A framework for applying real options analysis to information technology investments

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A framework for applying real options analysis to information technology investments

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Abstract: The selection and valuation of information technology (IT) investments are challenging as they usually have long durations and require significant amount of capital expenditure. Given the high uncertainty inherent in these investments, traditional tools are proven insufficient to identify the true values. On the other hand, real options analysis (ROA) is a powerful valuation tool that put emphasis on the 'real options' of projects. However, most IT managers do not have the necessary skills to carry ROA. In this paper, we give introduction of ROA and propose an easy-to-use framework for using ROA to value investment opportunities. In addition, we discuss common types of real options and describe a case study of deferral option in a real-world investment opportunity. This paper should serve as a good starting point for managers who want to put ROA into practice.

Keywords: real options; information technology; project management; project valuation.

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1 Introduction

Information technology (IT) investments are characterised by high uncertainty and irreversibility, mainly because of their unpredictable future pay-off, long duration, high switching, learning and adaptation costs. Some examples are investments in telecommunications IT infrastructure (Panayi and Trigeorgis, 1998), new product developments (Lint and Pennings, 2001), software platform selection (Taudes et al., 2000) and automated teller machine (ATM) banking network infrastructure (Benaroch and Kauffman, 1999, 2000). These strategic investments usually do not have immediate pay-off but open up future profitable opportunities. However, many IT projects are undertaken without a proper analysis. IT managers make their decision based on experienced intuition and tradition valuation tools, such as payback period, internal rate of return (IRR) and net present value (NPV). These static methods work best for situations with perfect certainty of future cash flows, but they do not take into account the value of managerial flexibilities, which refer to the ability to modify the strategy along the development of a project. Traditional methods are proven to have severely limited ability to correctly evaluate projects with high uncertainty. Therefore, managers usually undervalue strategic investments, which lead to suboptimal level of investment in the industry. A better quantitative method for projects with high uncertainty is highly desirable.

Real options analysis (ROA) has long been advocated in the literature to valuate highly uncertain projects. Real option is an analogue of financial option except the underlying financial asset is replaced by real asset. The framework utilises the option pricing theories from the finance literature and captures the option-like characteristics of IT investments. Put it in a simple way, ROA views the opportunity to invest in an IT project equivalent to a call option on the project, a real asset. This form of flexibility is what we refer to as an option to defer, which certainty have values. This important feature of ROA takes the value of managerial flexibilities into consideration. In real world situation, managers usually have discretion to start the investment and the ability to modify strategy as uncertainties unfold. Rational managers are supposed to start an investment at the right time and take necessary measures to maximise the values along the development of the project. This coincides with the ROA intuition that managers should limit downside risks and capture the upswings. Besides option to defer, there are other types of real options, such as option to expand, contract, switch, abandon and temporarily shut down operation, which we will go into detail.

ROA can also evaluate the efficiency of different options and gives better quantitative insights of risk mitigations. IT managers have been observed to misjudge the importance of different project risks, and hence pay greater attention to some risks at the expense of others (Schmidt et al., 2001). Under ROA, the cost and value of specific options can be identified. Managers can then actively embed real options into projects to keep a desire level of flexibility at affordable cost. The specific risks that are most worth controlling should dictate the choice of which real option to use. Benaroch et al. (2006) did an empirical research on option-based-risk management (OBRiM) that supports the existence of OBRiM's risk-option mapping. The OBRiM is a primitive framework that aims to control risks and determines the economically superior combination of real options for a project. Empirical evidence that supports this framework is one possible future research direction.

ROA seems to be a very capable tool. But there are several issues needed to be addressed when using ROA. First of all, limiting assumptions have to be made in the model. For example, we have to make assumption about future interest rate, volatility of project, duration and strike price of real options. Best estimates of these parameters are used in ROA. The estimation errors would inevitably inherit in the calculation, and hence affect the accuracy of the results. However, one very crucial point we want to stress is that, unlike option pricing in finance, ROA is not expected to give exact value of real options. It is used as a complementary model to other decision tools to give decision-makers a better idea of the big picture of the future. We believe ROA gives better estimate when future is highly uncertain. Secondly, ROA is not easy to use and a systematic model or procedure is yet to be developed. In fact, although many IT managers are applying the ROA logic in decision-making process, not many of them are aware of ROA research. Even if they have heard of real options, they usually find it too complicated to put it into practice and have no idea how to start. One main reason is that the skill set of IT managers does not include the finance knowledge needed to understand the terminology and theoretical issues in the analysis. Depending on which pricing model is being used, some procedures of ROA need sophisticated statistical skills like stochastic calculus. Nonetheless, making decisions based solely on intuition could lead to undesirable results. For this reason, we believe a systematic ROA should be used to support managerial intuition.

The purpose of this paper is to give a good introduction to ROA, from the very basic concepts to recent developments of the topic. It is written for IT managers with little finance knowledge, who want to know more about real options. We put our emphasis on the IT industry for several reasons. Firstly, IT investments are mainly strategic investments with high uncertainty and no immediate pay-off, which make them good candidates for application of ROA. Secondly, IT is a very important component in modern business world as globalisation continues with an increasing pace. Last but not the least, a more powerful valuation tool is needed for IT investments to avoid renaissance of technology bubble. People attribute the outrageous tech bubble in the end of the last century to the inability in calculating fair values of IT companies. This paper is a good starting point to understand and apply ROA. The paper tries to summarise the framework into an easy to use and practical tool that complements with other decision methods. We aim to bridge the gap between real options theory and practice.

The rest of this paper proceeds as follows. Section 2, gives a literature review of real options. Section 3, introduces the concept of ROA. A hypothetical investment example is discussed in Section 4. Section 5 summarises common types of real options. We then present a framework for using ROA in Section 6. Thereon, a case study in deferral option is discussed in Section 7. This paper concludes by emphasising the implications and limitations of ROA and identifying future research directions in Section 8.

2 Literature review

In the 1980s, early applications of real options focused on natural resource investments for two reasons. Similar to investments in IT, investments in natural resource are highly uncertain. The second reason was the existence of developed financial markets for forwards and futures on commodities. So parameters in the pricing models could be estimated from market values. These two reasons made real options framework a valuable tool for natural resource managers. Thereafter, real options have been applied to numerous areas that are inherently uncertain, including research & development, biotechnology, IT, new ventures and acquisitions, natural resources and foreign investment and strategy. Table 1 summarises papers on different areas. Similar tabulations can be found in Lander and Pinches (1998) and Miller and Park (2002).

Coy (1999) lists some real-world examples of real options. Hewlett-Packard has been using real options since the beginning of 1990s. It helps HP to effectively match supply to demand and balance the trade-off between component cost and flexibility. Intel Corp., and Toshiba Corp., use real options in their valuating process for licensing. Companies in Silicon Valley embrace real options because it encourages collaboration between companies. It helps Cadence Design Systems Inc., to set minimum price for licence of its electronic designs. According to Morin and Jarrell (2001), Merck & Co., analyses its R&D investments in a real options framework, which provides a proper valuation for the ability to abandon a research under high risk circumstances. Shell Oil's planning group uses ROA to analyse its capital projects and investment strategies. It uses timing options to model the optimal extraction time of a specific oil field.

Table 1 Real options literature by industry

Industry	*Article*
Information technology	Lankton and Luft (2008), Dai et al. (2007), Benaroch et al. (2006), Taudes et al. (2000), Benaroch and Kauffman (1999, 2000) and Panayi and Trigeorgis (1998)
Technology	Bobtcheff and Villeneuve (2010), Boer (2000), McGrath (1997) and Kumar (1996)
Biotechnology	Hartmann and Hassan (2006), Brach and Paxson (2001) and Kellogg and Charnes (2000)
Natural resources	Thompson et al. (2009), Kelly (1998), Smit (1997), Pickles and Smith (1993) and Brennan and Schwartz (1985)
Research & Development	Oriani and Sobrero (2008), Jensen and Warren (2001), Lee and Paxson (2001) and Herath and Park (1999)
Strategy	Mitchell and Hamilton (2007) and Bernardo and Chowdhry (2002)
Utility	Kumbaro-lu et al. (2008) and Rothwell (2006)

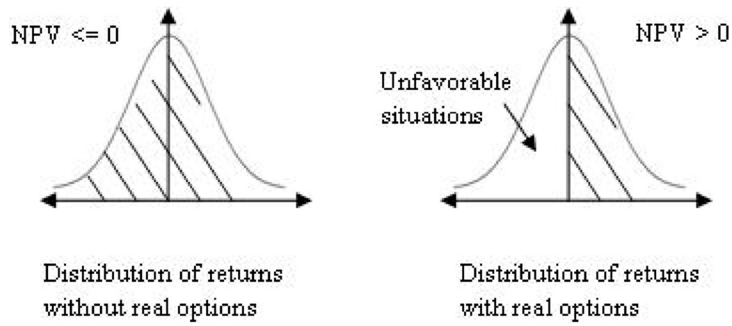
A large number of researches apply ROA to IT investment decision-making. For example, Taudes et al. (2000) discussed growth opportunity in software platform selection using ROA; Benaroch and Kauffman (1999, 2000) used the Black-Scholes model to evaluate Yankee 24's timing option; Tiwana et al. (2006) investigated different types of real options in software development; Benaroch et al. (2007) proposed an option-based risk management framework to evaluate real-world sequential IT investments; Chulkov and Desai (2008) applied option models to the issue of escalation in the development of IT projects; Wu and Ong (2008) developed a framework based on ROA and mean-variance theory to manage IT investments; and Chen et al. (2009) proposed an integrated real options model for IT projects with multiple risks.

3 Concept of real options

The term 'real options' was first used by Myers (1977). Since then researches on real options have been exploded. This branch of options was coined 'real' because their pay-offs are based on real assets, such as oil fields, mines, R&D projects and technology licences. Very different from financial options, real options are not explicitly stated as a contract or publicly traded. There is no underwriter for real options. It capitalises the idea of option thinking so that derivatives theories can be utilised to evaluate such opportunities. This logic corresponds to the real-world practice of limiting downside risks while capturing upside potentials.

For a project with normally distributed returns, Figure 1 shows how real options impact the valuation. For another example, assume a firm is deciding whether or not to invest in a new project. This opportunity gives the firm the right, but no obligation, to pay an initial investment cost and receive the future benefits of the project. This is analogous to financial call options with strike price and underlying asset replaced by initial cost and the project, respectively. This principle can be extended to many managerial decision-making situations and open up a whole range of applications of real options.

Figure 1 Distributions of returns of a project



An efficient financial market is assumed to have no persisting arbitrary opportunity. Under this assumption, the cost of buying a financial option is identical to the benefit it delivers. The situation is very different in real options. Since real options are not traded in the market, the cost of creating a real option may be very different from its benefit. For example, actively embedding a change of scale option creates value as the cost is substantially less than the value of flexibility it provides. ROA can help decision-makers to quantify and compare the value creation of embedding different combinations of real options. The costs of creating real options are usually project specific and the estimation is relatively certain. In this way, project values can be significantly increased by taking advantage of embedding the appropriate real options. Benaroch et al. (2006) discuss an option-based risk management framework for risk control and value maximisation in IT investment decisions. Benaroch (2002) discusses how to actively embed real options into IT investments and presents an approach for optimally control the balance between risks and rewards.

4 Hypothetical investment example

4.1 Background information

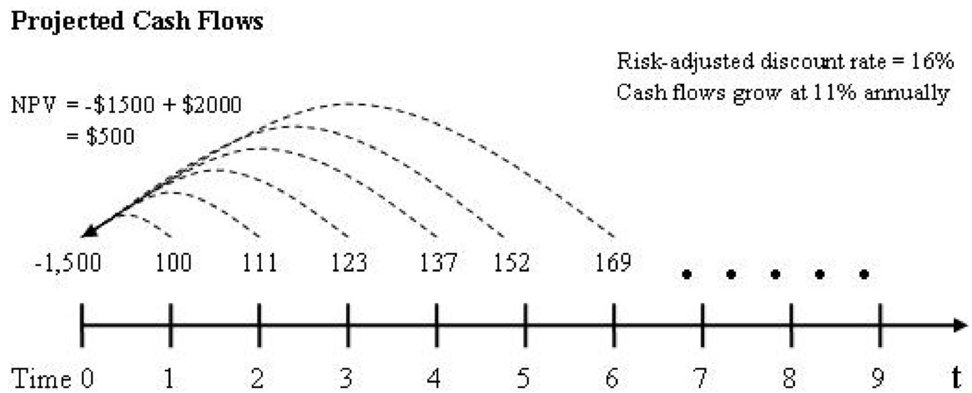
We now consider a hypothetical investment decision example, which demonstrates the values of real options and the deficiencies of net-present-value (NPV) analysis. Suppose a firm is having an opportunity to invest in a software development project and decision has to be made in two years. The project has an initial cost of \$1500 and is expected to earn an infinite stream of cash flows every year starting one year after investment. Cash flows are estimated to be \$100 in the first year and grow annually at a rate of 11%. Assume the volatility σ and the beta β of the project is 50% and 1.5. The risk-free rate r is 4%, and the market risk premium p is 8%.

4.2 NPV valuation

We first perform a simple NPV analysis. Using the capital asset pricing model (CAPM), the risk-adjusted discount rate for this project is $\beta \times p + r = 16\%$. Then the perpetual growing annuity is a geometric series with expected present value of \$2000. So the NPV is \$2000 − \$1500 = \$500. Figure 2 shows the cash flows of the project in a time line.

The decision rule of NPV tells us to accept the project if and only if NPV is positive and exceed the NPV of all mutually exclusive alternatives. In this example, two commonly neglected alternatives are investing next year and investing two years from now. The conventional approach to determine the optimal time of investing is comparing the opportunity costs of investment. If the firm invests next year, it saves the interest of the initial cost of \$1500 × 4% = \$60 and forgoes the first year cash flow of \$100. So the firm loses \$40 for waiting for one year. This is even worse for investing two years later. Therefore, considering the trade-off between interest saved and profit forgone, the firm should invest in this project immediately. This analysis, however, does not take into account the volatility and the insurance value entailed in this opportunity.

Figure 2 Projected cash flows of the project



4.3 Black-Scholes model valuation

In the logic of real options, the firm is having a two-year American call option on the project with the initial cost being the strike price. Decision can be made anytime before the option expired with no obligation. This is a deferral option in real options terminology. We first use the more straightforward approach, the Black-Scholes model, to calculate the option value. Even though the Black-Scholes formula is only applicable to European options, it still provides an insightful lower-bound value. The price of the underlying asset is equal to the present value of the project, \$2000. Since the cash flow would be \$100 if the project is developed, the continuous dividend yield is ln(1 + \$100/\$2000) = 4.879%. Plugging in the required variables into the Black-Scholes formula, the option value is \$686, which is 37% higher than the NPV.

4.4 Binomial model valuation

In the third approach, we are going to demonstrate the binomial model. The first step is to construct a binomial tree with two one-year period for the evolution of initial project cash flow. This implies the only variable in this example is the initial cash flow. Other assumptions like the growth rate and volatility are deterministic. So the present value of the project is just initial cash flow times an annuity factor of 1/(0.16 – 0.11) = 20. If the firm decides not to invest this year, the initial cash flow after one year will be either \$100 × exp(0.5) = \$164.87 or \$100 × exp(–0.5) = \$60.65. If the firm waits until expiry of the option, the initial cash flow will be \$100 × exp(0.5 + 0.5) = \$271.83, \$100 × exp(0.5 − 0.5) = \$ 100, or \$100 × exp(–0.5 − 0.5) = \$ 36.79. These numbers give us the binomial tree in Figure 3. Since it is not practical to replicate the pay-off of the project, the next step would be calculating the risk-neutral probabilities across the binomial tree. As a logical matter for real options, this only results in a fair price but not no-arbitrage price. Solving the equation $100 \times (1 + r)/(1 + \delta) = 164.87 \times p + 60.65 \times (1 - p)$, where p is the risk-neutral probability of moving up, $r = 4\%$ is the risk-free rate, and $\delta = 100/2000 = 5\%$ is the dividend yield, we found that $p = 0.3684$. Then we work backward through the tree and check for optimal decision by comparing intrinsic value and holding value. The results are shown in Figure 4, where the bolded value means early exercise is optimal at that note. The option value in CRR model is 787, about 50% higher than the NPV. Notice that the call option protects the firm from downside risk. If the project turns out to be unprofitable (node C and F), the firm will not exercise its option. This explains the discrepancy between NPV and option value. The moral of this example is that managerial flexibility creates values, especially for high-volatility projects.

Figure 3 Binomial trees and parameters for the hypothetical project

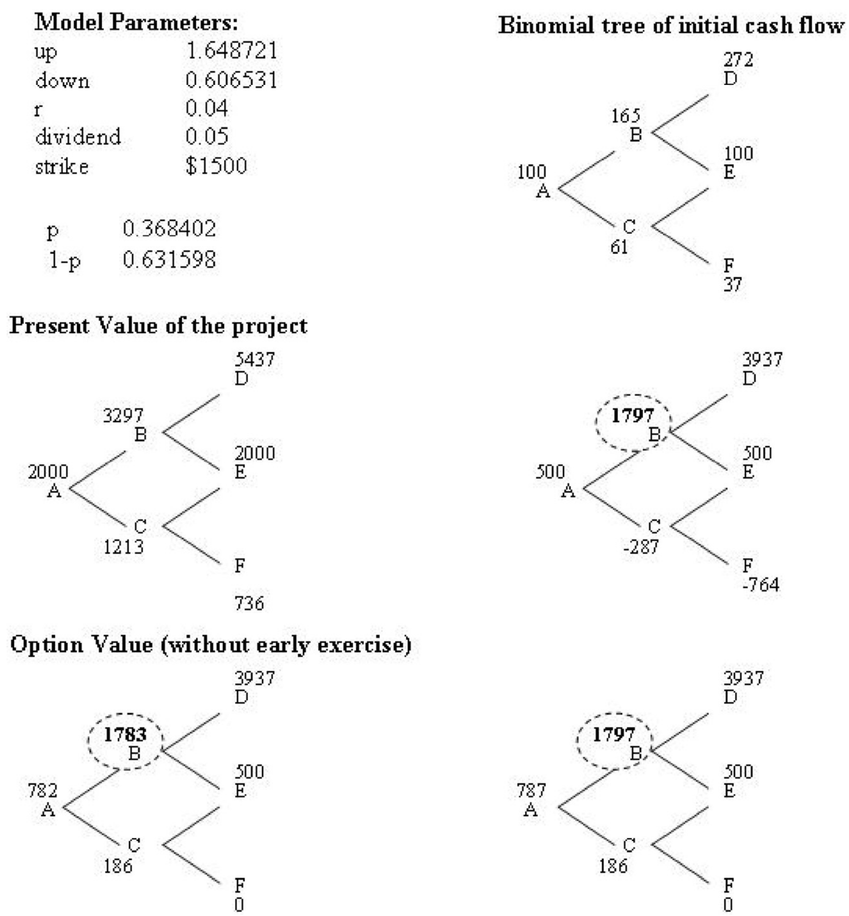
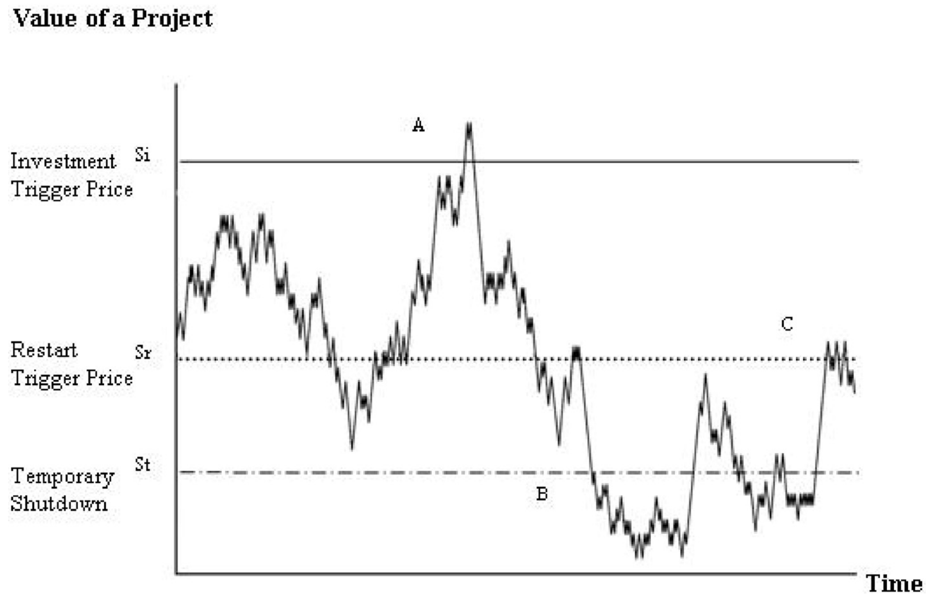


Figure 4 Simulated value of a project



The binomial approach is widely used in practice because of its flexibility and the ability to adapt to wide variety of assumptions and limitations. The tree shows clearly the evolution of cash flows. However, it is very important to keep in mind that the binomial model does not consist of any forecasting power or speculating component. Based on current information of the underlying asset and the market, the valuation gives a fair price of an investment. The model takes advantage of the risk-neutral probability that cash flows can be discounted at the risk-free rate instead of a set of varying risk-adjusted rates. ROA delivers a market based and objective quantification of project risk and uncertainty.

The above simplified example shows how managerial flexibilities create values. Besides deferral option, there are other types of real options, like abandonment options, expansion options, contraction options and strategic options. In practice, a typical investment opportunity usually inherits several standard real options. According to firm goals and risk preference, some real options are more valuable than others.

5 Common types of real options

5.1 Deferral options

Investment opportunities are not likely to be now-or-never. Managers are responsible to decide whether and when to invest, which constitute a deferral option. In other words, managers have to solve the timing problem of investment. Deferral option is like an American call option with initial investment cost being the strike price and the project being the underlying asset.

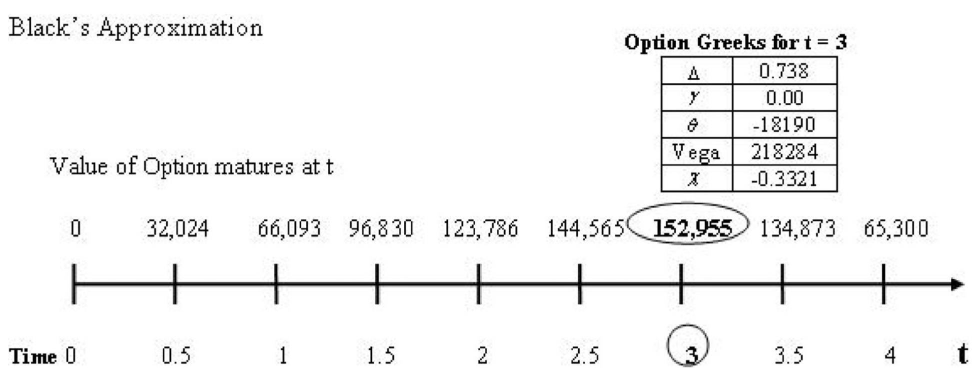
5.2 Expansion options and contraction options

In general, uncertainties reduce overtime. If the size of investment can be expanded or contracted at managers' discretion according to new information, then there exists an expansion and/or contraction option. An expansion option is like an American call option with expansion cost being the strike price and the additional capacity being the underlying asset. A contraction option is like an American put option with contraction cost being the strike price and terminating portion of investment being the underlying asset.

5.3 Abandonment options and temporary shutdown and restart options

The ability to permanently abandon a project before the end of its expected lifespan is an abandonment option. This protects a firm from further losses when the project turns out to be unprofitable. Abandonment option is like an American put option with the entire project being the underlying asset and salvage value minus closing down costs being the strike price. Examples can be found in technology researches. When new technology emerges, values of ongoing researches on obsolete technologies are drastically depreciated. On the other hand, it is common to have projects that are possible to be temporarily suspended and restarted later with certain costs. This property creates a temporary shutdown and restart option. This is like a series of options that one option is acquired following the execution or expiration of the previous option. When we exercise a put option to temporary shutdown a project, future losses are avoided but a call option on future profit is also acquired. Figure 5 shows a sample evolution of project value, where Si, St, Sr are investment trigger, temporary shutdown trigger and restart trigger price, respectively. These prices are instructive in making decision and closely related to volatility of the project. For instance, shutdown trigger price will be lower for highly uncertain projects since probability and magnitude of value appreciation is higher.

Figure 5 Option values for black's approximation



5.4 Strategic options (growth options)

Some projects do not set short-term profit as their primary goal. These projects aim to develop future opportunities and will open new avenues for growth if successful. Research and development projects in pharmaceutical and new technology are two examples. In order to remain competitive in the industry, research projects are usually prerequisite for potential opportunities. Lager number of researches gives firms exclusive advantage to elaborate successful projects. Value of research projects indeed comes heavily from the attached growth options. Growth options are like compound options, which take another option as underlying asset.

5.5 Flexible options

Flexible options allow firms to accept flexible inputs, produce a range of outputs and utilise different production technologies. Although this option is more about productions and operations, it can be actively embedded at the designing stage of a project. This option protects firm from being over dependent on specific inputs, outputs or production technologies. It is analogous to rainbow option, which has multiple underlying assets. Abdel-Malek et al. (2006) defines different types of flexibilities and optimises the selection of equipments in manufacturing. Even though they didn't mention real options explicitly, they indeed put a large emphasis on the value of flexibility. Rao (2009) proposed a systematic method to guide the selection of flexible manufacturing system (FMS), which also takes into account the value of flexibility in manufacturing.

6 A framework for ROA

In our opinion, the hesitation and reluctance of using ROA can be attributed to the technical complexity and ambiguity of the analysis. It is not straight forward even for managers familiar with financial options. In Block (2007), Fortune 1000 companies were surveyed. Only 40 out of the 279 respondents (14.3%) were using real options in their capital budgeting process. This number was improved comparing to previous studies, although real options remains as a minority method. The 40 ROA users were concentrated on industries, such as technology, energy and utilities, for which managers are conceivably having strong engineering or technology backgrounds. Some of the reported reasons for not using real options consist of lacking top management support, discounted cash flow being a proven method, and requiring excessive sophistication.

It has long been reiterated by real options' researchers, such as Dixit and Pindyck (1994), Trigeorgis and Schwartz (2004) and Kogut and Kulatilaka (2004), which traditional methods like NPV do not adequately address the values of flexibility. On the contrary, conservative managers argue that ROA encourages extensive risk taking. Indeed, both arguments have grounds. To bridge the discrepancy, we believe it is academia's responsibility to resolve practitioners' hesitation and propose a well-structured real options framework that is transparent and easy to communicate. Once managers understand the valuation of risk, they will be more comfortable to incorporate option thinking in their decision-making process and real option is no longer a black box. In what follows, we are going to present a preliminary ROA framework with general procedures and guidelines that can be implemented step-by-step.

6.1 Preliminary preparations

As we mentioned in previous paragraphs, ROA is a complementary tool to other decision methods. It specialises in evaluating high-uncertainty projects. So, the first step is to assess the level of uncertainty for a given project. Lint and Pennings (2001) suggested that projects can be assigned to one of the four categories, depending on two variables, project's expected returns and level of volatility.

Category A: projects with positive expected returns and low volatility. Traditional NPV rules adequately reflect the values of these relatively ideal projects. These projects should be activated as soon as they are identified.

Category B: projects with negative expected returns and low volatility. Prospect of these projects are doomed. Traditional NPV rules are applied and usually lead to rejection.

Category C: projects with positive expected returns and high volatility. This is a typical situation for today's investments in technology, where options values significantly impact project values. ROA should be performed to determine the optimal strategy.

Category D: projects with negative expected returns and high volatility. These are marginal projects that need closer examination. Postponement is likely to be the best strategy before uncertainty unfolds. ROA is used to capture favourable turns as new information arrived. A huge number of projects belong to this category but not many of them can make their way to implementation.

In short, only projects in category C and D need ROA. The static NPV is performed anyhow to give a rough benchmark of project values. Postponed projects are reviewed constantly to incorporate new information. Courtney et al. (1997) state that the old one-size-fits-all valuation methods are simply inadequate. They classify projects into four levels of uncertainty, namely clear enough future, alternate futures, range of futures and true ambiguity. According to risk level of a project, proper analysis is performed. Based on company's goals and risk preference, a dynamic portfolio of projects can then be built.

6.2 Identify real options

For projects that need ROA, the next step is to identify all the presumably attached and meaningful real options. Scenario analysis and candid discussion of project risk are vey useful in searching for real options. It is not uncommon to see a project that has more than several real options. Managers can start from standard real options, i.e. deferral and abandonment options, to more project-specific options, i.e. growth options. Unfortunately, values of real options are not linearly additive. That means, for example, the total value a deferral option and an abandonment option is not equal to the sum of the individual options values. The complex interaction between options makes additional options less valuable as the protection of downside risks may overlap. So instead of addressing all the recognised real options, a better approach is to isolate one or two real options that appear to be most significant. These options are usually associated to the most uncertain areas of the project. This step requires professional judgement and experience, but can reduce estimation complexity dramatically. ROA does not mean to provide an exact price for options like financial options models do. It is intent to address the ignored value of flexibility while not overly complicate the valuation process.

6.3 Choose the right valuation model

After identifying the targeted real options, the next question is choosing the right valuation model to quantify those flexibilities. The survey by Block (2007) found that binomial model, risk-adjusted decision trees, Monte Carlo simulation and Black-Scholes model are the four most prevailing valuation approaches. Among the surveyed real options users, 40% are using binomial model and 30% are using risk-adjusted decision trees. Surprisingly, less than 3% of the users use Black-Scholes model. Even though Black-Scholes model comes down to a convenient closed-form formula, the six variables it requires are not readily discernable in the case of real options. Expiration and dividend yield are two examples that pose problems. Decision-makings are seldom to be confined on a specific date as required by the Black-Scholes model. Nonetheless, the Black-Scholes model certainly gives a quick heuristic reference for option values with manageable additional effort.

The popular binomial model indeed has a number of favourable properties. It can be customised to adapt different business situations like complex exercising scheme. The model is easy to present and communicate. As long as the binomial tree is clearly depicted, senior management should have no problem in understanding the model. The simple assumption about evolution of prices, the recombining property and fixed risk-free discount rate make the math less formidable than other approaches. All in all, binomial model is probably the best model to begin with.

Although the risk-adjusted decision tree method is apparently similar to the binomial model, there is conceptual difference between them. Unlike standard binomial trees, decision trees are not recombining. That implies number of nodes at terminal time grows exponentially with number of periods. The unsystematic evolution of nodes makes valuation project specific, and hence generalisation becomes infeasible. More importantly, the risk-adjusted process consists of replication of risk at every node, which, if not impossible, is time consuming and involves sophisticated judgement. This method is not recommended for new users.

Monte Carlo simulation, to a certain extent, is like a black box as well. The simulation process itself is programming intensive. The model requires rigorous assumption about probability distribution of project outcome. Credibility of the simulated outcomes is difficult to verify.

To sum up, one or several methods can be adopted to quantify option value according to managers' preference, project characteristic, company culture, etc. For companies that already have sophisticated quantitative analysis in place, binomial model or Black-Scholes model may be appropriate. If conservative senior managers hesitate about using ROA for some reasons, then risk-adjusted decision tree should be able to provide sufficient transparency. The bottom line is managers who are evaluating real options should understand the strengths, weaknesses and implications of the model and be comfortable to explain and deliver the results. These models are by no means a perfect tool, but it represents the effort to correctly assess the otherwise ignored value of managerial flexibility.

6.4 Collect information

After appropriate model is selected, managers should have a clearer idea of what kind of information is necessary. The six basic variables of financial options including underlying asset, volatility, exercise price, expiration, interest rate and dividends are also crucial in real options. In financial options, most of these variables are observable and deterministic. In real options, these variables may appear as different forms and extra effort is needed to retrieve them.

6.4.1 Underlying asset

Real assets include a wide variety of assets, from petroleum reserve to technology licence. The non-tradability of these assets is always criticised. Critics argue that using OPM on real options is inappropriate because of the assumption of efficient market for underlying asset. It is true that replicating portfolio is not always possible in real options. However, the fair prices of real asset can be observed or estimated by other means with satisfactory accuracy. For example, the value of an undeveloped oil field can be estimated base on the future market of cruel oil. Value of a new technology project can be replicated by similar project in the past or companies that concentrate on similar projects. The traditional NPV process also gives good estimation on project value without optionality. Mason and Merton (1984) and Copeland and Antikarov (2005) claim that the present value of real asset is the best unbiased estimate of its market value. Again, we are focusing on fair price but not no-arbitrage price of real options.

6.4.2 Volatility

While somewhat abstract, volatility is a crucial variable in option pricing. It represents the best estimate of level of uncertainty. The historical volatility approach is simply not plausible for many real assets. Other common approaches include Monte Carlo simulation, twin security argument and implied volatility. Herath and Park (2002) use a simulation approach in their case study of multi-stage investments. If portfolio with high correlation to the real asset can be found, then the price of this portfolio implies the market valuation of volatility. Volatility of the correlated real asset can then be derived. Kelly (1998) valuates a mining property IPO by using the information from the futures market. In general, managers may utilise their experience and knowledge to give a fair estimate of volatility. But a common criticism is that volatility can be manipulated to achieve desired results to support specific decision. Managers have to base their estimation on solid and conservative grounds or the entire analysis would be unconvincing.

6.4.3 Strike price

Exercise price in real options refers to the cash outlay or inflow from exercising the option. It can be the cost of initiating a project, the residual value of terminating a research, the cost of expensing or the investment cost of follow-up projects. Although these costs may be one lump sum or sequential, they can always be represented as present value terms. Binomial model, in practical, is flexible enough to take care of different situations. Specific exercising criteria can be set at each node of the tree. Exercise price is relatively certain and usually has a direct one-to-one impact on option value since it is subtracted directly from benefit of the option.

6.4.4 Time to maturity

Most real options do not have specific expiration date. Instead, it is an approximate range of time that decision should be made. In fact, it is rather arbitrary. Since it is generally long in duration, minor variation of expiration does not affect option value much. But it may change during the course of project depending on business condition, exercise of other real options, competition, technology, etc. Experienced managers should be able to estimate appropriate time frame for real options. To better manage options, check points should be set along the way. Review of exercise criteria and decision-making should be carried mandatory at each checkpoint. Waiting for another period for more information can be a decision but procrastination is not. Again, the binomial model is able to handle different situations.

6.4.5 Discount rate

In traditional NPV, cash flows are discounted at risk-adjusted interest rate, because higher risk should be compensated by higher return. In option pricing, the assumptions of the existence of a replicating portfolio and risk neutral probability allow discounting cash flows at the risk-free interest rate. This rate is readily observable in the market at all time. The situation is a bit different in real options. Researchers argue that the non-tradability of real assets implies that unsystematic risk could not be reduced through diversification. Therefore, a higher discount rate should be used. Hull and White (2009) state a five-variable relationship for choosing the discount rate. But that allegation would lead us back to the risk-adjusted rate problem. In our point of view, risk-free interest rate should be used in the valuation because of four reasons:

1 uncertainty or risk of the underlying asset can be addressed by the stochastic elements in the analysis

2 risk-free interest rate is shifting overtime

3 real assets can be reasonably treated as tradable

4 estimating risk-adjusted rate will excessively complicate the analysis.

6.4.6 Dividends

Information regarding dividends is difficult to collect since it involves correctly estimating the future pay-offs of underlying asset. As holders of real options do not have possession of the underlying asset, they forgo any capital gain of the asset. Dividends in real options are usually unknown in advance and may change because of unexpected change in market environment. It may appear as different forms like cash payouts, potential profits and licence fee. The uncertainty inherited from inputs make estimation of dividends inevitably uncertain. Davis (1998) considers dividend yield problem for options to invest or abandon. As a rule of thumb, managers should focus only on currently available information to derive the best estimate of dividends.

6.5 Manage the real options

In order to fully capitalise the value of embedded real options, continuous monitoring and rigorous management are of great importance. Expiry and decision rule are usually ambiguous in real options. Therefore, exercising strategy and triggering criteria should be defined during the valuation process. Triggering criteria can be the passage of specific time period (like financial options), the touch of some hurdle prices of inputs, or the occurrence of specific events like the emergence of new competitors. This requires constant tracking of uncertain factors. Exercising strategy should succinctly state the corresponding measures for each and every evolution that are considered in the valuation. Fichman et al. (2005) provide useful guidelines for real options management. They suggest that explicit options checkpoints and milestones should be located at the outset. At each checkpoint, updated information is incorporated into the model for re-evaluation. Expectations are matched with actual realisations. Predefined action is triggered whenever criteria are met.

The two types of real options, calls and puts, encounter different management difficulties. A field study by Tiwana et al. (2006) finds that IT managers tend to overvalue real call options and undervalue real put options. The bias may be explained by the perception that calls, which have the function of increasing the potential gains, are easier to exercise, while puts, which provide protection for unfavourable turns, are more difficult to exercise in practice. In reality, terminating a project or abandon an investment is naturally painful as managers escalate commitment throughout the development of a project. Sometimes, it is equivalent to admitting team deficiencies. As company initiates more high-risk-high-reward projects, correct termination may be the key to contain further losses. So cultural education may be necessary for a disciplined exercise performance. Troubled projects should be terminated decisively as long as predetermined unfavourable outcome is recognised. The authors also suggest that exercise decisions should be tracked and proper options management must be rewarded with some combination of compensation, increased responsibility and public recognition.

7 Case study: the deferral options

Deferral options refer to the flexibility of whether and when to proceed with an investment opportunity. In general, every investment opportunity possesses certain degree of deferral option. It is not common to see now-or-never type of investments in practice. With option to delay, the decision is then about determining the optimal timing to maximise the value of investment within the duration of the option. It can be found by comparing the potential benefits and costs of delaying the investment. Benefits come from the fact that uncertainties generally reduce overtime. If the investment turns out to be unprofitable, firms can abandon it with limited cost. This flexibility allows firms to participate in the potential upswing, while control the downside probability. Costs include the forgone revenue and potential erosion of market share. Competitors may take the first-mover advantage, and hence capture a major portion of the market share. So decision-makers have to strike the balance between the competing factors.

7.1 Case in electronic banking network investment opportunity

A notable application of deferral options analysis comes from Benaroch and Kauffman (1999, 2000). The paper is among the first attempts to apply options analysis to real-world business situation. Yankee 24 was an electronic banking network services company, which provided ATM services in New England, USA. It was having an exclusive opportunity to enter the point-of-sale (POS) debit services market at that time. The POS market was anticipated to be fast growing with enormous revenue. Management realised that they had an option to wait for at least four years without imperiling the potential benefits, since no foreseeable competitor could match Yankee's infrastructure and network in near terms. However, there were several uncertainties that made immediate roll-out questionable. Firstly, consumer acceptance and retailer adoption rates were uncertain. These numbers could severely impact the growth of POS market. Secondly, the current regulations of the state of Massachusetts discouraged nonbanking business to adopt POS system. It was reasonable to assume that the regulations would be revised in the long run, if POS system became the next industry standard. Third, the infrastructure and network resources of Yankee were not sufficient to support the POS system at the time. Immediate roll-out required large system constructing cost that was not easy to justify. In fact, much of these uncertainties could be resolved by simply waiting. The acceptance rates of consumer and retailer could be better estimated by looking at the experience of POS market in other states like California. The initial costs would be better justified by learning more about the potential returns of the market. Yankee could also take actions to lower the risks and elicit variables during deferral. For example, it could lobby for change in the regulations in Massachusetts and initiate campaign to promote POS system. On the other hand, major costs for waiting were the forgone revenues and the potential loss of market share. Taking all of these factors into account, management thought that the best timing for entry was three years later. Although the logic of option thinking was clearly used, this conclusion was based solely on intuition and experience.

The authors then modelled this opportunity as a four-year American call option using the Black's approximation model. This is a procedural model that utilises the Black-Scholes formula to approximate the value of American options. The size of New England market was assumed to be 25% of the California market. Other variable were obtained by interviews with senior managers. The model indicated that the value of deferral options reached its maximum of $152,955 at year three, contrary to the minus $80,000 NPV for immediate roll-out. So the optimal deferral time was three years, coincided with managerial intuition. The option Greeks for sensitivity analysis was also calculated to support the results.

In fact, Yankee did defer entry for three years and believed it was just about optimal. Dramatic growth in the POS market was observed after investment. POS debit terminals of Yankee grew from zero to about 27,000 in just four years. This example shows how options-based analysis can help finding the optimal timing for investment. When using deferral option analysis, practitioners should beware that the results are the best estimate based only on current information with stringent assumptions. When business conditions change, the model should be modified to incorporate new information.

8 Conclusion and future research

In the realm of IT, ROA is especially applicable to quantify the option values for complex, strategic or innovative investments. Some examples are IT infrastructure investments, emerging technology investments, application design prototyping investments and technology-as-product investments. Values of these investments are highly uncertain and contingent on future growth. The IT managers realise that traditional approaches inevitably undervalue these opportunities as they do not take into account the contribution of managerial flexibilities and active management. Decisions on these investments are guided merely by experience and intuition. In most cases, managers incorporate option thinking into their decision process, qualitatively. The lack of proper background knowledge makes IT professionals hesitate about using real options. This paper introduces real options from an elementary perspective for IT practitioners who are looking for valuation tool that matches with their intuition. General guidelines and considerations for applying ROA are discussed. A step-by-step preliminary framework for ROA is proposed. Three case studies of commonly seen real options are then provided to demonstrate how ROA works in practice. Indeed, applying ROA poses no greater difficulties than traditional approaches in terms of information, labour and knowledge requirements. However, it does require managers to embrace a new perspective. The fundamental principle of ROA appreciates the combination of uncertainty and flexibility, which is consistent with the logic of active management. It defies the traditional rule of thumbs that both high uncertainty and long duration reduce investment values. Hence, cultural education that promotes principles of ROA and option thinking across the company is equally important as calculating the value of options.

In fact, ROA is still in a developing stage. Valuations rely mainly on financial options pricing models. In reality, the direct application of OPM does not address problems and technical details that are unique to real options. For example, price of real assets might go below zero, real assets are usually non-tradable, and expiry dates can be uncertain. Therefore, deriving standard valuation procedure and custom-built pricing model for different real options are expected to be major future research directions. To conclude, we list several essential issues in ROA that need further investigation.

Problems in control and management of real options do not receive deserved attention in the literature. One major problem is the lack of straightforward way to evaluate the accuracy of ROA. No matter how the future evolves, actual real-world realisation is just one scenario in the probability distribution of the outcome. So management of real options becomes the key to exploit embedded option values. This requires continuous monitoring, constant revaluation and precise exercise. Similarly, it is no easy task to measure the performance of managers. A post-analysis valuation method is yet to be developed. We believe this is important for producing empirical evidences that support the adoption of ROA.

Risk management is another potential area for ROA application. Total risk of a portfolio of IT projects can be gauged by ROA according to the risk preference. In this case, ROA is used in a similar fashion as implied volatility. Risks of each project are calculated and compared. Specific risk can be mitigated by creating corresponding real options. Projects are then structured and selected based on company's risk preference. Managers can maintain the total risk at desire level. This preliminary concept utilises the idea from CPAM that only projects with desired risk and return trade-off are selected.

A number of issues are also particularly interesting, including sensitivity tests for real options, real options with multiple source of uncertainties, and volatility expression of real assets. We believe ROA with option thinking is a promising tool and will become the next industry standard for IT researchers and practitioners.

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References

Abdel-Malek, L.L., Areeratchakul, N. and Otegbeye, M.K. (2006) 'Designing for manufacturing flexibility: a newsvendor approach', *Int. J. Industrial and Systems Engineering*, Vol. 1, Nos. 1/2, pp.201–220.

Benaroch, M. (2002) 'Managing information technology investment risk: a real options perspective', *Journal of Management Information Systems*, Vol. 19, No. 2, pp.43–84.

Benaroch, M. and Kauffman, R.J. (1999) 'A case for using real options pricing analysis to evaluate information technology project investments', *Information Systems Research*, Vol. 10, No. 1, p.70.

Benaroch, M. and Kauffman, R.J. (2000) 'Justifying electronic banking network expansion using real options analysis', *MIS Quarterly*, Vol. 24, No. 2, pp.197–225.

Benaroch, M., Lichtenstein, Y. and Robinson, K. (2006) 'Real options in information technology risk management: an empirical validation of risk-option relationships', *MIS Quarterly*, Vol. 30, No. 4, p.827.

Bernardo, A.E. and Chowdhry, B. (2002) 'Resources, real options, and corporate strategy', *Journal of Financial Economics*, Vol. 63, No. 1, p.211.

Block, S. (2007) 'Are "real options" actually used in the real world?' *The Engineering Economist*, Vol. 52, No. 3, p.255.

Bobtcheff, C. and Villeneuve, S. (2010) 'Technology choice under several uncertainty sources', *European Journal of Operational Research*, Vol. 206, No. 3, p.586.

Boer, F.P. (2000) 'Valuation of technology using "real options"', *Research Technology Management*, Vol. 43, No. 4, p.26.

Brach, M.A. and Paxson, D.A. (2001) 'A gene to drug venture: poisson options analysis', *R & D Management*, Vol. 31, No. 2, p.203.

Brennan, M.J. and Schwartz, E.S. (1985) 'Evaluating natural resource investments', *The Journal of Business*, Vol. 58, No. 2, p.135.

Chen, T., Zhang, J. and Lai, K. (2009) 'An integrated real options evaluating model for information technology projects under multiple risks', *Int. J. Project Management*, Vol. 27, No. 8, p.776.

Chulkov, D.V. and Desai, M.S. (2008) 'Escalation and premature termination in MIS projects: the role of real options', *Information Management and Computer Security*, Vol. 16, No. 4, p.324.

Copeland, T.E. and Antikarov, V. (2005) 'Real options: meeting the Georgetown challenge', *The Bank of America Journal of Applied Corporate Finance*, Vol. 17, No. 2, p.32.

Courtney, H., Kirkland, J. and Viguerie, P. (1997) 'Strategy under uncertainty', *Harvard Business Review*, Vol. 75, No. 6, p.66.

Coy, P. (1999) 'Exploiting uncertainty: the real-options revolution in decision making', *Business Week*, No. 3632, p.118.

Dai, Q., Kauffman, R.J. and March, S.T. (2007) 'Valuing information technology infrastructures: a growth options approach', *Information Technology and Management*, Vol. 8, No. 1, p.1.

Davis, G.A. (1998) 'Estimating volatility and dividend yield when valuing real options to invest or abandon', *Quarterly Review of Economics and Finance*, Vol. 38, p.725.

Dixit, A.K. and Pindyck, R.S. (1994) *Investment under Uncertainty*, Princeton: Princeton University Press.

Fichman, R.G., Keil, M. and Tiwana, A. (2005) 'Beyond valuation: "options thinking" in it project management', *California Management Review*, Vol. 47, No. 2, p.74.

Hartmann, M. and Hassan, A. (2006) 'Application of real options analysis for pharmaceutical R&D project valuation – empirical results from a survey', *Research Policy*, Vol. 35, No. 3, p.343.

Herath, H.S.B. and Park, C.S. (1999) 'Economic analysis of R&D projects: an options approach', *The Engineering Economist*, Vol. 44, No. 1, p.1.

Herath, H.S.B. and Park, C.S. (2002) 'Multi-stage capital investment opportunities as compound real options', *The Engineering Economist*, Vol. 47, No. 1, p.1.

Hull, J. and White, A. (2009) 'An overview of contingent claims pricing', *Canadian Journal of Administrative Sciences*, Vol. 5, No. 3, pp.55–61.

Jensen, K. and Warren, P. (2001) 'The use of options theory to value research in the service sector', *R&D Management*, Vol. 31, No. 2, p.173.

Kellogg, D. and Charnes, J.M. (2000) 'Real-options valuation for a biotechnology company', *Financial Analysts Journal*, Vol. 56, No. 3, p.76.

Kelly, S. (1998) 'A binomial lattice approach for valuing a mining property IPO', *Quarterly Review of Economics and Finance*, Vol. 38, p.693.

Kogut, B. and Kulatilaka, N. (2004) 'Response: real options pricing and organizations: the contingent risks of extended theoretical domains', *Academy of Management the Academy of Management Review*, Vol. 29, No. 1, p.102.

Kumar, R.L. (1996) 'A note on project risk and option values of investments in information technologies', *Journal of Management Information Systems*, Vol. 13, No. 1, p.187.

Kumbaro-lu, G., Madlener, R. and Demirel, M. (2008) 'A real options evaluation model for the diffusion prospects of new renewable power generation technologies', *Energy Economics*, Vol. 30, No. 4, p.1882.

Lander, D.M. and Pinches, G.E. (1998) 'Challenges to the practical implementation of modeling and valuing real options', *Quarterly Review of Economics and Finance*, Vol. 38, p.537.

Lankton, N. and Luft, J. (2008) 'Uncertainty and industry structure effects on managerial intuition about information technology real options', *Journal of Management Information Systems*, Vol. 25, No. 2, pp.203–240.

Lee, J. and Paxson, D.A. (2001) 'Valuation of R&D real American sequential exchange options', *R&D Management*, Vol. 31, No. 2, p.191.

Lint, O. and Pennings, E. (2001) 'An option approach to the new product development process: a case study at Philips electronics', *R&D Management*, Vol. 31, No. 2, p.163.

Mason, S.P. and Merton, R.C. (1984) *The Role of Contingent Claims Analysis in Corporate Finance*, Division of Research, Graduate School of Business Administration, Harvard University, Boston, MA (Soldiers Field, Boston 02163).

McGrath, R.G. (1997) 'A real options logic for initiating technology positioning investments', *Academy of Management the Academy of Management Review*, Vol. 22, No. 4, p.974.

Miller, L.T. and Park, C.S. (2002) 'Decision making under uncertainty – real options to the rescue?' *The Engineering Economist*, Vol. 47, No. 2, p.105.

Mitchell, G.R. and Hamilton, W.F. (2007) 'Managing R&D as a strategic option', *Research Technology Management*, Vol. 50, No. 2, p.41.

Morin, R.A. and Jarrell, S.L. (2001) *Driving Shareholder Value: Value-Building Techniques for Creating Shareholder Wealth*, New York McGraw-Hill.

Myers, S.C. (1977) 'Determinants of corporate borrowing', *Journal of Financial Economics*, Vol. 5, No. 2, pp.147–175.

Oriani, R. and Sobrero, M. (2008) 'Uncertainty and the market valuation of R&D within a real options logic', *Strategic Management Journal*, Vol. 29, No. 4, p.343.

Panayi, S. and Trigeorgis, L. (1998) 'Multi-stage real options: the cases of information technology infrastructure and international bank expansion', *Quarterly Review of Economics and Finance*, Vol. 38, p.675.

Pickles, E. and Smith, J.L. (1993) 'Petroleum property valuation: a binomial lattice implementation of option pricing theory', *The Energy Journal*, Vol. 14, No. 2, p.1.

Rao, V.R. (2009) 'Flexible manufacturing system selection using an improved compromise ranking method', *Int. J. Industrial and Systems Engineering*, Vol. 4, No. 2, pp.198–215.

Rothwell, G. (2006) 'A real options approach to evaluating new nuclear power plants', *The Energy Journal*, Vol. 27, No. 1, p.37.

Schmidt, R., Lyytinen, K., Keil, M. and Cule, P. (2001) 'Identifying software project risks: an international Delphi study', *Journal of Management Information Systems*, Vol. 17, No. 4, p.5.

Smit, H.T.J. (1997) 'Investment analysis of offshore concessions in The Netherlands', *Financial Management*, Vol. 26, No. 2, p.5.

Taudes, A., Feurstein, M. and Mild, A. (2000) 'Options analysis of software platform decisions: a case study', *MIS Quarterly*, Vol. 24, No. 2, p.227.

Thompson, M., Davison, M. and Rasmussen, H. (2009) 'Natural gas storage valuation and optimization', *Naval Research Logistics (NRL)*, Vol. 56, No. 3, pp.226–238.

Tiwana, A., Keil, M. and Fichman, R.G. (2006) 'Information systems project continuation in escalation situations: a real options model', *Decision Sciences*, Vol. 37, No. 3, p.357.

Wu, L. and Ong, C. (2008) 'Management of information technology investment: a framework based on a Real Options and Mean-Variance theory perspective', *Technovation*, Vol. 28, No. 3, p.122.