Real Options in IT Risk Management:

An Empirical Validation of Risk-Option Relationships

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Abstract

Recently, an option-based risk management (OBRiM) framework has been proposed to control risk and maximize value in IT-investment decisions. While the framework is prescriptive in nature, its core logic rests on a set of normative risk-option mappings for choosing which particular real options to embed in an investment in order to control specific risks. This study tests empirically whether these mappings are observed in practice. The research site is a large Irish financial services organization with well established IT risk management practices not tied to any real options framework. Our analysis of the risk management plans developed for a broad portfolio of 50 IT investments finds ample empirical support for OBRiM's risk-option mappings. This shows that IT managers follow the logic of option-based risk management, though purely based on intuition. Unfortunately, reliance on this logic based on intuition alone could lead to suboptimal or counterproductive risk management practices. We therefore argue that managerial intuition ought to be supplemented with the use of formal real option models, which allow for better quantitative insights into which risk mitigations to pursue and combine in order to effectively address the risks most worth controlling.

Keywords: IT investment, risk, real options, risk management.

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INTRODUCTION

There is a large body of research on information systems (IS) risk management; however, it falls short of demonstrating that it meets practical needs. An extensive analysis of the IS risk management literature reveals an area rich in terms of approaches (e.g., case studies, surveys) and theoretical foundations (e.g., structural contingency theory, prospect theory) (Ropponen 1999). Yet, this research has two gaps that are of concern to this study. *First*, it focuses mainly on the discovery of risk factors affecting information technology (IT) projects and of risk countermeasures for controlling risks but without empirically studying the connections between the two (Ropponen 1999). *Second*, it does not offer adequate ways to quantify risk and risk countermeasure as well as their consequence on the cost and value of an IT investment. Because of these gaps, it is impossible to know whether any specific combination of risk countermeasures used for a target IT investment is optimal or even adds value from an economic perspective.

Real Options Theory and IT Risk Management

Some IT research suggests using real options theory (ROT) to address these gaps. Initial work sought to establish the importance of flexibility in risky IT investments. When deciding, for example, on whether to accept an IT investment (Taudes et al. 2000) or on the timing of an investment (Benaroch and Kauffman 2000), it is suggested to conceptualize and value different forms of flexibility as real options (defer, pilot, stage, and so on). Although this early work has no direct link with IT risk management, it explicitly recognizes that the value of flexibility afforded by options is driven by the presence of risk.

Later work has looked at the link between flexibility, real options, and IT risk management. Flexibility is a crucial success factor in IS development (Evans 1991), as it enables deployment of risk countermeasures contingent on the materialization of risk (Avison et al. 1995). On this ground, ROT was used to justify certain IT project management practices relating to risk (Kumar 2002, Kim and Saunders 2002). Further, it was argued that, since flexibility is not inherent in any investment, proactively embedding options (flexibility) in risky IT investments can add value (Benaroch 2002). In the same vein, ROT has been proposed as a sound theoretical basis for managing software development risk from an economic perspective (e.g., Boehm and Sullivan 2000, Gaynor and Bradner 2001, Erdogmus and Favaro 2002). This proposal coincides with the fact that certain risk mitigation strategies identified by IT and software engineering research map directly to real options; for example, prototyping and abandonment (Boehm 1989).

Building on these ideas, the recently proposed option-based risk management (OBRiM) framework more explicitly expands the scope of ROT to IT risk management (Benaroch 2002). OBRiM finds the most cost-effective combination of real options (or forms of flexibility) to embed in an IT investment in order to optimally control risk and maximize investment value. A principle tenet of the framework is that the specific risks one seeks to control should dictate the choice of which specific options to use. OBRiM respectively proposes a set of prescriptive risk-option mappings for making this choice. For example, to control risk due to the size and complexity of an investment, some mappings prescribe using the 'stage', 'prototype', 'lease' and 'outsource' options, but not the 'defer' and 'abandon' options. However, OBRiM posits these mappings based on purely theoretical rationales. These mappings remain to be tested empirically, as there are only case studies offering anecdotal support for their validity (Brautigam et al. 2003, Benaroch et al. 2005). Another important tenet of OBRiM is that, when multiple combinations of options are suitable for controlling the same risks, real option models are needed to identify which combination is economically superior. Based on these two tenets, OBRiM enables determining what forms of, and how much, flexibility to build into an investment in order to manage risk effectively.

Research Objective and Approach

This research tests empirically the risk-option mappings posited by the OBRiM framework and, more generally, the theorized link between real options and IT risk management. The goal is to verify whether these mappings correspond well with the intuitions and practices that experienced IT managers use in risk management.

To this end, we analyze the risk management plans developed for 50 real IT investments by experienced managers who did not rely on any real options framework. Based on the mitigations used to address specific IT risks, we examine whether the managers systematically relied on the presence of, or made decisions which create, options that make those mitigations feasible. Establishing this link between risks, respective mitigations, and their enabling options should tell us whether OBRiM's risk-option mappings are observed in practice.

The research site is a large Irish Financial Services Organization (IFSO) with 2,500 employees and revenues of 3 Billion Euros in 2003. IFSO was deemed highly suitable for this study because of its sophisticated IT risk management practices. IFSO operates a dedicated Project Investment Department (PID) responsible for evaluating IT investments and ensuring that their business cases include an adequate risk management plan. Importantly, IFSO's IT managers were not relying on any real options model or framework at the time of this study.

Contribution and Significance

This study makes a contribution to the IT literatures on real options and on risk management. Relative to the former, our study offers empirical support for the risk-option mappings OBRiM posits, thus lending weight to the validity of their underlying ROT rationales. Since OBRiM is prescriptive in nature, validating this aspect of the framework is an essential condition for its prescriptions to be valid. As to the IT risk management literature, our study empirically supports the theorized link between the way IT risk is managed and the presence of real options. Our findings indicate that, in the focal research site, IT managers' thinking and intuitions correspond well with the logic of option-based risk management. Taken together, our findings suggest that expanding the scope of ROT to IT risk management could open another useful venue for investigating a host of behavioral and economic issues.

The significance of our contribution follows from the way the OBRiM framework could benefit IT risk management practices. IT project managers have been observed to improperly evaluate risks before prioritizing them for management attention and thereby to pay greater attention to some risks at the expense of others (Schmit et al. 2000). Additionally, research offers IT managers no adequate way to quantify the economic value of mitigations relative to risk. The OBRiM framework can help in both respects. It adds to current IT risk management practices a conceptual overlay which uses ROT to yield better economic insights into which mitigations should be pursued in order to effectively address the risks most worth controlling. Interestingly, formal adoption of a real options perspective on R&D projects by firms was shown to benefit the success rate of such projects (Kumaraswamy 1998). We believe that the same should apply to IT projects as well; however, testing this belief is a subject for a separate study.

The rest of the paper proceeds as follows. We review existing research on IT risk management to identify some of its weaknesses and how they can be resolved by IT research on ROT. We then present the research model and the data used to test it. Afterward, we analyze the data using factor analysis and logistic regression. Finally, we summarize the findings and their limitations, discuss implications for research and practice, and identify directions for future research.

THEORETICAL BACKGROUND

This section first offers a critical review of extant research on IT risk management. It identifies two weaknesses that IT work on real options could resolve. It then explains how the OBRiM framework offers an integrated solution to both weaknesses, while elaborating on the part of OBRiM we test empirically.

IS Risk Management Research

Work on IT risk management has been fueled by the discovery of a negative relationship between IT risk and IT project success (Barki et al. 1993, Jiang et al. 2002). This work spans various aspects, including: the concept of risk and its antecedents, risk factors, risk analysis techniques, and risk resolution strategies

(Ropponen 1999).

Since risk and risk management are concepts central to this study, it is useful to start with their definition. Classical *decision theory* conceptualizes the risk of a decision alternative in terms of variation in possible outcomes, in their likelihoods, and in their subjective values (Arrow 1965). This view implicitly considers a decision-maker to be passive in managing risk, as it assumes that all alternatives are given and their features cannot be changed to affect risk. By contrast, according to the *behavioral view* of risk, decision-makers associate risk with a probability concept and with the magnitude of a bad outcome (March and Shapira 1987), but they do not treat uncertainty over positive (good) outcomes as an important aspect of risk (Shapira 1986). Moreover, bringing risk under control is seen as entailing the active mastering of the environment, for example, by negotiating uncertainty-absorbing contracts or by delaying decisions (MacCrimmon and Wehrung 1986). The *real options view* represents a middle ground. It defines risk as the downward or upward variation in expected outcomes. It also considers risk management to be a proactive process aimed at favorably skewing the variation in expected outcomes, by means of building the flexibility needed to respond to the occurrence of risk with corrective actions (Amran and Kulatilaka 1999, Benaroch 2002).

In this paper, we adopt the real options view of risk. IT research traditionally defines risk in terms of negative outcomes, e.g., unskilled analyst could lead to poor system design (Boehm 1989, Barki et al. 1993). However, it now recognizes that risk can also have positive consequences, e.g., customer acceptance rate exceeding expectations can present follow-up investment opportunities (Vitale 1986, Alter and Sherer 2004).

Much work has focused on discovering the sources of IT risk, also known as risk factors (Alter and Sherer 2004). A risk factor is a trait of an IT investment or its contextual environment that affects the degree of variation in expected outcomes. Software engineering (SE) work initially identified technical execution risk factors such as: IT personnel skills, project size, technical complexity, cohesion of project team, and a continuous stream of requirement changes (Boehm 1989). Work on IS implementation additionally identified such risk factors as: technology maturity, user involvement, top management commitment, and conflicts between user departments (Barki et al. 1993, Keil et al. 1998, Ropponen and Lyytinen 2000, Schmidt et al. 2001). Other work on IT investment financial success further identified such risk factors as: project funding uncertainties, dependence on a market (customer usage, supplier adoption), and lack of barriers to competitive duplication (Clemons 1991, Kemerer and Sosa 1991).

Some of the same work has also identified risk countermeasures. The SE literature focused on countermeasures directed at technical execution risks, including: incremental development, prototyping, requirements scrubbing, design-to-cost, design for software reuse, team building programs, and fee-based contracts (Boehm 1989). IS implementation research added such countermeasures as: dividing a project into manageable chunks, piloting, managing end-user expectations, seeking a champion, drawing a line between desirable and necessary functionality, and educating users on the impact of scope changes (Keil et al. 1998, Lyytinen et al. 1998). Interestingly, many of these risk countermeasures coincide with real options. Some are in themselves options; e.g., prototyping, piloting, staging, and abandonment (Boehm 1989, Fairly 1994). Others are granular countermeasures whose deployment is enabled by the flexibility afforded by real options; e.g., deferral permits developing better payoff estimates or learning about the adequacy of an emerging technology.

It is important that the risk mitigation strategies pursued and how they are combined fit the risks affecting an IT investment. This point was shown empirically in (Barki et al. 2001). Yet, recent research identified the following as important open questions (Schmidt et al. 2000, p. 29):

> What are the countermeasures that project managers can employ against each highly ranked risk factor? Which of these are deemed most effective, and why? What interactions among risk factors and countermeasures can improve or hinder risk management efforts?

These questions imply two broad unresolved research challenges:

(1) How to approach IT risk management from an economic perspective?
(2) How to choose adequate mitigations and combine them to effectively address specific risks?

Relative to the first challenge, two widely known attempts to quantify the notions of risk and risk countermeasures are offered in (Boehm 1989) and (Barki et al. 1993). However, both attempts suffer shortcomings: they consider only downside risk, and they do not link the monetary consequences of risk and countermeasures to the payoff side of an investment. IT research on real options offers an alternative way to address this challenge. This work originally investigated the importance of managerial flexibility afforded by options in risky IT investments. Table 1 lists studies that examine the economic impact of various types of options in connection with different risks. In parallel, SE economists have proposed using ROT as an economic basis for improving software development risk management (Erdogmus 1999, Favaro and Favaro 1999, Chatterjee and Ramesh 1999, Boehm and Sullivan 2000, Erdogmus and Favaro 2002) and, more generally, for approaching software development from an economic optimization perspective (Sullivan et al. 1999). The OBRiM framework essentially formalizes this line of thinking, as explained shortly.

Sample IS studies	Option	Main Risks Present	Explanation
Benaroch & Kauffman (2000)	*Deferral*	Customer usage/acceptance Vendor adoption Restrictive legislation	The flexibility to defer investment commitment is attractive when it enables learning about the nature of uncertain payoffs (and immediate forgone cash flows are small).
Kulatilaka et al. (1999) Kambil et al. (1993)	*Explore –* *Pilot* or *Prototype*	IS skills and experience Technology maturity IT infrastructure adequacy Organizational adoption	The flexibility to partially invest in a pilot or prototype effort enables learning about the extent to which technical and organizational risks affect the ability to complete (and realize the expected benefits) of a full-scale investment.
Benaroch et al. (2005)	*Stage*	Infrastructural fit Management support Organizational adoption User involvement/support	The flexibility to stage an investment and kill it in midstream (after gateway reviews) is valuable when there are risks due to technical complexity risks, user involvement, architectural compliance, etc.
Kulatilaka et al. (1999) Gaynor & Bradner (2001)	*Change-Scale*	Project size and complexity Technology maturity (emerging standards)	The flexibility to alter – expand or contract – the scope of an investment adds value when it allows reacting to observed conditions concerning technical risk, user involvement risk, etc.
Brautigam et al. (2003) Benaroch et al. (2005)	*Abandon*	Customer usage/adoption IT infrastructure adequacy (quality of data platform)	The flexibility to abandon an investment and put its resources to alternate uses provides partial insurance against failure due to client acceptance risk, organizational adoption risk, etc.
Whang (1992) Lammers & Lucke (2004)	*Outsource* *Development* *Operations*	IS skills and experience Cost escalation Customer demand/usage Uncertain investment benefits	The flexibility to outsource development is valuable when the risk of development failure can be transferred to a third party with the requisite capabilities and experience. The ability to outsource a business process (and re-insource it), contingent on when business conditions (process transactions load) are sufficiently unfavourable (favourable), transfers benefits risk to a third party offering the same process services to other client firms.
Clemons and Weber (1991)	*Lease*	Customer adoption Organizational adoption Development failure	The flexibility to lease investment resources is valuable when the investment can be abandoned in order to save the residual cost of resources, when abandonment could occur during development or after the investment become operational.
Benaroch & Kauffman (2000), Zhu (1999), Taudes et al. (2000)	*Strategic Growth (Expansion)*	Above expected customer adoption/usage rate	The flexibility to take advantage of favorable investment outcomes (due to positive risk) is valuable when the investment creates capabilities and opportunities for follow-up investments.

Table 1: types of real options studied in connection with specific IT investment risks

As to the second challenge, there are conceptual non-option-based proposals aimed at linking risk factors with adequate risk mitigations (e.g., Keil et al. 1998). However, these proposals are abstract for the most part. There is also empirical work identifying risk management practices and environmental contingencies for addressing risks, but even this work sought only to generate (not test) hypotheses (Ropponen and Lyytinen 2000). IT work on real options approaches this challenge from a different angle. It looks at the link between risk, flexibility, and real options. Some work explains how three types of options (defer, abandon, and change-scale) can help to justify certain project management decisions made in relation to certain IT risks (Kumar 2002, Kim and Saunders 2002). The OBRiM framework offers a more comprehensive and direct way to link the management of different risks with the forms of flexibility afforded by different options (Benaroch 2002). It does so, in part, using the normative risk-option mappings that this study tests empirically.

Option-Based IT Risk Management (OBRiM)

The OBRiM framework seeks to address in an integrated fashion both the above challenges. The idea guiding the framework is as follows. To track the goal of maximizing investment value, a good manager: (1) sizes up relevant risks, (2) builds flexibility into the investment to the extent that the flexibility is expected to add value, and (3) continually evaluates new information and takes corrective actions within the bounds of flexibility built into the investment. OBRiM formalizes this idea by viewing real options as high-level risk mitigation strategies for building different forms of flexibility necessary to deploy corrective actions when risk occurs. It helps to find a combination of options that adds the most value relative to the risks specific to an investment. The option types OBRiM considers are: defer, pilot, prototype, stage, alter-scale, abandon, outsource, lease, and strategic growth (see Table 1).[1]

Since this paper's primary interest is in validating a theory-based aspect of OBRiM, we focus here on two relevant tenets of the framework and refer the reader to (Benaroch 2002) for details.

(1) Real options must be proactively embedded in an IT investment based on the specific risks one seeks to control. (Thus, the presence of risk precedes any decision to embed options.) On this premise, OBRiM proposes a set of risk-option mappings that prescribe which options to embed for which specific risks. In Table 2, cells marked with a "+" posit that a certain option is suitable for controlling a specific risk. These mappings expand slightly on those originally proposed in (Benaroch 2002). Our survey of the latest IT literature on real options yielded studies offering an explicit rationale or economic model to support most of these mappings of options to risk. Because (Benaroch 2002) does not include a complete discussion of the rationales for these mappings, we provide a synthesis of these rationales in Appendix A.[2]

(2) Different combinations (subsets) of the options mapped to the risks affecting an investment yield competing investment configurations. Each combination may allow controlling the same risks to varying degrees, and may also have a different associated cost. In other words, different combinations of options may impact the investment value differently. Using option pricing models to quantitatively evaluate the possible investment configurations can reveal an economically superior one.

These tenets suggest two ways in which OBRiM could benefit current IT risk management practices. One is the ability to map given risks to the forms of flexibility (options) needed to deploy an affective combination of mitigations. Another is the ability to economically evaluate risk and flexibility and to optimally manage their balance. The latter is important considering empirical evidence about managers' limited ability to value the flexibility options afford. It was found that decision-makers' intuitions agree with the qualitative prescriptions of ROT, but their subjective option valuations differ from formal option valuations (Jägle and Howell 1996, Busby and Pitts 1997). This is so especially with regard to the affect of risk. Some studies found that subjective option valuations increased with risk in the case of deferral options (Bjornstad et al. 2001, Sirmans and Yavas 2001), while others did *not* find consistent option-value increase in response to increased risk in the case of growth options (Howell and Jägle 1997, 1998). Another study with experienced financial officers found that half the respondents agree that option values should increase as risk increases, while the other half disagreed or were neutral (Busby and Pitts 1997). These findings indicate that managers' intuition about the value of flexibility that options afford ought to be supplemented by the quantitative tools of ROT.

For these benefits of OBRiM to be viable, however, it is necessary to empirically validate the risk-option mappings OBRiM prescribes. We focus hereafter on this task.

RESEARCH MODEL AND DATA

Research Model

Because the research model is grounded in the perceived role of options in IT risk management, it is important to understand better the logic of real options. According to OBRiM, if an IT investment is subject to a particular risk, then a suitable option could provide the flexibility to favorably modify the investment trajectory in case the risk materializes. Adding to the *passive* (traditional) net present value (NPV) of an investment the value of flexibility the option affords yields the investment's *active* NPV:

$$\text{Active NPV} = \text{Passive NPV} + \text{value of managerial flexibility due to an embedded option} \quad \textbf{(1)}$$

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[1] The *switch input/output* option is not included in this list because it has rarely been discussed in connection with IT investments. This option is typically used in manufacturing and power generation investment projects. It allows changing the (physical) inputs going into a flexible production facility and/or the finished outputs produced without changing the production facility itself.

[2] Appendix A is available online at: http://whitman.syr.edu/facstaff/mbenaroc/PAPERS/risk-option/Appendix-A.pdf

Risk Area		Option / Risk Factor (Opportunity)	Defer	Explore		Stage / Incremental Development	Abandon (switch-use)	Contract	Outsource Development	Lease	Expand
				Pilot	Prototype						
Monetary Risks	Costs	Firm cannot afford the project (unacceptable financial exposure)		+ [8]							
		Development or operational costs may not remain in line with projected benefits	+ [1]		+ [8]	+ [4,14]	+ [18]	+ [1]	+ [7]	+	
	Benefits	Poor estimation, no process to harvest benefits, etc.	+ [3,25]	+ [8]						+	
Project Execution Risks	Project	Staff lacks needed skills and experience	+ [4,26]		+ [4,8,13,26]	+ [4,13,26]			+ [23,28]		
		Project is too large or too complex		+ [8,10,13, 17,20]	+ [8,10,13, 17,20]	+ [4,13,22]		+ [4,13,17, 19,26]	+ [28]	+ [27]	
		Lack of architectural stability or compliance, inadequate implementation infrastructure	+ [16]		+ [9,11,17, 20,26,29]	+ [12]		+ [6,17, 20,29]		+ [27]	
	Function	Inadequate design (e.g., system does not do what is expected of it, performance shortfalls)			+ [2,8,13]	+ [13]		+ [4,13]	+	+ [27]	
		Problematic requirements (stability, completeness, etc.)	+ [21]	+ [8]	+ [8,13]	+ [13]		+ [4,13]			
Organizational		Uncooperative internal parties	+	+ [2]		+ [2]	+ [2]			+ [27]	
		Parties slow to adopt the application		+ [17,24]		+ [1,17,20,21]	+ [2]	+		+ [27]	
Competition		Competition's response eliminates the firm's advantage	+ [8,19]	+ [8]			+ [19]	+ [19]		+	
		Competitive preemptive action	+ [19,26]	+							
Environmental		Low customer/supplier/partner demand/adoption/usage	+ [3,11, 15]	+ [10,20, 24]		+ [7,10,27]	+ [1,7,21]	+ [12,24]		+ [9,27]	
		Demand exceeds expectations (follow-up opportunities exist)	+ [3]	+							+ [7,10,19, 20,21,27]
		Demand/usage may overwhelm the application	+ [8]	+			+ [8]	+		+	+
		Unanticipated action of regulatory bodies	+ [3,21]				+ [7]			+	
Technological		Application may be infeasible with the technology considered, or the technology is immature	+ [1,15, 21,26]		+ [17]	+ [16]	+		+ [1]	+	
		The introduction of a new superior implementation technology may render the application obsolete	+ [15,21, 26]				+ [21,27]			+	

[1] = Amran and Kulatilaka (1999)
[2] = Benaroch et al. (2005)
[3] = Benaroch and Kauffman (2000)
[4] = Boehm (1988)
[5] = Boehm (1989)
[6] = Boehm and Sullivan (2000)
[7] = Brautigam et al. (2003)
[8] = Clemons (1991)
[9] = Clemons and Weber (1990)
[10] = Ekström and Björnsson (2003)
[11] = Erdogmus (2002)
[12] = Erdogmus (1999)
[13] = Erdogmus and Favaro (2002)
[14] = Fairly (1994)
[15] = Favaro and Favaro (1999)
[16] = Gaynor and Brander (2001)
[17] = Kambil et al. (1993)
[18] = Keil and Montealegre (2000)
[19] = Kim and Saunders (2002)
[20] = Kulatilaka et al. (1999)
[21] = Moran (2002)
[22] = Panayi and Trigeorgis (1998)
[23] = Richmond and Siedmann (1993)
[24] = Savavasson (2004)
[25] = Schwartz and Zozaya-Gorostiza (2003)
[26] = Sullivan et al. (1999)
[27] = Techopitayakul and Johnson (2001)
[28] = Whang (1992)
[29] = Zhu (1999)

Table 2: IT investment risks mapped to operating options that can control them (adapted from [Benaroch, 2002])
(cells correspond to different risk-option pairs, and those marked with a "+" posit that a specific option could be used to control a particular risk)

Figure 1 schematically expands on Equation (1) by showing the parameters needed to compute the value of an embedded option. These parameters are: the value of the option's underlying asset (which is usually the passive NPV), the volatility (variability) of the underlying asset value due to exposure to risk factors, the option's exercise price, the option's time to maturity, and the risk-free interest rate (Amran and Kulatilaka 1999). The impact of risk on volatility is the parameter central to our research objective. The presence of risk is an absolute prerequisite for any option to have a positive value – when there is no risk, the volatility is zero, and the option value is zero (Hull 1987).

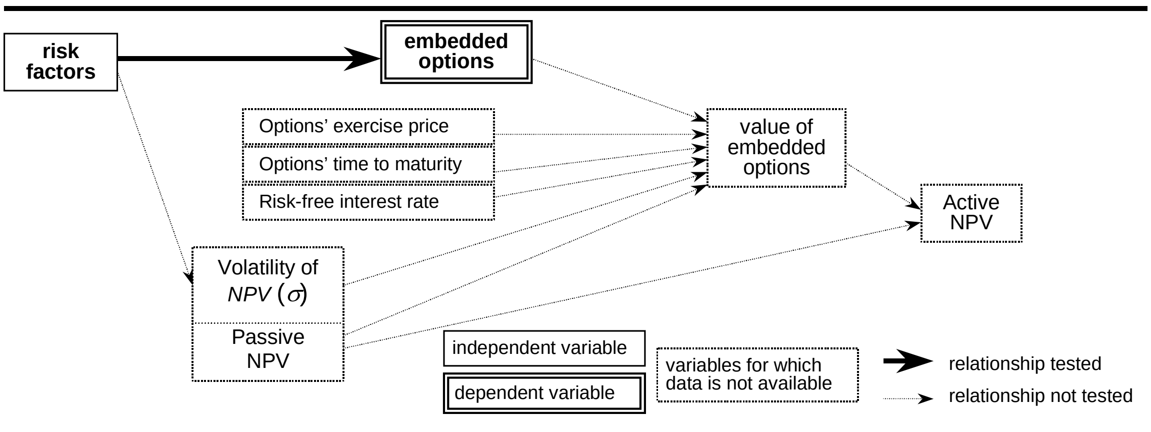

Figure 1: research model in context

We test empirically a small but crucial part of the model shown in Figure 1 – the relationship between the presence of various risks and the presence of different options in projects facing those risks. Thus, we are not concerned with determining the monetary value that embedded options add to an investment as a direct result of their use to manage risk; the difficulties involved in collecting data about all parameters are prohibitive, mainly because of data confidentiality issues. In summary, since the presence of risk is a prerequisite for embedded options to have a positive value, we only seek to determine whether the strategies experienced IT managers use to manage different risks are consistent with the presence of real options.

Research Site and Data Collected

The research site is an Irish Financial Service Organization (IFSO) that was chosen for two reasons. IFSO has a critical mass of large IT projects (programmes[3]) that allows for effective empirical research. More importantly, IFSO operates a dedicated Project Investment Department (PID) that evaluates every proposed IT investment and thoroughly documents its practices. Investment sponsors build a business case for each proposal and submit it to PID. The business case is a comprehensive document including: the project description, resources required, benefits and financial plans, and a risk management plan. The last segment is the target of our analysis. Although IFSO and PID managers did not rely on any real options framework at the time of this study, we sought to determine whether the intuitions and practices that managers used to construct risk management plans correspond well with the risk-option mappings posited by the OBRiM framework.

The data for this study was provided by PID and two of its managers. We were not given the full business cases because of the confidential nature of many IT projects. Instead, we received documentation about the risks present in every project, and the two managers agreed to answer questions relating to other data we needed. Although this may have excluded the project sponsors' point of view, the PID managers are better qualified to act as an interface with the business cases. They had substantial tacit knowledge missing in the business cases. They oversaw every project from the moment it was initially proposed, through all revisions

[3] IFSO uses the term *programme* to refer to large-scale projects, recognizing that such projects typically interact with one another. As such, it is possible that some projects (or parts of projects) in our sample constitute options on other projects in the sample. Such options could be either nested options or compound options. In this study, we are not concerned whether or not such options exist, so we do not check for their presence in our data.

the sponsor may have been asked to make to the business case, until it was eventually approved or rejected. Furthermore, once projects went live, the PID managers maintained an oversight role, for example, in the gradual release of approved budgets contingent on outcomes of milestone reviews. Finally, given the need to interview the PID managers on each project, it was agreed that we would be given only data for the 50 most recent IT projects.

We started by identifying the projects sample (see Appendix B). Of the 50 projects in the sample, seven were not accepted for investment and 10 were mandatory (regulatory) projects. We then obtained directly from business cases the complete risk assessment data IFSO originally collected for each project. We matched the data against risk items in the IT literature and used confirmatory factor analysis to extract risk factors paralleling the risk categories in OBRiM. Also, through structured interviews with the PID managers we collected for each project data about project cost, a proxy of project benefits (as actual benefits were not made available), and the mitigations planned for controlling project risks. We then coded the risk mitigations and used them to establish the real options present in each project. Equipped with the extracted risk factors and the options present in projects, we used regression analysis to test all possible risk-option pairs.

Cost and Benefits Data

While we collected only partial data about investment costs and benefits, these data helps to better understand the projects sample.

Investment *cost* is measured as the Euro amount approved for a project. Table 3 summarizes cost data for: all investments proposed, approved investments, discretionary projects, statutory compliance projects, and rejected projects. The mean and standard deviation of cost for statutory projects and rejected projects is the lowest. In fact, five of the seven rejected projects cost less than €0.5m. This suggests that PID does not reject projects due to cost concerns. One PID manager explained that: "due to the size of IFSO, it is rare that there is an investment it cannot afford; rather, investments are usually rejected for not providing enough value above anything else."

Category \ Cost	**Below €. 5m**	**€. 5m - €1m**	**€1m - €1.5m**	**€1.5m - €2m**	**€2m - €2.5m**	**Above €2.5m**	**Average Cost (€)**	**Standard Deviation**	**Total *N* (total %)**
***All proposed* Investments**	10 (20%)	17 (34%)	8 (16%)	2 (4%)	6 (12%)	7 (14%)	€1.46m	€1.68m	50 (100%)
***Approved* Investments**	5 (11.6%)	16 (37.2%)	8 (18.6%)	2 (4.6%)	5 (11.6%)	7 (16.3%)	€1.61m	€1.74m	43 (100%)
***Discretionary* Investments**	5 (15.2%)	9 (27.3%)	5 (15.2%)	2 (6%)	5 (15.2%)	7 (21.2%)	€1.62m	€1.84m	33 (100%)
***Statutory* Investments**		7 (70%)	3 (30%)				€0.80m	€0.29m	10 (100%)
***Rejected* Investments**	5 (71.4%)	1 (14.3%)			1 (14.3%)		€0.56m	€0.70m	7 (100%)

Table 3: basic investment cost statistics

Data about investment *benefits* was collected using a proxy measure. While the business cases contain benefits projections based on NPV and Payback calculations, IFSO agreed to provide only a proxy in the form of a benefits-to-cost ratio. This ratio is measured on a 5-point scale: 1 or 2 indicates that projected benefits are significantly less or just less than project cost, 3 means that projected benefits are similar to project cost, and 4 or 5 indicates that the expected benefits are larger or much larger than the project cost. Table 4 shows the frequencies of benefits-to-cost ratios. Few discretionary projects have a benefits-to-cost ratio lower than 3, indicating the severe statutory obligations on IFSO. Surprisingly, however, contrary to the intuition that accepted investments usually have higher expected benefits, there is virtually no difference between all projects proposed and those accepted for investment. PID managers explained this by citing other reasons for rejecting projects in the sample: two projects had a high benefits-to-cost ratio but did not fit IFSO's IT portfolio, and two projects had an acceptable benefits-to-cost ratio (of 3) but their project sponsors built a poor business case.

	Benefits-to-Cost Ratio					
	1	**2**	**3**	**4**	**5**	Grand total
***All proposed* investment**	10	3	10	12	15	50
***Approved* projects**	8	2	8	11	14	43
***Discretionary* investment**	2	2	10	12	14	40
***Statutory* investments**	8	1			1	10
***Rejected* investments**	2	1	2	1	1	7

Table 4: frequency of benefit-to-cost ratios

Risk Data

Risk data was taken directly from the business cases. The risk assessment for each project rates the project along various risk indicators. It was originally developed by the project sponsors in conjunction with PID, using a 47-question instrument. Below is a sample question:

Question: "To what extent is the success of the project contingent on stability in the business environment?"

0	1	2	3	4	5	6	7	8	9	10

Strictly speaking, the instrument measures only uncertainty, as it reflects no magnitude of loss (Barki et al. 1993). But to remain consistent with IFSO's terminology, we will continue using the term "risk" hereafter. The answer for each risk indicator is assigned a value between zero and 10: a zero means no risk, and a 10 means extremely high risk. Table 5 lists the risk indicators and basic statistics for how they fair across the projects sample.

----------------------- insert TABLE 5 about here -----------------------

Figure 2 shows the distribution of mean risk scores (i.e., [Σ_i risk indicator i] / 47) across all 50 projects. The projects appear to be reasonably balanced vis-à-vis risk: only 2% of the projects are in the very low range, with scores below 1; 54% are in what PID considers the low range, with scores between 1 and 2; 34% are in the medium-to-high range, with scores between 2 and 4; and 10% are considered by PID to be extremely risky, with scores above 4. Interestingly, the mean and median risk scores for the seven rejected projects, 2.29 and 1.908 respectively, compare well with the mean and median for the entire sample. This indicates that these projects were not rejected for being exceedingly risky.

To gain further insight, we mapped the risk indicators in IFSO's instrument to risk items in the IT literature (see Table 5). Of the 47 indicators in the instrument, 43 were previously identified in the literature, although some at a different level of granularity. This is not surprising considering that IFSO's risk instrument was developed by external consultants who are probably familiar with the IT risk literature. However, excluded from IFSO's instrument are some 20 previously discussed risk items (Boehm 1989; Barki et al. 1993; Keil et al. 1998; Schemidt et al. 2001). These items fall into two groups. One group includes items such as: lack of frozen requirements, team size, team turnover, and lack of clarity of role definition. According to the PID managers, such risk items are less relevant to business case evaluation because they relate mostly to project execution. The other group includes such risk items as: (a) failure to manage end-user expectations, (b) number of users, (c) conflicts between user departments, (d) linkages to other organizations, (e) number of external users, (f) threat of competitive duplication, and (g) ineffective (or new) development methodology. The PID managers explained that items like (a)-(c) are implicit in other risk indicators already in the instrument, items like (d)-(f) are indeed missing because of IFSO's inward focus on IT risk, and items like (g) are of less concern because IFSO uses a standard development methodology across all IT projects.[4] In summary, while IFSO's risk instrument does have some gaps, it seems comprehensive relative to the business case evaluation task.

Careful inspection of the instrument yielded another useful observation. Some risk indicators overlap (e.g., indicators 36-38), and some do not map to any risk item in the literature. We therefore used factor analysis to extract risk factors that parallel OBRiM's risk categories, as explained in the data analysis section.

[4] Generally, IFSO manages IS projects according to a tailored version of the Dynamic Systems Development Method (DSDM 2003).

No.	Indicator Name	Instrument Question	Parallel risk items in the IS Literature	Min	Max	Mean	Std Dev.
1	Clear Benefits	How clear are the benefits from the programme? Is there significant additional work needed to achieve the (needed clarity of) benefits?	Uncertain benefits [4,5]	0	10	2.66	2.953
2	Clear Future State	Is the future state anticipated by the implementation of the programme clearly understood and stated in the plan?	Changing/unclear scope/outcomes [7,3], Unclear task specification [2,6]	0	9	1.18	1.945
3	Credible Benefits	How credible is the logic chain linking the benefits claimed with the direct outputs of the work?	Uncertain benefits [4,5]	0	10	2.10	2.816
4	Validated Benefits	To what extent have the projected benefits and the assumptions been validated?	Uncertain benefits [4,5]	0	10	3.36	3.042
5	Adapted Business Change	How much of the projected benefits will be realized if the business priorities change?	Unstable business/corporate environment [6,7]	0	10	0.84	1.822
6	Sensitive Business Environment	To what extent are the benefits contingent on stability in the business environment?	Unstable business/corporate environment [6,7]	0	5	1.18	1.535
7	Adapted Customers	Are the benefits achievable if customer needs change?	Unstable business/corporate environment [6,7]	0	5	0.62	1.260
8	Business Involvement	To what extent have the business areas been involved in the creation of the business case?	User involvement / commitment [1,3,7], Project plan approval by all relevant parties [7]	0	8	1.10	1.972
9	Change Impacted Support	How much do those impacted by the change support the initiative?	User commitment/support [7], Organizational support [2,7]	0	7	1.56	1.842
10	Sponsor willing	How ready, willing and able is the sponsor to make the programme a success?	Top management support [2,3,6,7], Sponsorship / ownership [7]	0	6	0.76	1.709
11	Clear Outcomes	How clearly understood are the programme deliverables and the relationship between these deliverables and the achievement of the programme benefits?	Unclear task specification [2,6], Changing/unclear scope/outcomes [3,7]	0	8	1.90	1.961
12	Clarity of Focus Areas	To what extent have the key areas and full detail of IT work been incorporated into the overall plan?	Scope creep [3,7]	0	9	2.64	2.577
13	IT Mature	How mature is the technology to be used in the initiative?	IT Novelty [2], New technology [7,6]	0	10	0.94	2.445
14	Architecture Aligned	To what extent is the proposed technology aligned with the organization’s IT architecture?	Stability of technical architecture [7]	0	10	2.64	3.994
15	Security	To what extent will the proposed programme be compliant with the organization’s security policies?	Stability of technical architecture [7]	0	10	1.98	3.502
16	IT Skill	Will the IT people to be used on the programme (internal and external) have adequate technical skills?	Development expertise [2,7]	0	10	1.54	2.314
17	Business Skill	Are the people to be assigned to the programme adequately versed in the business area functions and the new concepts by the programme?	Team’s experience with client’s business [6] and/or application area [2,7,8]	0	10	1.14	1.990
18	Project Management Skill	How experienced are the relevant resources in program and project management?	Project management skills/experience [2,7,6,8]	0	10	1.38	2.364
19	ADB Involvement	How much have *architecture*, design and build support (ABD) resources been involved in the development of this programme?	Stability of technical architecture [7]	0	10	1.26	2.068
20	Common Resources	Will the IT work within the programme use common technical resources?	(Availability of) IT skills and expertise [2, 7]	0	3	0.32	0.768
21	Programme Size	How big is the IT work involved in the programme?	Project size [2,3,7,6,8]	0	10	7.20	2.828
22	Complexity	How do(es) the IT project(s) within the programme rank in complexity relative to other IT projects in the organization?	Technical and Task Complexity [2,3,7,6,8]	0	10	3.94	2.590
23	Criticality of Performance	To what extent are the benefits dependent on a consistently high level of performance from the products of the programme?	Performance shortfalls [1]	0	10	7.28	3.338
24	Dependence on Initiatives	To what extent is the success of the IT work dependent on the successful completion of other IT or business change initiatives?	Number of links to other IT/IS initiatives [2,6,8]	0	10	2.10	2.929
25	Dependence on Individuals	How dependent is the successful completion of work on the skills and experience of specific team members?	Dependence on a few key people [2]	0	9	3.36	2.505
26	Dependence on Suppliers	How dependent is the successful completion of work on particular suppliers?	Dependence on external suppliers [2,7]	0	10	4.16	4.112
27	Planning Guidelines	To what extent do the plans conform to good project management practice?	Inadequate planning [7], Project management skills/methods [7]	0	10	1.82	2.529
28	Estimates & Contingency	How sound is the work on cost estimates and contingency?	Unrealistic budgets and schedules [1], Bad estimation [7]	0	10	2.22	2.518
29	Quality Assurance	Are there effective quality assurance processes planned for the programme?	No/inadequate planning [7]	0	10	1.88	2.496
30	Decision Making	Are there effective processes in place for decision-making and escalation of issues to allow timely and sound resolution?	Poor risk management [7]	0	10	1.78	2.682
31	Contingency	To what extent does the programme allow for contingency approaches to cope with unforeseen events?	Poor risk management [7]	0	10	2.48	2.735
32	Support capabilities	How well can we support and maintain the deliverables from the programme?	Understanding maintenance [7,8]	0	7	0.96	1.665
33	Computer Ops Support	How committed is IT development to providing effective on-going support?	Under funding of maintenance [7,8]	0	7	0.50	1.446

No.	Indicator Name	Instrument Question	Parallel risk items in the IS Literature	Min	Max	Mean	Std Dev.
34	Benefits Realization Plan	Are all the initiatives needed to realize benefits, and how these will be tackled, identified in the programme?	Uncertain benefits [4,5]	0	10	3.04	3.220
35	Process to Capture Benefits	What processes are there to capture and leverage benefits that were not expected but are discovered?		0	10	2.78	3.046
36	Measurable Outcomes	To what extent can we measure the projected outcomes or benefits?	Uncertain benefits [4,5]	0	10	2.08	2.679
37	Metrics and Targets	Have metrics and time-based targets been established for key outcomes / benefits?	Uncertain benefits [4,5]	0	10	2.28	3.175
38	Baseline Measures	Have baseline measures been captured for outcomes / benefits?	Uncertain benefits [4,5]	0	10	2.26	3.056
39	Capitalization	To what extent is the programme time boxed so that some benefits are achieved if the programme is terminated at an intermediate stage?		0	10	4.14	4.243
40	Impact on Other Areas	How widespread is the impact of the programme?	Extent of change brought (to users, user tasks, organizational structure, etc) [2,6,8]	0	10	2.32	2.684
41	Dep. on Business Initiatives	To what extent are benefits dependent on the successful completion of other *business* programmes?		0	10	1.46	2.565
42	Depend. on Org Initiatives	To what extent are benefits contingent on expected *organization-wide* initiatives?		0	7	0.82	1.870
43	Sponsorship	Is the business committed to providing strong sponsorship, are they included in PR objectives?	Sponsorship / ownership [7], Top management support [2,3,6,7]	0	10	4.52	4.097
44	Resource Commitment	Are appropriate resources available to the programme from business areas affected by the program?	(Adequate) User involvement [1,3,7]	0	10	2.38	2.641
45	Benefits Harvesting	How strong an approach is the business taking to realizing benefits?	Uncertain benefits [4,5]	0	10	3.52	3.587
46	Change Capacity	Does the impacted staff have the capability and capacity to assimilate the business changes implied by the programme?	Change management [7], Resistance to change [2], Fit of corporate culture with business process change [7]	0	8	0.80	1.726
47	IT Sophistication	To what extent have the areas affected had to deal with equivalent sophistication in technology?	Lack of user experience with technology [2,6,8], Client's capability to handle implementation [6], Change management [7]	0	10	1.76	2.662

[1] = Boehm (1991) [3] = Keil et al. (1998) [5] = Sosa and Kemerer (1991) [7] = Schemidt et al. (2001)
[2] = Barki et al. (1993) [4] = Clemons (1991) [6] = Moynihan (1997) [8] = Jiang et al (2002)

Table 5: IFSO's risk indicators mapped to the IS risk literature

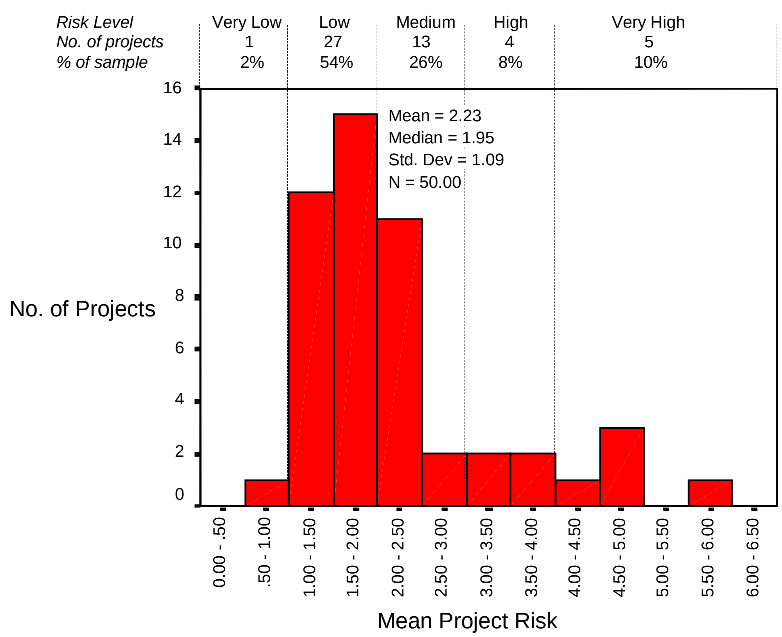

Figure 2: frequency of overall mean risk scores in IFSO's IS projects

Data on Risk Mitigations and Options

Data about mitigations planned for different risks was collected through structured interviews aided by a questionnaire (see Appendix C). We used these data to identify the options present in each project.

A trial questionnaire constructed following the OBRiM framework was administered for 10 randomly selected projects in the sample. The questionnaire asked directly about options present in each project: Was the project a pilot effort? Was the project expanded in scale after go-live? and so on. Before administering the questionnaire, the two managers received an explanation of real options as well as a legend page that defined terms in the questionnaire and listed the OBRiM options. Then, both managers answered the questionnaire during a 2.5 hours session. They discussed each project until they agreed on the answers, and then the interviewing author and the managers filled in the questionnaire. An initial discussion of the questionnaire followed the interviewing session and several follow up phone conversations were held. Both managers explained that the notion of options was not clear. One manager felt that the questionnaire was not effective because the terminology was new to him. It became evident that the managers were more comfortable addressing risks and their countermeasures because of the risk-driven methodology used by PID.

We developed another questionnaire that prompted the managers with risks and asked for respective mitigations (see Appendix C). The goal was to identify mitigations originally included in the risk management plan for each project, whether these were eventually deployed or not. We hoped that these mitigations could afterwards be linked to the presence of specific option types (forms of flexibility) that made the mitigations feasible. Since going through all 47 risk indicators in 50 projects was not pragmatically possible (as it would involve 50x47=2,350 questions), a questionnaire was customized for each project based on the risks rated 10 in that project. For each risk, the questionnaire asked an open-ended question: "How did the business case mitigate risk X in the target project?" The final questionnaire had on average 3.2 risk items per project (stdev=2.4), with a maximum of 13 and a minimum of zero. To ensure that no mitigations were overlooked, each questionnaire also included a last risk item labeled "others" for which the question asked was: "Were there other mitigations used for risks not listed in this questionnaire?"

The second questionnaire was administered 10 weeks after the trial questionnaire. Only the more experienced manager participated; he was very familiar with risk countermeasures and had greater interest in our research. The manager answered all 50 questionnaires during three four-hour sessions spread over a three week period. The time spent on each project averaged 15 minutes; the manager knew the projects well, as they were the most recent projects central to his responsibility for the IT investment portfolio. While the questionnaire was being administered, the manager did not use any *a-priori* list of risk countermeasures, since we were not permitted to compile such a list from the business cases. Moreover, the manager was not given any list of options, as the questionnaire sought to identify only risk countermeasures.

The interview for each project started with the participating manager offering background information about the project. Thereafter, the manager was prompted with a risk listed on the questionnaire, he used the business case to identify mitigations that were planned for that risk, and then he and the interviewer filled in the questionnaire. The manager often volunteered information about certain mitigations' ability to address additional risks not listed on the questionnaire. When he answered the "others" question with a yes, the risks and mitigations he identified were similarly recorded. Also, while he was answering questions, the interviewer elicited clarifications that would later enable associating mitigations with the presence of options. In particular, whenever the manager identified a mitigation that was deployed in actuality, he was asked to clarify whether the mitigation was part of the risk management plan and contingent on the actual occurrence of risk.[5]

Table 6 lists a sample of the mitigations identified and their mapping to specific options. After data collection, all the mitigations identified were grouped by similarity and then categorized into the types of options present in projects. The presence of options was determined by matching information we gathered against conditions that the OBRiM framework originally identified as necessary for different option types to exist (see Appendix D[6] for details). Interestingly, however, there were 36 instances of "miscellaneous"

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[5] Mitigations that were deployed non-contingently or as part of an unplanned reaction to unanticipated risks are fundamentally different, as their deployment was decided upon before some respective risks materialized or irrespective of the presence of any form of flexibility. These mitigations fit under what Boehm (1988) calls a risk avoidance strategy, as we point out in Appendix A.

[6] Appendix A is available online at: http://whitman.syr.edu/facstaff/mbenaroc/PAPERS/risk-option/Appendix-D.pdf

mitigations we did not link to any option, since these mitigations where non-contingent on the actual occurrence of some risk; however, no subgroup of projects (approved, mandatory, rejected) seemed to have more or less of these mitigations.

Mitigations classified into option types	**Defer**	**Pilot**	**Prototype**	**Stage / Incremental**	**Abandon / Exit**	**Contract**	**Expand**	**Outsource**	**Lease**
Project was deferred for 6 weeks	•								
Get corporate sponsor	•								
Plan for change management	•								
Do detailed statistical analysis to get better benefits baseline measures	•								
Extra planning for lack of benefits metrics, targets and baseline measures	•								
Research on how to structure project so (partial) benefits could accrue sooner	•								
Research / better project planning	•								
Planning to see how to run this enormous project effectively	•								
Rewrite (parts of) the project plan / Further planning and proposals	•								
Learn via communication planning with the impacted business areas	•								
Planning how to implement project in a way that ensures business could cope with change	•								
Put QA process in place	•								
Planning/research on the project architecture, which must be passed by architectural committee	•								
Extra planning / research into security issues	•								
Make / new plan to get security compliance	•								
Obtain resource commitment from the business areas involved	•								
Deployed in a small market segment		•							
Piloting also allowed resolving other issues in the main project		•							
More testing of IT elements of the project			•						
Extensive testing of the project's technology underpinning			•						
Learning and evaluation of security logons			•						
5-10% of investment gone into research prior to full commitment			•						
Research / studies to get architectural compliance			•						
Performance (gateway) reviews				•					
Staged implementation – rolling releases				•					
Functionality was unsure, so several (planned) scale ups occurred				•					
MOSCOW (get project's Must haves, then Should haves, Could haves, and finally Would haves)				•					
Project has not been abandoned but it might be yet					•				
Contingency plan / possibility to abandon existed					•				
Some deployment cost would be saved by abandonment					•				
No one uses system hardly -- may be abandoned in near future					•				
Change scale						•			
Scale down to reduce role of supplier in project if necessary						•			
Just did project as cheaply and quickly as possible						•			
Introducing project with reduced functionality was a possibility						•			
Project planned for scale up 2 months after go-live							•		
Will be expanded in the near future							•		
Negotiate to get source code from supplier								•	
Miscellaneous mitigations (not linked to the presence of any option)									
Extensive / extra testing of software / system (with no contingency)									
A larger than usual investment in testing									
Extra training of employees to ensure employees understood how to use new CRM system									
Communication plan with affected areas was put in place (after go-ahead was given to project)									
Invest in change management									
Strong contract penalties with supplier									
Establish communication plan with vendor as a result of skills transfer from the vendor									

Table 6: sample risk mitigations identified and their categorization into real option types

Table 7 lists the types of options present in the projects sample and their prevalence. The number of options per project had an average and a standard deviation of 1.48 and 1.35, respectively. While 14 projects had no options at all, 11 projects had one option, eight projects had two options, nine projects had three options, and five projects had four options. The distribution of options exhibited no visible pattern across different groups of projects (proposed, made, and discretionary).

Option Type	No. (%) of options found
Defer	17 (23%)
Pilot	14 (19%
Prototype	17 (23%)
Stage	7 (9%)
Abandon	7 (9%)
Contract/Scale-down	6 (8%)
Expand/Scale-up	2 (3%)
Outsource	4 (5%)
Lease	0 (0%)
Total	**74 (100%)**

Table 7: distribution of identified options by type

DATA ANALYSIS

We next discuss the way data concerning risks and options were analyzed.

Confirmatory Factor Analysis of Risk Factors

Since some indicators in IFSO's risk instrument overlap or repeat themselves, confirmatory factor analysis (CFA) was used to identify risk factors that parallel OBRiM's *a priori* risk categories. We first grouped the indicators based on their correspondence with risk items in the IT literature (Table 5), on our understanding of the indicators, and on comments made earlier by PID managers. As a result, 11 risk factors emerged and seven indicators were excluded from further analysis (see Table 8).

Two of the 11 factors each have a single indicator. The 'IT maturity' factor is measured by indicator 13, which asks: "How mature is the technology to be used?" The IT literature consistently uses the term 'maturity' to refer to "new, or bleeding edge, technology" (Schmidt et al. 2001, p. 17) or "any state-of-the-art requirements for technologies, languages, hardware, and so on" (Carr et al. 1993, p. B4). Explicit use of this self-explanatory term in the question therefore suggests that indicator 13 does capture its intended risk factor. Similarly, the 'performance shortfall' factor is commonly used to refer to poor performance of the resulting system (Boehm 1989) relative to response time and computing efficiency (Ropponen and Lyytinen 2000). Since indicator 23 explicitly asks about "the consistently high level performance from the products of the programme," this indicator is believed to capture its intended risk factor.

Seven risk indicators were excluded for the following reasons. Indicator 47 is ambiguous as it maps to both technology risk and change management risk. The other indicators simply did not map to risk items in the literature or to OBRiM's risk categories. Indicators 32-33 concern post implementation IT support. Indicators 41-42 relate to how dependent the investment business success is on other (*non-IT*) business and organization-wide initiatives. And indicators 35 and 39 check for the presence of mitigations as opposed to risks.

Finally, although indicators 27-31 are not covered by OBRiM's risk categories, we did not exclude them from the analysis because they map to risk items in the literature (e.g., poor risk management, inadequate planning [Schmidt et al. 2001]). We simply wanted to see if they form a factor.

The 11 risk factors in Table 8 were subjected to a CFA using PLS (Barclay et al. 1995). PLS has the ability to handle relatively small sample sizes, making it appropriate for our data set. All risk indicators were modeled as reflective indicators.[7] We used PLS-Graph Version 3.00 with bootstrap re-sampling (400 re-samples) to determine the significance of path loadings as well as to assess internal consistency, discriminant validity, and convergence validity.

Internal consistency is established when the loadings of indicators on their constructs exceed the 0.7 level (Fornell and Larcker 1981). Most indicators exhibited adequate loadings, except for SKILLEXP2, SKILLEXP3, SIZECPLX3, SIZECPLX5, ARCHSTAB3, ORGSUPRT4, BIZENVER3, and EXECFLEX5. These latter indicators were dropped and revised constructs were put to another round of validation, after which acceptable psychometric properties were observed. Loadings for all final indicators exceed 0.725 and are significant at the 0.01 level. Also, as

[7] Risk indicators were modeled as reflective for two reasons. First, the indicators for each of the risk factors are unidimensional (i.e., they have only one underlying concept in common) and correlated (i.e., if one of the indicators changes in a particular direction, the others will change in a similar manner, assuming all are coded in the same direction). For example, with respect to the factor 'size and complexity', if the indicator 'dependence on other initiatives' increases, the size indicator and the complexity indicator will increase as well. Second, as is the case with our study, reflective indicators are generally preferred to formative ones when there is a relevant theory and when the objective is theory testing rather than theory building (Chin, 1998b).

shown in Table 9, the composite reliability scores for all resulting constructs exceed the 0.7 recommended value (Chin 1998).

Risk Factor and its Definition	Risk Indicator	IFSO Indicator Number and Name		Excluded from CFA	Dropped after CFA	Parallel IS Factors
BENEFITS The degree of uncertainty over whether the expected investment benefits are clear, validated, credibly projected, and linked to adequate realization plans.	BENEFITS1	1	Clear Benefits			Benefits [4,5]
	BENEFITS2	3	Credible Benefits			
	BENEFITS3	4	Validated Benefits			
	BENEFITS4	34	Benefits Realization Plan			
	BENEFITS5	36	Measurable Outcomes			
	BENEFITS6	37	Metrics and Targets			
	BENEFITS7	38	Baseline Measures			
	BENEFITS8	45	Benefits Harvesting Approach			
SKILLEXP (Skills & Experience) The degree of uncertainty over the existing level of IT skills and experience being adequate for the project investment.	SKILLEXP1	16	IT Skill			Expertise [2]
	SKILLEXP2	17	Business skill		did not load	
	SKILLEXP3	18	Project Management Skill		did not load	
	SKILLEXP4	20	Common Resources			
SIZECPLX (size & complexity) The degree of uncertainty due to the size complexity of the application task as well as due to dependence on individuals. (Indicator 25 is included because, the larger is the project, the more people will be needed and the likelihood of staffing shortfalls increases.)	SIZECPLX1	21	Programme Size			Project size [2, 3, 8], Project complexity [2]
	SIZECPLX2	22	Complexity			
	SIZECPLX3	24	Dependence on Initiatives		did not load	
	SIZECPLX4	25	Dependence on Individuals			
	SIZECPLX5	26	Dependence on Suppliers		did not load	
ARCHSTAB (Architectural Stability) The degree of uncertainty about compliance with the firm's technical architecture, which gives rise to architecture instability and inadequate infrastructural support.	ARCHSTAB1	14	Architecture Aligned			Architectural Instability [7]
	ARCHSTAB2	15	Security			
	ARCHSTAB3	19	ADB Involvement		did not load	
PERFORMA The degree of uncertainty about the application meeting the performance level expected/needed by the intended users.	PERFORMA1	23	Criticality of Performance			Performance shortfall [1]
CLRSCOPE (Clarity of Scope) The degree of uncertainty over the scope of the investment, and hence over the ability of the resulting application to provide the functionality expected/needed by all the target users. (Indicator 12 is included because: if the IT work has been outlined but not yet detailed, a project with a broad scope is more likely to involve details pertaining to areas outside the sponsor's area.)	CLRSCOPE1	2	Clear Future State			Scope creep [7], Changing scope [3]
	CLRSCOPE2	11	Clear Outcomes			
	CLRSCOPE3	12	Clarity of focus areas			
ORGSUPRT (Organizational Support) The degree of uncertainty over the organizational support offered at the level of sponsorship, management, business units, and users.	ORGSUPRT1	8	Business Involvement			Management commitment [3], Sponsorship [7], Business / user involvement [2, 3]
	ORGSUPRT2	9	Change Impacted Support			
	ORGSUPRT3	10	Sponsor willing			
	ORGSUPRT4	43	Sponsorship		did not load	
	ORGSUPRT5	44	Resource Commitment			
CHNGIMPC (Change Impact) The degree of uncertainty over the ability of the affected business units to handle change. (Indicator 40 is included because: If a project has a widespread impact on other areas, more problems are expected relative to the capacity of the business to change.)	CHNGIMPC1	40	Impact on other areas			Organizational change [2,7]
	CHNGIMPC2	46	Change Capacity			
BIZENVER (Business Environment) The degree to which the business environment is unstable and unpredictable to the point where it could impact the ability to fully obtain the expected investment benefits.	BIZENVER1	5	Adapted Business Change			Turbulence of business environment [2,6,7]
	BIZENVER2	6	Sensitive Business Environment			
	BIZENVER3	7	Adapted Customers		did not load	
TECHNOVL (Technology Novelty) The degree of uncertainty over the maturity of the implementation technology.	TECHNOVL1	13	IT Mature			New technology [3,7]
	TECHNOVL2	47	IT Sophistication	ambiguous		
EXECFLEX (Project Execution Flexibility & Risk Mgmt) The degree of uncertainty over the adequacy of project and risk management planning and of the associated processes incorporated into the business case (including contingencies for harnessing partial benefits and limiting loss).	EXECFLEX1	27	Planning Guidelines			Risk / project management [7]
	EXECFLEX2	28	Estimates & Contingency			
	EXECFLEX3	29	Quality Assurance			
	EXECFLEX4	30	Decision making			
	EXECFLEX5	31	Contingency		did not load	
Others (not a factor)		32	Support capabilities	not in OBRiM		
		33	Computer Ops Support	not in OBRiM		
		35	Process to capture benefits	not in OBRiM		
		39	Capitalization	not in OBRiM		
		41	Dependence on other business initiatives	not in OBRiM		
		42	Dependence on other org-wide initiatives	not in OBRiM		

[1] = Boehm (1991) [3] = Keil et al. (1998) [5] = Sosa and Kemerer (1991) [7] = Schemidt et al. (2001)
[2] = Barki et al. (1993) [4] = Clemons (1991) [6] = Moynihan (1997) [8] = Jiang et al (2002)

Table 8: risk factors and their respective risk indicators

	No. of Indicators	Factor Composite Reliability	AVE	BENEFITS	SKILLEXP	SIZECPLX	ARCHSTAB	PERFORMA	CLRSCOPE	ORGSUPRT	CHNGIMPC	BIZENVER	TECHNOVL	EXECFLEX
BENEFITS	8	0.958	0.742	**0.861**										
SKILLEXP	2	0.806	0.674	0.22	**0.821**									
SIZECPLX	3	0.809	0.585	0.00	0.26	**0.765**								
ARCHSTAB	2	0.878	0.783	0.16	0.08	-0.02	**0.885**							
PERFORMA	1	N/A[+]	1.000	-0.33*	0.06	0.19	-0.26	**1.000**						
CLRSCOPE	3	0.844	0.644	0.48**	0.20	-0.04	0.06	-0.06	**0.802**					
ORGSUPRT	4	0.876	0.640	0.52**	0.20	-0.07	0.05	-0.03	0.51**	**0.800**				
CHNGIMPC	2	0.740	0.588	-0.05	0.05	0.08	0.14	0.12	0.17	0.27	**0.767**			
BIZENVER	2	0.802	0.669	0.32*	0.10	0.02	0.23	0.00	0.44**	0.11	-0.02	**0.818**		
TECHNOVL	1	N/A[+]	1.000	0.33*	0.41**	0.24	0.07	0.00	0.35*	0.29*	-0.16	0.14	**1.000**	
EXECFLEX	4	0.896	0.683	0.48**	0.21	0.02	0.17	-0.15	0.34*	0.46**	0.05	0.05	0.22	**0.826**

** correlation significant at the .01 level (two-tailed)
* correlation significant at the .05 level (two-tailed)
[+] Factor Composite Reliability is meaningless for factors with a single indicator

Table 9: indicators composite reliability, correlation between constructs, and Square Root of AVE Values (shaded cells)

Indicator (Factor →)	No.	BENEFITS	SKILLEXP	SIZECPLX	ARCHSTAB	PERFORMA	CLRSCOPE	ORGSUPRT	CHNGIMPC	BIZENVER	TECHNOVL	EXECFLEX
BENEFITS1	1	**0.94****	0.12	-0.01	0.16	-0.33*	0.44**	0.53	-0.05	0.24	0.31*	0.50**
BENEFITS2	3	**0.81****	0.23	0.09	0.05	-0.15	0.38**	0.53**	0.00	0.20	0.38**	0.44**
BENEFITS3	4	**0.79****	0.08	0.12	0.05	-0.19	0.52**	0.57**	0.02	0.10	0.26	0.55**
BENEFITS4	34	**0.87****	0.14	-0.12	0.08	-0.23	0.40**	0.44**	-0.04	0.32	0.27	0.36**
BENEFITS5	36	**0.94****	0.17	-0.04	0.22	-0.29*	0.51**	0.44**	-0.06	0.32*	0.29*	0.38**
BENEFITS6	37	**0.87****	0.41**	0.03	0.20	-0.35*	0.50**	0.40**	-0.04	0.37**	0.35	0.43**
BENEFITS7	38	**0.82****	0.33*	0.05	0.13	-0.37**	0.39**	0.29*	-0.12	0.36*	0.24	0.36*
BENEFITS8	45	**0.84****	0.07	-0.11	0.18	-0.35*	0.46**	0.42**	-0.05	0.33	0.19	0.32*
SKILLEXP1	16	0.32*	**0.82****	0.14	0.10	-0.01	0.26	0.26	0.12	0.08	0.53**	0.16
SKILLEXP4	20	0.04	**0.82****	0.28*	0.03	0.12	0.07	0.07	-0.04	0.07	0.14	0.19
SIZECPLX1	21	-0.04	0.16	**0.72****	-0.19	0.10	0.05	-0.02	0.04	-0.01	0.22	-0.08
SIZECPLX2	22	-0.03	0.10	**0.76****	-0.08	0.22	-0.11	-0.05	0.03	0.04	0.18	-0.06
SIZECPLX4	25	0.05	0.31*	**0.81****	0.21	0.13	-0.06	-0.10	0.11	0.03	0.16	0.09
ARCHSTAB1	14	0.05	-0.02	-0.17	**0.88****	-0.25	-0.02	-0.06	0.07	0.14	0.09	-0.01
ARCHSTAB2	15	0.23	0.15	0.14	**0.88****	-0.21	0.13	0.14	0.17	0.26	0.04	0.31*
PERFORMA1	23	-0.33*	0.06	0.19	-0.26	**1.00****	-0.06	-0.03	0.12	0.00	0.00	-0.15
CLRSCOPE1	2	0.51**	0.18	-0.03	-0.01	-0.13	**0.84****	0.42**	0.26	0.33*	0.23	0.29*
CLRSCOPE2	11	0.67**	0.05	0.04	-0.11	0.01	**0.82****	0.34*	-0.06	0.34*	0.27	0.14
CLRSCOPE3	12	0.45**	0.26	-0.12	0.29*	-0.03	**0.75****	0.48**	0.21	0.39**	0.35*	0.38**
ORGSUPRT1	8	0.56**	0.17	-0.15	0.00	-0.14	0.50**	**0.84****	0.16	0.05	0.13	0.73**
ORGSUPRT2	9	0.47**	0.05	-0.15	0.08	-0.10	0.45**	**0.76****	0.26	0.30*	0.17	0.38**
ORGSUPRT3	10	0.222	0.15	-0.10	-0.06	0.05	0.23	**0.82****	0.28*	-0.03	0.21	0.55**
ORGSUPRT5	44	0.42**	0.26	0.17	0.14	0.11	0.44**	**0.78****	0.16	0.04	0.42**	0.44**
CHNGIMPC1	40	0.01	-0.01	0.07	0.21	0.13	0.26	0.22	**0.77****	0.12	-0.11	0.06
CHNGIMPC2	46	-0.08	0.09	0.06	0.00	0.06	0.01	0.18	**0.77****	-0.16	-0.12	0.01
BIZENVER1	5	0.43**	0.15	-0.04	0.07	-0.10	0.41**	0.19	-0.11	**0.82****	0.21	0.14
BIZENVER2	6	0.10	0.01	0.07	0.30*	0.10	0.31*	-0.01	0.08	**0.82****	0.03	-0.07
TECHNOVL1	13	0.33*	0.41**	0.24	0.07	0.00	0.35*	0.29*	-0.16	0.14	**1.00****	0.22
EXECFLEX1	27	0.56**	0.14	-0.10	0.14	-0.28*	0.30*	0.41**	0.11	0.05	0.26	**0.84****
EXECFLEX2	28	0.35*	0.18	-0.06	0.12	0.05	0.27	0.56**	0.07	-0.04	0.09	**0.86****
EXECFLEX3	29	0.38**	0.17	0.01	0.30*	-0.28*	0.16	0.36*	-0.12	0.00	0.24	**0.82****
EXECFLEX4	30	0.30*	0.22	0.10	-0.01	0.02	0.38**	0.38**	0.10	0.15	0.13	**0.78****

** significant at the .01 level   * significant at the .05 level

Table 10: factor loadings and cross-loadings for the final indicators

Convergent validity is observed when the average variance extracted (AVE) scores for all factors exceed the 0.5 level (Fornell and Larcker 1981). As seen in Table 9, all factors meet this requirement, indicating that each factor shares more variance with its indicators than with other factors.

Discriminant validity is established by observing that two conditions are met (Chin 1998b, Hair et al. 1998). First, as Table 9 shows, the square root of the AVE on the diagonal is consistently greater than the off-diagonal (inter-construct) correlations. Second, as seen in Table 10, all final indicators load more highly on their own construct than on other constructs, with correlations being significant at the 0.01 level.

In summary, 10 of the 11 confirmed factors are identical to, or have a strong parallel with factors identified by past studies (see Table 8). The eleventh factor is 'benefits' risk. Its association with eight different risk indicators shows the strong emphasis that IFSO puts on this form of risk.

Validation of Risk-Option Relationships

Based on the research model in Figure 1, the relationship between the risk factors identified and the presence of specific real options was analyzed using regression. Since the dependent variable is binary, we used logistic regression (Hosmer and Lemeshow 2000).[8] The goal was to test whether the risk-option mappings posited by the OBRiM framework (Table 2) are observed in the risk management practices of IFSO's managers.

In order not to overlook risk-option mappings that may be present in the data but are not posited by OBRiM, 70 (10x7) logistic regression runs were used to test all possible risk$_i$-option$_j$ pairs. There is a total of 10 risk factors (since the EXECFLEX factor is not in OBRiM's risk categories) and seven option types (defer, pilot, prototype, stage, abandon, contract, and outsource). The 'expand' and the 'lease' options were excluded because they appeared in projects only two and zero times, respectively. In each run, the independent variable is risk factor *i*, whose value is computed as a simple average of the risk indicators that loaded on it in the factor analysis, and the dependent variable is option type *j*, whose value is 1 if option *j* is present in a project and 0 otherwise.

Table 11 summarizes the logistic regression results (produced in SPSS). In the rightmost columns, cells painted in gray represent risk-option mappings posited by OBRiM and non-empty cells represent mappings supported by the data. Support for these mappings is determined based on three different statistics, of which the first two are customary in logistic regression and the third is added because it is sensitive to the sample size (Hosmer and Lemeshow 2000).

(1) The *Wald* statistic tests the significance of *B*, the estimated logistic coefficient for the independent variable (see footnote 8).[9] It tests the null hypothesis "H_0: Exp(B)≠1 (or B≠0)." We report results only for risk-option pairs whose Wald statistic is significant at the 0.01 or 0.05 level (except for one pair).

(2) The *–2 log-likelihood* ratio (–2LL), also called the *model chi-square* statistic, tests the overall logistic model produced for a risk$_i$-option$_j$ pair.[10] It tests the null hypothesis "H_0: knowing the independent variable does make a difference in predicting the dependent variable." When –2LL has a significant level of 0.05 or smaller, the null hypothesis is accepted. We report results only for risk-option pairs whose –2LL statistic is significant at the 0.01 or 0.05 level (except for one pair).

(3) The *Hosmer-Lemeshow* (H-L) statistic is "more robust than the traditional goodness-of-fit statistics used in logistic regression, *particularly for … small sample sizes*" (SPSS 2004, p. 11).[11] It tests the null hypothesis "H_0: the model predicts values significantly *different* from the observed values." If its significance level exceeds 0.05, the null hypothesis is rejected, implying that the model's estimates fit the data at an acceptable level. We report results only for pairs for which there is no evidence for a lack of fit.

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[8] The logistic regression model is simply a non-linear S-shaped transformation of the linear regression model:

$$\ln[p/(1-p)] = \boldsymbol{a} + \boldsymbol{B}X + e$$

where p is the probability that the event Y occurs, p(Y=1), the term $p/(1-p)$ is called the "odds ratio", and all other terms are the same as in the linear regression model.

[9] The Wald statistic, $Wald=[B/\text{s.e.}(B)]^2$, is distributed Chi-square with 1 degree of freedom.

[10] $-2LL=-2[LL(a)-LL(a,B)]$, is distributed chi-square with d degrees of freedom, where d is the number of independent variables and LL(·) is the log-likelihood function. LL(a,B) is evaluated with the independent variables included and LL(a) with only the constant included.

[11] The Hosmer-Lemeshow statistic is based on grouping cases into deciles and comparing the observed probability with the expected probability within each decile, and then computing a chi-square from observed and expected frequencies. Then a probability (p) value is computed from the chi-square distribution (with the degrees of freedom equaling the number of deciles) to test the fit of the logistic model. If the observed and expected counts within each grouping are close to one another, we should see a small Chi-Square statistic and a large p-value (≥0.05), and we would accept the null hypothesis that the model fit is good.

To further increase our confidence in the results, we checked additional diagnostics (magnitude of logistic coefficients, 95% confidence interval for coefficients, classification tables, and correlations between variables). We found no unacceptable behaviors.

Risk Category	OBRiM's risk factors	Parallel risk factors in IFSO's instrument	Test statistics	Defer	explore		Stage / Incremental	Abandon / Exit	Contract	Outsource
					Pilot	Prototype				
Benefits	Benefits estimation, predictability, and realiazability	Benefits (BENEFITS)	*B*	1.4**	1.3*					1.4**
			-2LL	9.0***	2.9*					4.2**
			H-L	3.5 (.84)	3.48 (.87)					9.6 (.21)
Project	Team lacks needed (technical) skills	IT skills and experience (SKILLEXP)	*B*			1.2**	1.3**			1.3**
			-2LL			7.5**	5.1**			5.1**
			H-L			2.7 (.65)	5.7 (.22)			2.8 (.57)
	Project is too large or too complex	Size and task complexity (SIZECPLX)	*B*		1.6**	1.9**	1.9**		2.1**	1.72**
			-2LL		5.1**	4.8***	6.4***		4.8**	4.20**
			H-L		7.9 (.34)	3.4 (.85)	2.6 (.92)		1.65 (.98)	5.41 (.61)
	Inadequate infrastructure for implementation / architectural stability or compliance	Architectural stability (ARCHSTAB)	*B*	1.47**		1.39**				
			-2LL	14.34***		4.26**				
			H-L	7.21 (.41)		6.97 (.43)				
Functionality	Inadequate design (e.g., performance shortfalls)	Performance shortfall (PERFORMA)	*B*			1.2**	1.1**		1.60**	1.4**
			-2LL			4.9**	9.8***		4.40**	3.9**
			H-L			8.9 (.39)	3.8 (.88)		8.29 (.40)	7.2 (.52)
	Problematic / unclear requirements (stability, completeness, etc.)	Clarity of scope (CLRSCOPE)	*B*	1.4**	1.4**	1.3**				1.5**
			-2LL	4.0**	4.2**	3.9**				3.9**
			H-L	2.4 (.88)	4.4 (.63)	2.8 (.83)				4.0 (.68)
Organizational	Uncooperative internal parties	Organizational support (ORGSUPRT)	*B*	1.5**				1.2**		
			-2LL	5.0**				4.7**		
			H-L	1.7 (.82)				2.93 (.57)		
	Parties slow to adopt and/or adapt to the application	Change impact (CHNGIMPC)	*B*		1.48**			3.12***	1.71***	
			-2LL		5.16**			22.04***	6.08***	
			H-L		6.8 (.23)			9.41 (.34)	3.5 (.62)	
Environmental	Unpredictable business environment (low customer demand, changing customer needs, etc.)	Business environment stability and predictability (BIZENVER)	*B*	1.12**	1.23**			1.79**	1.18**	
			-2LL	3.97**	4.07**			4.28**	4.81**	
			H-L	3.5 (.62)	6.86 (.23)			6.44 (.73)	3.46 (.62)	
Technological	The implementation ITs considered may be immature or infeasible for the application	Technology newness (TECHNOVL)	*B*		1.2**	1.64***	1.36**			2.03**
			-2LL		7.32**	8.87***	6.21**			7.12**
			H-L		4.41 (.35)	6.94 (.22)	9.64 (2.10)			8.78 (.26)

*** significant at the 0.01 level
** significant at the 0.05 level
* significant at the 0.10 level
B-row: shows the logistic coefficient value, Exp(*B*), and the significance of the *Wald* statistic based on *B*
-2LL-row: shows the *–2 log-likelihood* statistic
H-L-row: shows the *Hosmer-Lemeshow* goodness-of-fit statistic (and its significance level); a significance ≥ 0.05 implies no evidence for lack of fit

Table 11: summary of logistic regression results for risk-option associations found to be significant

The results in Table 11 indicate that risk-option relationships predicted by the OBRiM framework are found in practice, and equally important that relationships *not* predicted by OBRiM are *not* found. Of the 42 predicted relationships we tested, 31 were significant (i.e., 74% are supported). Of the 28 tested relationships that OBRiM is not predicting, 25 were not significant (i.e., 89% are supported as non-existent). Taken together, relationships were over six times as likely to be found where predicted (74%) than where not predicted (11%). Put another way, the ratio of tested relationships matching predictions to those not matching predictions is 0.8 ([31+25]/[42+28]). These results support the theorized link between the way IT risks in the projects sample are managed and the options present in those projects.

Considering the small size of our sample (*n*=50), the possibility for Type II errors arises, and statistical power becomes an issue. Unfortunately, in logistic regression, power analysis is meaningless with a sample size of *n*<400 (Hosmer and Lemeshow 2000). On the bright side, however, note two important points. First, with the –2LL statistic and the Hosmer-Lemeshow statistic testing a hypothesis (i.e., regression model fits the data) and its negation, Type II errors are less likely. Second, the number of positive events per covariate is even more important than sample size – "a minimum of 10 events per parameter is sufficient to avoid problems of over estimated and under estimated variances and thus poor coverage of Wald-based confidence intervals and Wald tests of coefficients" (Hosmer and Lemeshow 2000, p. 346). Three of the options we tested meet this requirement (defer, pilot, and prototype). Results for the remaining options should therefore be treated with some caution.

DISCUSSION

This section summarizes the findings of our study and discusses their implications for research and practice. Limitations of the study and directions for future research are identified throughout the discussion.

Main Findings and Limitations

Our overall goal has been to test empirically the relationship between the way IT risk is managed and the presence of real options.

We started by investigating the risk instrument used by a large organization having sophisticated IT risk management practices and relating its items to the IT risk literature. Although the instrument includes overlapping questions, our factor analysis yielded risk factors that parallel factors identified by past studies. This finding reconfirms the notion that a universal set of risk factors exists in IT investments (Keil et al. 1998). However, the instrument raises a psychometric issue: the zero to 10 rating scales for risk indicators should probably be an ordinal one, as the difference between indicators is not consistent. It is not clear how this problem may have, or if it, impacted our findings.

We subsequently used logistic regression to test the relationship between the risk factors identified and the real options present in projects exposed to these risks. The results suggest a strong relationship between the two: A higher level of specific risks for which mitigations were planned was found to be associated with an increased presence of specific options (forms of flexibility) that facilitate deployment of the mitigations. The results validate the majority of risk-option mappings posited by the OBRiM framework, supporting the overall logic of option-based risk management. It could be that support is found only for the majority of mappings because IFSO's managers did not formally subscribe to the real options thinking, although our findings suggest that these managers' natural intuitions match this thinking considerably. Another finding worth mentioning is the relative lack of 'expand' options in the data. It could be that IFSO's managers put little emphasis on managing positive risk (e.g., higher than expected customer usage rate) and follow-up investment opportunities it may bring about. We argue that IFSO and other organizations should be more sensitive to positive risk if they are to better manage beneficial opportunities by means of creating, or exploiting the presence of, 'expand' options.

Here, too, it is important to note potential limitations of our study. *First*, biases in the business cases – a downward bias on risks and an upward bias on (or overuse of) mitigations – were possible as "normal" manipulation by project sponsors, although the project investment department (PID) was supposed to scrutinize and correct such biases. If such biases existed, they could have impacted our findings. *Second*, our questionnaire may have introduced a range restriction problem by asking explicitly only about highly rated risks. We tried to avoid this problem by asking a separate question about all "other" risks, but we may still have missed some mitigations and thus overlooked some options present in the projects sample. Therefore, the data collected may not have covered all of OBRiM's mappings or suppressed other mappings that might have been found in the data otherwise. *Third*, only the interviewing author mapped the mitigations identified to different option types. Carrying out this mapping independently by all authors would have enabled offering inter-rater reliability statistics that could increase confidence in the mapping results. Moreover, the lack of a formally validated scheme for establishing the presence of options may have allowed for some subjectivity in the mapping of mitigations to options. This is a clear gap in the real options literature that future research should investigate. *Finally*, we are mindful of our relatively small sample size. We reported multiple test statistics that increase confidence in our results. Nevertheless, at least the results obtained for options with fewer occurrences (stage, abandon, contract, and outsource) need to be treated with some caution.

The fact our data came from a single organization impact the generalizability of our findings. On one hand, using a single research site controls for exogenous differences in firm and industry characteristics that might confound a similar study spanning multiple firms. On the other hand, IFSO's sophistication of IT risk management practices is an important distinct capability that may limit our findings to organizations having a similar capability. In this light, conducting similar studies in organizations with different profiles could determine whether our findings extend to other kinds of organizations. We believe that other organizations exhibit the same level of reliance on real options in managing IT risk. For example, the number of options in IFSO's projects sample is comparable to that found in the IT portfolio of a manufacturing firm with no visibly distinct IT risk management practices (Kenneally and Lichtenstein 2001).

Implications for Research and Practice

Our study's main contribution has important implications for research and practice. It is the first empirical effort to examine the relationship between IT risk management and the presence of real options in a reasonably large IT portfolio. Most IT work on real options focuses on the utility of ROT in IT investment evaluation. Our findings indicate that the scope of ROT can and should be expanded to the management of IT risk, in order to open another useful venue for studying a host of behavioral and economic issues.

The key benefit from expanding the scope of ROT to the management of IT risk is the ability to approach this endeavor from an economic *optimization* perspective. Our results show that IT risk management practices in the focal research site are consistent with the logic of option-based risk management. They suggest that managers intuitively rely on this logic to decide which and how many options it pays to embed in IT investments. Unfortunately, unless supplemented by formal ROT models, intuition alone can lead to suboptimal or even counterproductive decisions. This is so because options are typically created proactively and at a cost, and because the value of options is usually non-additive. First, when multiple options exist in an investment, one or more of them could contribute towards mitigation of the same risks (Trigorgies 1996). In such cases, there is excess flexibility and the cumulative (non-additive) value of options could be smaller than the cost incurred to create them. Second, different combinations of options may allow mitigating the same risks differently, where some combinations could have a greater value than others (Benaroch 2002). In light of these reasons, it is essential to quantitatively evaluate and contrast different combinations of options in relation to the risks one needs to control. The OBRiM framework and its quantitative elements were developed exactly for this purpose. Recall, however, that this study in itself does not demonstrate that full adoption of OBRiM necessarily adds value, or is superior to the intuitive approach currently employed at the research site. It seems plausible that full adoption would add benefits as well as costs (i.e., effort and time). Future research could assess empirically whether the benefits outweigh the costs.

A related contribution of this study is the identification of two shortcomings of the OBRiM framework. Throughout this study we were juggling between the practitioners' world and the academics' world, attempting to fit theoretical ideas into real world practices. One shortcoming we revealed is that OBRiM cannot account for all types of risk mitigations – several mitigations in our data do not correspond to any type of option. This represents a gap between practice and OBRiM's underlying theory. Reconciling this gap is an interesting issue for future research. A second shortcoming is that managers appear to have difficulties applying real option concepts. Our questionnaire development effort has demonstrated the complexity IT managers face in fitting real option concepts with their risk management practices. It could be that the relatively new academic literature on real options simply has not yet been recognized by IT practitioners.

If two things happen, OBRiM could perhaps become common in practice. One is better training of IT personnel in financial concepts. A recent study with CIOs on factors affecting the successful adoption of IT portfolio management practices reveals a significant skills gap (Jeffery and Leliveld 2004):

> As many as 46% of the respondents agreed that IT staff lack working knowledge of financial concepts. Although most IT staff can tell what NPV stands for and how to calculate it, they have trouble making a strong business case in partnership with business-unit executives … To improve the financial skills of IT people, successful ITPM adopters must make such skills a formal part of training curricula. (p. 47)

Additionally, developing strong methodological aids for, or a simplified version of, OBRiM could better guide organizations in the management of IT risk from an economic perspective. For example, decision support tools (or an expert system) embodying the "mechanics" of OBRiM would greatly simplify its application.

In summary, we hope that our findings and their implications stimulate both researchers and practitioners to explore more closely the option-based approach to IT risk management. Only collaboration of these two communities could culminate in an operational version of the OBRiM framework and in empirical assurance that its use indeed benefits organizations.

CONCLUSION

The present study found strong empirical support for the core logic of the OBRiM framework, which uses ROT and fundamental principles from the area of financial risk management as a theoretical backdrop. This is the first empirical study to explicitly examine the relationship between the way different IT risks are managed and the presence of specific real options in a large portfolio of IT investments. It confirms this relationship and thus supports the notion that the scope of ROT can and ought to be expanded to the management of IT risk. Although this study's findings are based on the IT portfolio of a single organization, there is sufficient reason to believe that they can be generalized to other organizations with well established IT risk management practices.

Perhaps the most important practical implication of this study is that organizations stand to gain from formally adopting the OBRiM framework. We found strong evidence that practitioners indeed follow the logic of real options in managing the risk of their IT investments, though largely based on intuition. Using this logic based on intuition alone could lead to suboptimal or counterproductive results. Intuition ought to be supplemented by the ability to formal ROT models to quantify the value that options add to IT investments in relation to their creation cost and to the mitigations they enable. This ability is a prerequisite to approaching IT risk management from an economic optimization perspective. Our experience with managers at the focal research site, however, indicates that full adoption of the OBRiM framework requires better training of IT personnel in financial concepts.

The findings of this study have some important implications on research as well. The fact that the natural intuitions of IT managers correspond well with the logic of real options opens up opportunities to use ROT to study a host of behavioral and economic issues in IT risk management. This prospect is exciting but we also found that IT managers continue to have difficulties applying real option concepts in practice. Also, while our results reveal a clear link between IT risk management and the flexibility afforded by real options, these results could be tainted by our small sample size and other limitations of our methodology. We highlighted several directions for future research that could be helpful in these regards.

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APPENDIX A: RATIONALES FOR OBRiM's RISK-OPTION MAPPINGS

Available online at: http://whitman.syr.edu/facstaff/mbenaroc/PAPERS/risk-option/Appendix-A.pdf

APPENDIX B: PROJECTS IN THE SAMPLE

Table B1 lists the 50 projects in our sample and some relevant data collected on each project. The sample offers a complete snapshot of a broad portfolio of large-scale IT projects. Projects varied from centralized workflow developments, through system upgrades, to e-business development projects. Six projects were in IT infrastructure, 26 support operations (HR management, technology development, and procurement), eight support the sales and marketing functions, and 10 support customer service functions. Since IFSO is a services organization, it is no surprise that none of the investments were inbound or outbound logistics projects.

Project	Investment / Project Name	Rejected	Discretionary vs. Statutory	Total Risk Score	Benefits-to-cost ratio (1…5)	Investment Sought (in Euros €)	Proposed Duration (months)
1	Centralised Management System		D	3.851	5	3,000,000	20
2	Direct Insurance Development		D	3.617	4	825,000	6
3	Enhanced Internal Management Processes		D	1.872	4	2,000,000	4
4	Cost Containment Project		D	2.894	5	1,300,000	9
5	Centralised Workflow Development		D	0.872	3	3,124,000	12
6	Enhanced Customer Value Proposition	+	D	1.617	1	100,000	2
7	Risk Assessment and Processing		D	1.957	5	1,100,000	10
8	Electronic Purchasing		D	4.702	5	6,600,000	12
9	Data Management and Training Programme		S	1.362	2	1,000,000	7
10	Automated Staff Overview System		D	5.766	5	400,000	6
11	Customer Insurance Protection Plan	+	D	1.809	5	307,000	11
12	e-Business Development		S	1.681	1	1,470,000	13
13	Income Management System		D	1.979	5	500,000	10
14	Electronic/Direct Insurance Initiative		D	4.915	3	1,600,000	15
15	Direct Insurance Development (I)		D	1.872	4	2,250,000	12
16	Direct Insurance Development (II)		D	2.128	3	642,000	9
17	Enhanced System Functionality		D	1.957	4	400,000	19
18	Risk/Reward Measure Project		S	2.298	1	715,000	20
19	Customer Service Enhancement Project		D	3.085	4	3,000,000	9
20	Direct Insurance Developments - Phase II		D	1.426	5	2,300,000	10
21	Policy Reconciliation System		S	2.255	1	550,000	9
22	Data Management & Sales Programme		D	1.468	3	630,000	11
23	Centralised Risk Assessment and Processing		D	2.128	5	294,000	4
24	Electronic Processing System		D	1.553	5	550,000	10
25	Systems Alignment (I)	+	D	4.170	3	600,000	11
26	Systems Alignment (II)		D	1.277	5	600,000	11
27	New Concept Policy		D	2.340	4	1,400,000	4
28	Core Software Upgrade		D	2.191	3	5,400,000	14
29	Centralised Processing Consolidation	+	D	1.319	2	200,000	6
30	New Types of Customer Policy		S	1.723	1	596,000	7
31	Consumer Choice Policy		S	1.723	1	596,000	7
32	Central Policy Database Automation		D	1.872	5	320,000	9
33	Replacement Electronic Premium		D	2.085	3	500,000	6
34	Customer App. Processing Development		S	1.702	1	542,000	9
35	Central Fraud Protection Project		D	1.106	5	1,300,000	4
36	Major System Upgrade		D	4.681	3	8,500,000	7
37	Enhanced Measurement Systems		D	1.468	4	4,500,000	20
38	Central Performance Measurement Project		D	2.277	5	1,500,000	12
39	Sales Project		D	2.319	4	120,000	2
40	Legal/Compliance Office Development		S	2.043	1	700,000	4
41	Centralised Process Efficiency Development		D	1.255	2	500,000	6
42	Electronic File Management System		D	1.468	3	1,250,000	24
43	New Personal Insurance Product		S	2.277	5	915,000	4
44	Data Assessment, Processing and Sales		D	1.213	4	596,000	12
45	Electronic Payments System	+	D	2.532	3	2,100,000	14
46	Electronic Insurance Developments		D	1.936	4	2,100,000	13
47	Direct Customer Service Initiative	+	D	1.277	1	284,000	7
48	New Type of Policy		S	1.128	1	1,000,000	4
49	Direct Payment System Development		D	1.872	4	2,000,000	11
50	Customer Policy Development	+	D	3.319	4	300,000	8
	Total	**7**	**33 / 10**				

Table B1: 50-projects sample with some of the relevant data collected

APPENDIX C: DATA COLLECTION QUESTIONNAIRE

The questionnaire used to collect data about risk mitigations was customized for each project based on the risks rated 10 in that project (see Figure C1 for an example). For each project, the risk indicators rated as 10 were copied into the questionnaire. During the interviews the interviewee was asked for each such risk an open-ended question: "How did the business case mitigate risk X in the target project?" Each questionnaire also included a last risk item labeled "others," aimed at collecting mitigations for all lower rated risks not explicitly listed in the questionnaire.

Program Name or Description	Electronic Purchasing (15.12.2000)	
Program Cost (in $)		
Program Benefits Level (1…5)		
Program Duration/ (in months)		
Program (Main) Risks	**Mitigation type**	**Explanation / Comments**
IT Maturity		
Programme Size		
Planning Guidelines		
QA		
Decision Making		
Impact on other areas		
Benefits Harvesting Approach		
Others*		

*Where there any other mitigations used for risks not listed in this questionnaire?

Figure C1: final data collection questionnaire (tailored for a specific project)

APPENDIX D: MAPPING RISK MITIGATIONS TO REAL OPTIONS

Available online at: http://whitman.syr.edu/facstaff/mbenaroc/PAPERS/risk-option/Appendix-D.pdf