturally follows from our approach. Consider how this scheme works for s_V alone. If there are n risk factors known to contribute to the uncertainty of payoffs (competition risk, market risk, etc.), s_V can be broken down into its components:

$$s_V = \sum_i s_{R_i} + \sqrt{\sum_{i=1}^{n} \sum_{\substack{j=1 \\ i \neq j}}^{n} s_{R_i} s_{R_j} r_{R_i R_j}} \qquad \textbf{(6)}$$

where s_{R_i} is the contribution of risk factor R_i to the volatility of V, and $r_{R_i R_j}$ is the correlation coefficient between risk factors R_i and R_j. Each s_{R_i} can now be estimated separately using one of the schemes mentioned above (i.e., subjectively, based on proprietary information, or based on market data). Equation 6 enables maximum reliance on market data, by permitting estimation of those risk components s_{R_i} known to be correlated with traded assets using market-based schemes.[5] (However, as with every new estimation scheme, only real-world experience with our proposed scheme could tell whether it does improve the estimation of s_V.)

Lastly, upon computing the NPV^A of every viable investment configuration, sensitivity analysis must be conducted with respect to each of the above parameters. The idea is to see whether the configuration with the highest NPV^A is robust to changes within reasonable parameter value ranges. Sensitivity analysis could be a demanding task, however, it is necessary regardless of whether we use ROA, DTA, or any other evaluation approach.

ISC Illustration (continued)

We next illustrate how to evaluate the staged development configuration in Figure 7 by calculating its NPV^A. Recalling that steps 1 through 3 conceptually produce a "complete" decision tree containing all viable configurations, Figure 8 depicts only the tree portion reflecting this configuration. If not for the difficulty of finding a suitable risk-adjusted discount rate, we could have used DTA to do the evaluation. Instead, we use an options valuation model. Since only V is uncertain in the ISC investment, we use the log-transformed binomial model. As we said, this model is a natural (but adjusted) extension of DTA; to see why, suffice to look at the similarity of the decision node valuation rules in Figure 8 to the option valuation rules used by the log-transformed model in Appendix B. We proceed with the valuation based on the data in Figure 7, however, we emphasize that the primary focus is on the interpretation of the derived option values. (To allow readers to see exactly how these option values are derived, our ISC example was designed to fit a generic investment configuration whose evaluation is explained in great details in [32, pp. 227-256]; the options embedded in this generic configuration are similar to the ones involved in Figure 7.)

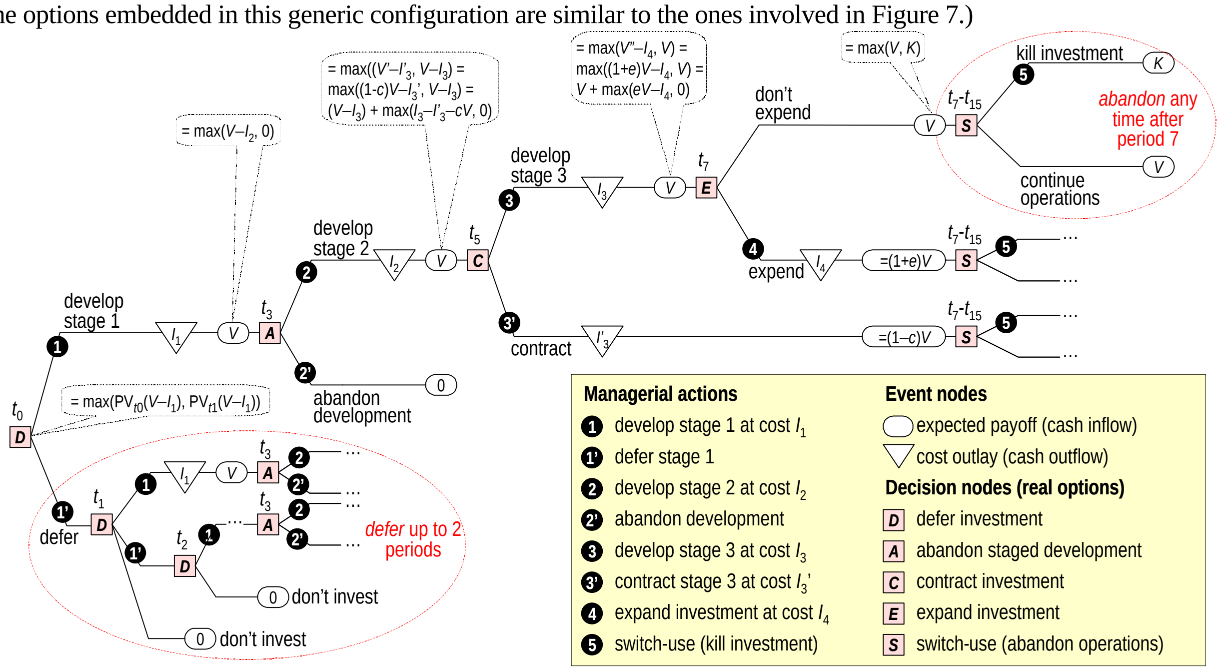


Figure 8: decision tree reflecting the ISC investment configuration shown in Figure 7
(and rules for evaluating decision nodes in the tree)

[5] The best market-based scheme relies on the notion of "twin security". Where W is the price of a traded asset that has the same risk characteristics as V (or I), the target investment payoffs (costs), V (or I) and W have the same rate of return, and so s_V (or s_I) can be estimated as the volatility of the rate of return on W. This scheme is readily applicable when a risk factor effecting V (payoffs) is also known to effect the payoffs generated by the primary products or services (e.g., ATM services, Web advertising) of a publicly traded firm, or when a risk factor effecting I (costs) is due to the use of an IT that is the main product of some traded firm (e.g., CASE tools, multimedia tools). Moreover, the notion of a twin security could be more broadly interpreted as a basket of relevant assets. For example, in the case of Netscape's launching of its

We start the configuration valuation by calculating the NPV^{P}. For simplicity, assume that all cash inflows and outflows are discounted at the risk-free rate r_f=5%, that the computed present value of payoffs expected from the investment becoming operational in time period 5 is V=100, and that the volatility of payoffs is estimated at s=50%. Where $e^{-r_f \cdot t}$ is the continues-time discounting operator, the calculated NPV^{P} is negative:

$$\text{NPV}^{\text{P}} = V - I = V - (I_1 e^{-r_f \cdot 0} - I_2 e^{-r_f \cdot 3} - I_3 e^{-r_f \cdot 5}) = 100 - 114.7 = -14.7\ .$$

The picture changes drastically once we consider the five shadow options: *defer* (*D*) is an American put maturing in 2 years, *stage* with abandonment (*A*) is a European put with 3 years maturity, *contract* (*C*) is a European put maturing in 5 years, *expand* (*E*) is a European call maturing in 7 years, and *switch-use* (*S*) is an American put maturing in 15 years. Table 7A shows the value that the log-transformed binomial model calculates for every combination of these options. A key result is that the NPV^{A} is significantly higher than the NPV^{P}:

$$\text{NPV}^{\text{A}} = \text{NPV}^{\text{P}} + \text{combined value of all shadow options} = -14.7 + 86.6 = 71.9.$$

------------- TABLE 7 is on the last page -------------

Before we proceed to see which of these options is worth creating, it is useful to link this result to the point we made concerning the non-additivity of options value. Because of strong interactions between these options, their combined value is reduced by almost half, from a straight sum of values of 159 to 86.6. The impact of these interactions is more visible in the case of put options. While the simple sum of values of the four put options present (*D*, *A*, *C*, and *S*) is 124, their combined value (combination *DACS*) is only 53.4. This is mainly the result of overlaps between the poor tree branches that these options cut out. By contrast, the value of *E* – the only call option present – drops from 35 to only 28.4. In this case, the value of *E* is reduced because some of the other options could lower the size of its underlying asset. This brief analysis clearly illustrates why it is important to consider the non-addivity of options value, especially since most real options are put options.

Let us now take a closer look at the net value contribution of each option separately. Based on Table 7A, option *E* stands out the most. Its value is 35 and it adds at least 28.4 to every combination of options. Of all five options, only *E* is a call option that permits enhancing good investment outcomes. Since *E* costs only 20 to create (Figure 7, assumption 1b), it has a positive net value that makes it worthy of conversion into a real option. Of the remaining options, *D* also adds considerable value to combinations involving *E*. It is worth 41 alone (Table 7A), and it adds at least 16 to those combinations (Table 7B). Even if this suggests that option *D* has a substitute relation with other options, it is not a very strong one. As to the cost side, the configuration assumptions (Figure 7) indicate that creating option *D* carries no cost (i.e., during deferral, no cash flows are foregone and no market share is lost to the competition). This suggests that option *D* should be created as well. The remaining options present a more interesting case (Table 7C). Options *A*, *C* and *S* combined increase NPV^{A} from 69.4 (combination *DE*) to 86.6 (combination *DACES*). Starting with option *A*, it adds no value to combinations *AES*, *DAES*, *ACES*, and *DACES*. Ignoring the fact that this result is intended by design, to show that some options can add no value, should we still create option *A*? We need to look at its cost. The moment we decide to stage the development effort, the option to abandon development in midstream is obtained at no cost.[6] Additionally, it seems like options *A* and *S* have an especially strong substitute relation, where *A* costs nothing and *S* adds a bit more value to all combinations involving options *E* and *D*. Under the configuration assumptions (Figure 7), using Java gives the flexibility to expand and to switch-use with salvage value. Since use of Java adds 20 to the configuration cost (Figure 7, assumption 1b), option *S* is created by default when option *E* is created. Hence, it is still worth creating option *S* even though it adds only 2.60 to combination *DACES*. Finally, based on combination *DACES*, option *C* adds at least 0.90 to the NPV^{A}. Unless the cost of creating *C* exceeds 0.90, option *C* should also be created.

In summary, applying the same evaluation procedure to other investment configurations is useful in two ways. First, it determines which options in each configuration ought to be created (i.e., actually embedded in the investment). Second, it identifies which investment configuration has the highest NPV^{A}.

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browser as a totally new product, Netscape's potential range of outcomes could have been estimated by examining the volatility of a stock index of new publicly traded firms in the technology (or Internet) sector [2].

[6] If a staged development is more costly than a non-staged development, some of the cost differential could be seen as the cost of creating option *A*. Nonetheless, since every investment configuration can be evaluated as an independent investment (involving its own assumptions about payoffs, costs, and embedded options), it is valid to consider the cost of option *A* as being zero relative (only) to the configuration in question.

5. Discussion and Future Research

The approach we presented offers two benefits that enable management to optimally configure an IT investment. It facilitates a systematic identification of investment configurations by framing operating flexibility in terms of risks that real options can control. In turn, it supports a solid quantitative configuration valuation for the purpose of identifying the most valuable configuration. This does not mean that the approach is perfect. Of course, real-world use and empirical assessment is needed to determine the true benefits and drawbacks of the approach presented as well as the proposed procedure for estimating the variability of investment payoffs and costs (Equation 6). Nevertheless, a quick look at issues concerning the practicality and usability of the approach immediately reveals two areas where the approach could improve. One pertains to the valuation of investment configurations, the other to the treatment of strategic growth options.

5.1. Valuation of Investment Configurations

The value of the two above benefits can be seen another way. Failing to recognize some of the operating options that could be embedded in an IT investment can seriously understate the investment value, and simply summing up the value of these options can overstate the investment value. Ignoring some embedded options can understate the value of those options that we do consider. The presence of later options increases the effective underlying asset for prior options, and exercise of a prior option may alter the underlying asset and the value of later options on it. At the same time, considering more and more options increases the valuation complexity without necessarily adding much value. As our ISC example shows, the more options are considered, the harder it is to isolate the value contribution of each option, especially when the options bear strong substitute relations. Because the marginal contribution of each additional (substitute) option usually gets smaller and smaller, ignoring some options makes the error negligible, especially if the options we do consider are selected to minimize substitute relations.

This interpretation suggests two ways to improve the valuation aspect of our approach. One way is to devise a scheme for isolating the value contribution of each option in a series of cascading options. The scheme that the ROA literature [32] uses is: compute the value contribution of all option combinations and then compare the values of “adjacent” combinations to find the marginal contribution of each option. This ad-hoc scheme makes the valuation of multiple investment configurations more demanding. A more serious problem can be illustrated using the expand option and the switch-use option in the ISC example (Figure 7). Our analysis suggests creating the switch-use option because its creation cost is already accounted for by the expand option (i.e., using Java creates the option to expand, and implies that the switch-use option can be created for free). Is it more correct to attribute some of this cost to the creation of the switch-use option? If so, how much? Inability to answer such questions necessitates the development of a better way to isolate the value contribution of each option.

The other way to improve the approach involves the use of more versatile models for valuating series of cascading options. We investigated the log-transformed binomial model and found it intuitive and relatively easy to use for investments whose cost side is certain. In the same spirit, it is necessary to investigate new option valuation models (e.g., the extended log-transformed binomial model [16]) for more complex investments involving both stochastic payoffs and stochastic costs.

Overall, extending the approach along these directions would permit building a powerful decision support system that is capable of automatically screening out inferior investment configurations, identifying tradeoffs based on traits of the options involved, etc. Such a decision support system could significantly simplify the application of the approach even to the most complex IT investments.

5.2. Considering (Strategic) Growth Options

While we have thus far overlooked growth options, their importance cannot be underestimated. Growth options could be embedded in almost every IT investment, and especially in IT investments that aim at creating capabilities which confer preferential access to future investment opportunities that are open to competitors as well. For example, in the mid 1980’s, the First Boston Co. built a suite of computer-aided software engineering tools whose initial aim was not to generate revenues, but rather to form a novel infrastructure that offers the quick application development capabilities needed to cope with the rapidly changing pace of financial services [9]. In this sense, the capabilities of a firm can be seen as a bundle of shadow growth options for future strategic choice [6]. These shadow options arise from the interplay of the firm's existing investments, its knowledge and capacities, and environmental opportunities. They are exercised in response to market signals – the arrival of an opportunity or the imminent closure of the opportunity (e.g., due to the threat of, or actual, competitive preemption). When a growth option is exercised, the resulting configuration of organizational capabilities, in turn, expands and yields new options for future exercise.

In this light, considering growth options requires going beyond the intra-investment view of risk we adopted for operating options. It requires viewing risk from an *inter-investment*, or even a *cross-organizational*, perspective. Such a view rests on the premise that maximizing value to the firm requires looking at the firm's portfolio of IT investments. The portfolio must create a set of valuable investment opportunities, or growth options, which allow limiting risk, acting on opportunities, and exploiting inter-investment and cross-organizational synergies.

Like with operating options, the recognition of growth options can be driven by the notion of risk, however, from a broader perspective. Risk generally can be defined as failure to respond to threats or act on opportunities. These threats and opportunities can be identified by an economic assessment of the firm's internal environment (strategic goals, capabilities, constraints) and external environment (business markets, competitors, technology markets). Although this view of risk is broader than the one we used for operating options, it can be easily incorporate into our approach.

The valuation of growth options, however, is more problematic. Under the inter-investment perspective, valuing a single IT investment embedding growth options requires measuring its *strategic NPV*, denoted NPV^S:

$$NPV^S = NPV^A + \text{value of growth options associated with inter-investment opportunities.}$$

Growth options have two unique traits that make their precise valuation difficult. First, it is difficult to identify up-front all the investment opportunities that a growth option spawns. Even if all these opportunities could be identified, it is hard to estimate their payoffs or even determine whether they are likely to materialize, depending on internal and external conditions. Second, a growth option is like an operating option to *expand*, except that its underlying asset – the payoffs expected from future investment opportunities – is not the asset that creates it in the first place. When an option involves multiple underlying assets, standard option valuation models cannot directly measure the value of synergetic effects among interdependent investments. Relative to these two traits, the case that Taudes et al. [31] describe (in relation to the role of growth options in the decision to upgrade from SAP/R2 to SAP/R3) is different. This case is simpler: not only does it assume that all spawned investment opportunities and their respective valuation parameters can be identified upfront, it also assumes that these opportunities are independent of each other (i.e., no cross-investment synergies exist). These assumptions facilitate reliance on standard option valuation models.

In light of the above discussion, expanding our approach to IT investments embedding growth options remains a challenge. It requires looking at the management of risk (threats and opportunities) at the level of a portfolio of IT investments. Any research that is successful at operationalizing this view might open the door to answering several fundamental questions; for example: (1) how to allocate resources over time across infrastructure investments and "tactical" investments so as to maximize the value of a portfolio of IT investment? and (2) how to divide investments in IT infrastructure across business units in a way that meets the IT needs of these business units as well as maximizes firm-wide synergies? The answers to such questions are key to the ability of a firm to maximize return on its IT investments while ensuring that these investments are aligned with the firm's short- and long-term business goals.

6. Conclusion

This paper expands IS research on the use of ROA in the context of IT investment decision-making. Previous IS work in this area has focused mainly on using ROA to evaluate options already known to be embedded in an IT investments. The present paper focuses on issues pertaining to how to apply ROA from a risk management perspective. In particular, this paper presents an approach that exploits real option concepts in order to optimally configure an IT investment in light of its risks. The paper also presents a relevant illustration of the approach in action. Finally, a critical examination of the approach and the accompanying example helps to identify several issues along which the approach can be expanded. Future research aimed at addressing these issues could expand our work in two ways. It could broaden the scope of our approach to handle IT investments involving growth options and, in turn, portfolios of IT investments. Additionally, it could permit developing decision support tools that would facilitate applying the approach with greater ease, even to the most complex IT investments.

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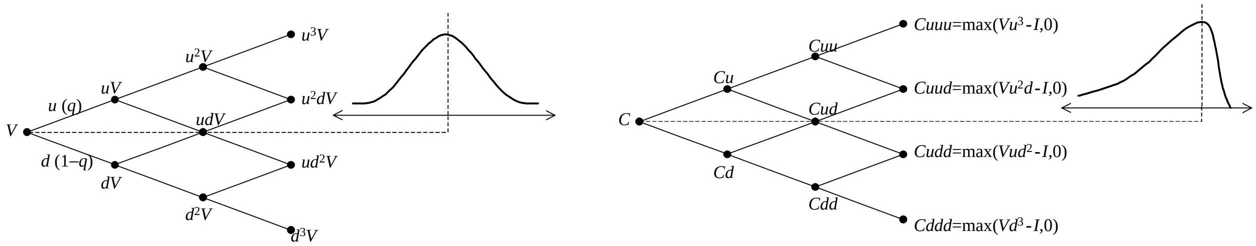
Appendix A: Fundamentals of Options and Option Valuation

A financial option on some underlying asset, V, is a side-bet on V's future value, between the option seller and the option buyer. The basic financial options are *calls* and *puts*. A *European call* (*put*) gives its holder the right to buy (sell) V for an agreed upon exercise price, I, at a fixed expiration date, T. Hence, the payoff functions modeling the terminal value of a call and a put are $C_T=\max(0,V_T-I)$ and $P_T=\max(0, I-V_T)$, respectively. Unlike a European option, an *American option* can be exercised any time before it expires. As is well known [18], the current value of a call, C, feeds mainly on the volatility (variability) of the underlying asset's value, s, and its time to maturity, T. The higher is s, or the longer is T, the higher is C.

The analogy between financial options and real options is straightforward, although it depends on the type of real option in question. For example, take an investment embedding a deferral option. Holding the option is akin to holding an investment opportunity, and exercising the option is akin to converting the opportunity into an operational investment. The option parameters are: V – present value of expected payoffs; I – present value of expected costs; T – maximum investment deferral time; and, s – standard deviation of expected payoffs. Like with a financial option, the value of a deferral option is contingent on how V is expected to change during deferral.

Two fundamental models have been developed for valuing financial options – the binomial model and the Black-Scholes model – and they are readily adapted to real IT options. Benaroch and Kauffman [3] offer a comparative analysis of these models, showing that they make the same key assumptions. To understand the intuition underlying these models, suffice to look at how the binomial model works in the context of European call options.

The *binomial model* [18] assumes that V, the value of the option's underlying risky asset (or present value of expected investment payoffs), is governed by a binomially distributed multiplicative diffusion process. Starting at time zero, in one time period Dt, V may rise to uV with probability q or fall to dV with probability $1–q$, where $d<1$, $u>1$ and $d<r<u$, with r being $1+r_f$ and r_f is the risk-free interest rate. For the multi-period case, V can be modeled in this fashion using a binomial tree (see Figure A1a).



(a) binomial tree modeling the symmetric probability distribution of V, the option's underlying asset

(b) modeling the value of a call option on V reflects an asymmetric probability distribution of the option value

Figure A1: value of an underlying asset and of a respective call option

Where I is the option's exercise price, the terminal value of a call on V that matures in Dt is $C_u=\max[0,uV–I]$ or $C_d=\max[0,dV–I]$ with probabilities q and $1–q$, respectively (see Figure A1b). By setting $p\equiv(r–d)/(u–d)$, where p is the risk-neutral equivalent of probability q, the value of the call option, C, can be written as:

$$C = \frac{pC_u + (1-p)C_d}{r} = \frac{p\max[0,uV-I] + (1-p)\max[0,dV-I]}{r}. \qquad \textbf{(A1)}$$

Equation A1 can be applied to determine the two possible values of the call option at time 1, C_u and C_d, for which the option's underlying asset is uV or dV, respectively. When equation A1 is applied for the case of a call maturing in n time periods, where $Dt=T/n$ and T is the option's time to maturity, it yields the expression:

$$C = V\,\mathrm{B}(a;n,p') - Ir^{-n}\,\mathrm{B}(a;n,p) \qquad \textbf{(A2)}$$

where **B(·)** is the complementary binomial distribution, or the probability that V would make a or more up moves out of n moves, with p and p' being the probabilities for an up and down move, respectively. When $n\to\infty$, $Dt\to 0$ and equation A2 converges into:

$$C = V\,\mathrm{N}(d_1) - e^{-r_f T}\,I\,\mathrm{N}(d_2), \qquad d_1 = \frac{\ln(V/I)\,r_f\,T}{s\sqrt{T}} + \frac{1}{2}s\sqrt{T}, \qquad d_2 = d_1 - s\sqrt{T}, \qquad \textbf{(A3)}$$

where **N(·)** is the cumulative normal distribution and s is the volatility (or variability) of the expected rate of return on V. Equation A3 is also known as the *Black-Scholes model* [18].

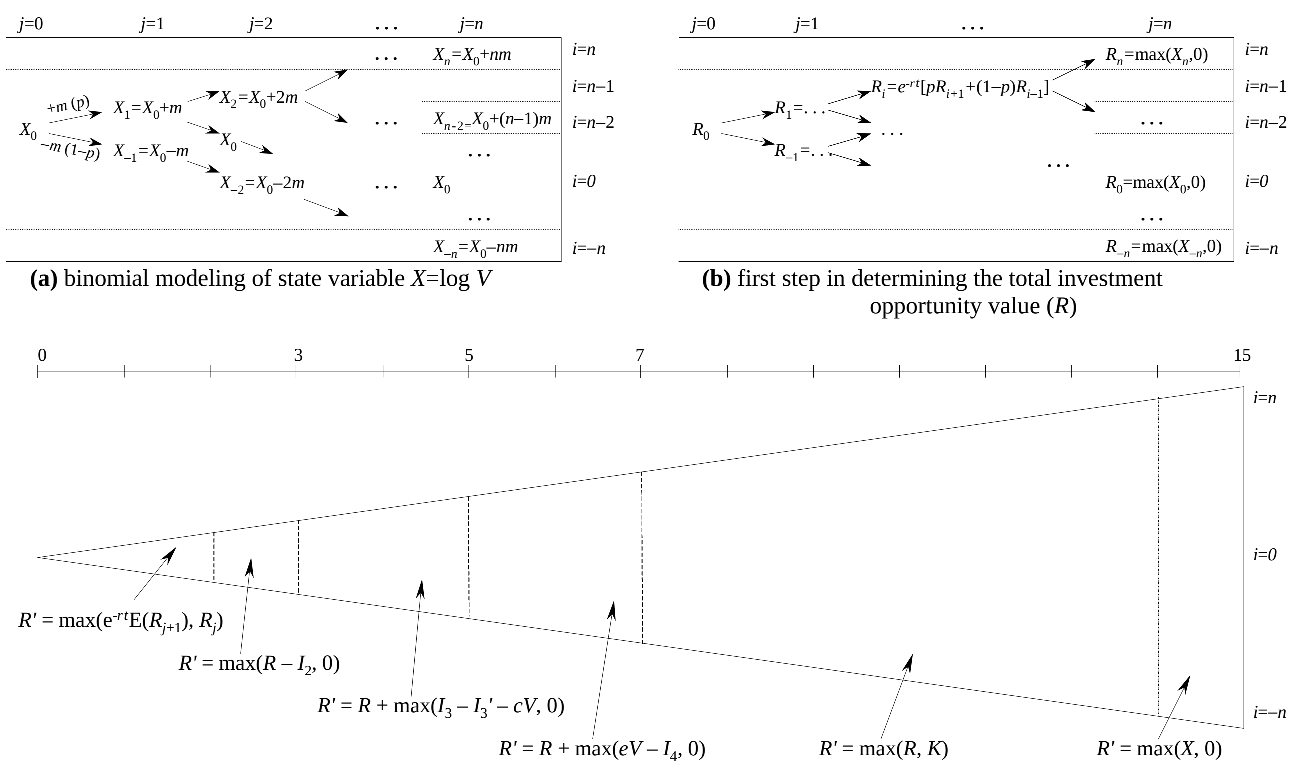
Appendix B: Log-Transformed Binomial Model

The log-transformed binomial model was developed to address mainly one problem with the standard binomial model: when the volatility of the expected rate of return on V (s) or the number of time steps are small, parameter p in Equations A1 and A2 can become negative or exceed one, and therefore lose its probabilistic meaning [32,3]. Additionally, as we show shortly, it is relatively easy to implement the log-transformed model using spreadsheets. This feature is especially useful in the evaluation of investments embedding multiple compound options.

Whereas the binomial model views the behavior of V (the underlying asset or investment value) as being governed by a multiplicative diffusion process, the log-transformed binomial model transforms this process into an additive one [32]. Suppose that the behavior of V is modeled using a standard binomial tree (see Figure A1) with n time steps, each of length $k = s^2 T/n$ (also denoted $t = T/n = k/s^2$). Instead of looking directly at V, the log-transformed binomial model looks at state variable $X = \log V$. X can make up and down moves of magnitude $m = \sqrt{k + (mk)^2}$, where $m = r/s^2 - 1/2$, with the probabilities $p = 1/2\,(1 + mk/m)$ and 1–p, respectively. Let i, $-n \le i \le n$, be the index of state variable X corresponding to the net number of up less down moves, so $X_i = X_0 + im$. Thus, whereas V's behavior is governed by the multiplicative diffusion process seen in Figure A1a, the behavior of $X = \log V$ is governed by the additive diffusion process shown in Figure B1a.

Now, let R_i denote the total investment value, including embedded options (i.e., NPV^A), at state i. Where index j denotes the number of time steps, each of length k, we can determine R_i as follows (see Figure B1b). For each state i, set the terminal boundary value of the investment at j=n to be $R_i = \max(V_i, 0) = \max(e^{X_i}, 0) = \max(e^{X_0 + im}, 0)$. Then, for $j<n$, determine R_i by working work backwards. For a time step where no embedded option can be exercised, let $R_i = e^{-r_f t}[pR_{i+1} + (1-p)R_{i-1}]$, with $e^{-r_f t}$ being the continuous-time discounting operator. And, for a time step where an embedded option can be exercised, determine R_i based on option-specific adjustment rules. For the options embedded in the ISC example seen in Figure 8, the adjustment rules are as follows (see Figure B1c): [7]

1. Defer: $R' = \max(e^{-rt}E(R_{j+1}), R_j)$, where E() is the expectation operator;
2. Stage (and abandon): $R' = \max(R - I_2, 0)$, where I_2 is the cost outlay being defaulted;
3. Contract: $R' = R + \max(I_3 - I_3' - cV, 0)$, where $I_3 - I_3$' is the cost reduction if we contract by c%;
4. Expand: $R' = R + \max(eV - I_4, 0)$, where I_4 is the cost outlay needed to expand by e%;
5. Switch-Use: $R' = \max(R, K)$, where K is the salvage (or alternate use) value.



(a) binomial modeling of state variable X=log V

(b) first step in determining the total investment opportunity value (R)

(c) second step in determining R – adjusting for embedded options (for the ISC example in Figure 8)

Figure B1: evaluating an investment embedding multiple real options using the log-transformed binomial technique

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[7] These adjustment rules resemble the rules used to evaluate decision nodes in the decision tree seen in Figure 8. Only rule 3 differs from the corresponding one in Figure 8, because the log-transform model includes I_3 in I (i.e., $I = I_1 + I_2 + I_3$).

Combin-ation	Value	Contribution of Option				
		D	***A***	***C***	***E***	***S***
D	41.00	41.00				
A	36.80		36.80			
C	6.90			6.90		
E	35.00				35.00	
S	39.30					39.30
DA	51.10	14.30	10.10			
DC	42.20	35.30		1.20		
DE	69.40	34.40			**28.40**	
DS	52.90	13.60				11.90
AC	37.30		30.40	0.50		
AE	65.30				28.50	30.30
AS	39.30		0.00			2.50
CE	41.80			6.80	34.90	
CS	40.20			.90		33.30
ES	69.40				30.10	34.40
DAC	51.50	14.20	9.30	0.40		
DAE	82.90	17.60	13.50		31.80	
DAS	52.90	13.60	0.00			1.80
DCE	71.80	30.00		2.40	29.60	
DCS	53.40	13.20		0.50		11.20
DES	85.70	16.30			32.80	16.30
ACE	66.60		24.80	1.30	29.30	
ACS	40.20		0.00	0.90		2.90
AES	69.40		0.00		30.10	4.10
CES	70.60			1.20	30.40	28.80
DACE	84.00	17.40	12.20	1.10	32.50	
DACS	53.40	13.20	0.00	0.50		1.90
DAES	85.70	16.30	0.00		32.80	2.80
DCES	86.60	16.00		0.90	33.20	14.80
ACES	70.60		0.00	1.20	30.40	4.00
DACES	86.60	16.00	0.00	0.90	33.20	2.60
	Min	13.20	0.00	0.40	**28.40**	1.90

(A) All option combinations

Combin-ation	Value	Contribution of Option			
		D	***A***	***C***	***S***
DE	69.40	34.40			
AE	65.30				30.30
CE	41.80			6.80	
ES	69.40				34.40
DAE	82.90	17.60	13.50		
DCE	71.80	30.00		2.40	
DES	85.70	16.30			16.30
ACE	66.60		24.80	1.30	
AES	69.40		0.00		4.10
CES	70.60			1.20	28.80
DACE	84.00	17.40	12.20	1.10	
DAES	85.70	16.30	0.00		2.80
DCES	86.60	**16.00**		0.90	14.80
ACES	70.60		0.00	1.20	4.00
DACES	86.60	**16.00**	0.00	0.90	2.60
	min	**16.00**	0.00	0.90	2.60

(B) combinations including option *E*

Combin-ation	Value	Contribution of Option		
		A	***C***	***S***
DE	69.40			
DAE	82.90	13.50		
DCE	71.80		2.40	
DES	85.70			16.30
DACE	84.00	12.20	1.10	
DAES	85.70	0.00		2.80
DCES	86.60		0.90	14.80
DACES	86.60	0.00	0.90	2.60
	min	**0.00**	**0.90**	**2.60**

(C) combinations including *D* and *E*

Table 7: comparative value contribution of options in the second structuring alternative (Figure 8)