Migration to Cloud as Real Option: Investment decision under uncertainty

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Migration to Cloud as Real Option

Investment decision under uncertainty

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***Abstract* — If cloud is so good then why aren't companies using it more? In this paper we look at how companies should make a decision to move some IT services or their IT infrastructure into the cloud. The move may initially look attractive in that it offers cost benefits but there is also considerable uncertainty; not least around security and information stewardship. Within the paper we propose the use of a real option model to help think about when to switch to cloud based on the expected benefits, uncertainties and the value a company puts on money.**

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I. Introduction

If we are to believe the press cloud computing offers huge cost benefits for companies. Yet its adoption is slow, with most established companies continuing to run their own IT services. Within this paper we explore the factors involved in the decision to switch and use real option [1], [2], [3], [4] models to understand when the conditions are right for a particular company to switch to using cloud services. The model suggests that one of the key factors influencing the decision is our perception on uncertainty as to the value and costs associated with cloud, and also our individuality and attitude towards decision making. Trust and security are significant factors contributing to the uncertainty as we rely on others to act as stewards for our data.

In thinking about a company switching some or all of their IT to the cloud we need to look at the enterprise IT stack. A company will typically have a set of IT services to support their business processes, each of these services may involve one or more applications. These may be standard applications but often enterprise applications will require considerable customization to get them to fit with the company's business processes. These services and applications are often run by separate teams. They sit on top of a platform provided by middleware (including identity services, messaging and databases) along with data centers (providing storage and processing power). The company will also have network and client computing teams. Traditionally a company will have an IT security team who ensure IT risks are managed by setting security policies and managing security processes.

Many companies find it hard to maintain or run their own IT systems and instead look to outsource some or all of their IT functions to large computer service companies. Typically this decision involves a long negotiation with one or more IT providers who write a bespoke contract [5] for each deal. The outsourced provider then takes ownership of the existing IT services, infrastructure and staff. Some deals may involve a piece of the IT systems; for example, it is common to outsource the networking, data centers and applications separately and even to different companies. This in itself is a complex decision process but one that has been done many times by many companies over many years. The company outsourcing their IT still remains in control.

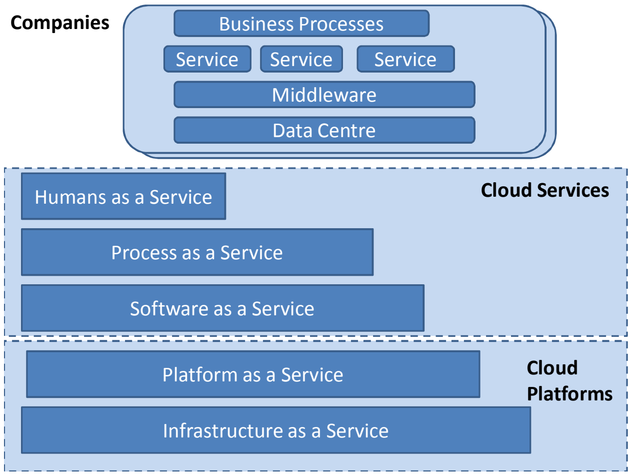


Figure 1. The cloud and enterprise IT stack

Cloud is somewhat different. A service provided within the cloud will offer a set of terms and conditions that they consider appropriate. A customer must decide whether they are acceptable. As such the cloud customer relinquishes a lot of control on how their IT systems and consequentially their business processes are run. Offering a standard service with standard terms and conditions allows the cloud service provider to scale efficiently to support many different customers at a relatively low cost, but on occasions may required to compromise on provider's standard terms and conditions.

Cloud services can be obtained at many different levels [6]. For example, many services today are at the platform as a service or infrastructure as a service level effectively replacing the middleware and data center layers of the enterprise architecture. Currently there are a limited set of business level services (for example the CRM services provided by salesforce.com) but we believe this will be the growth area. Instead of companies moving data center resources into the cloud and still running the applications we believe companies will eventually look to cloud services to offer support for their business services and even help them get outsourced human labour, mainly driven by the flexibility that Cloud offers [7].

As we look at when companies should and will adopt cloud services we need to ask how the decisions are made (section II). We follow this by a real option based switching model that can help companies assess when the conditions are right for them to move (Sections III). In section IV we look at the issues around using real options models and conclude in section V.

II. CLOUD AND SECURITY DECISION MAKING

As we look towards cloud we believe the way IT decisions are made will change and this will have a particular impact on security and information stewardship. Currently the security team will design a set of security policies that need to be met in any IT installation. When we move to using cloud computing this process breaks as the cloud service will offer standard terms and conditions. Within this section we look at security decision making and how this changes as cloud emerges.

In large organisations, security decisions involve many stakeholders, including IT, finance, compliance, business and risk managers. This makes the decision process more complex as different stakeholders all have different knowledge, expertise, and incentives relating to security. For example, the security team normally has the subject matter expertise, but lack the business context to properly make the business case for an investment. The business will often prioritise functionality over what they may see as unlikely security risks.

A key element with security decisions is the complexity of the problems. Typically, a decision to implement one or another security procedure requires the consideration of a huge range of inter-dependent factors, some of which vary in complex ways. Moreover, it is difficult to know or predict the actual impact of different choices on these factors. Extensive background knowledge about security and the company, prior experience of making similar decisions, and established standards such as ISO27000, see [7], help security professionals to cope with some of this complexity. However even with this approach security experts are still challenged to justify or sell their security proposals. Common requirements are to see a return on investment, or cost benefit type of analysis. These can be difficult to do well and effectively and there is ongoing research exploring methods and appropriateness of the frameworks, see Gordon and Loeb [9] on return on investment justification for security decisions, Schneier [10] on cost benefit analysis as providing a more appropriate framework for justifying business decisions.

In previous work the authors and other colleagues [11] took the view that a broader economic framing is more appropriate to handle business decisions about security that are by nature multi-stakeholder, multi-attribute, multi-objective decisions made in conditions of high uncertainty (see Keeney and Raiffa [12] for a comprehensive description of approaches to multi-stakeholder, multi-objective, multi-attribute decisions). In this approach economic framing is used to help stakeholders identify and prioritise between the multiple objectives. The framing is provided by a form of multi-criteria utility function. In practice, it is very difficult to extract a formal utility function direct from the organisation. We approach this with a multi step process that guides participants to select outcomes and preferences relevant to their organisation. This includes choosing how these outcomes can be measured, which are the most important, at which points performance in a particular outcome becomes 'intolerable' and predicting what effect the security decision could have on the multiple outcomes. A fuller exposition of the method is given in [11], and further discussion and examples of applying and using this style of utility function are given in [13] and [14].

The switching model framework discussed here has been designed to support security decision making in the context of cloud computing, specifically when enterprises consider 'migrating' to using the cloud. A relevant question is to explore whether cloud security decision making is (or needs to be) significantly different from standard IT security decision making.

Many organizations have already outsourced portions of their IT or business functions and there are many definitions that could be used to draw the line between outsourcing and cloud consuming. For the purposes of this discussion the difference relates to the nature of the market of service providers, and the implications this has for choice and control. With outsourcing many internal IT services remain the same, and organizations have the ability to define bespoke agreements and contracts. In contrast, cloud services seem to be menu driven implying that they (and/or the market) will have more influence on the security agreements and operation.

From a security management perspective the interesting lesson from outsourcing is that even large organizations with control over the contractual arrangements have not been able to specify appropriate security. At the Institute of Information Security Professionals workshop [15] this was related to organizations not having an explicit understanding of their security management lifecycle, and it is likely that this is still the case, so there are likely to be many issues as these organizations migrate to the cloud.

Moving from an IT environment that the business owns and controls to one which relies on a plethora of 3rd party suppliers will bring significant change to the way enterprises manage risk and security. That said at any moment in time every business will be unique in terms of legacy and maturity of internal IT, business needs, ability to invest, patience for a return, information security concerns and so on. Moreover any large organization will have multiple internal stakeholders with different preferences and priorities for whether, why, how, and when their business should adopt a cloud service.

At one level this still seems like a multi-objective, multi-attribute problem and so no different. However a difference here is that the business decision is clearly about cloud migration, with security adding some degree of uncertainty to the value. It is also different from a regular investment or project that demands a return on investment type business case that can be used to compare with other investment projects. In this case the business is trying to compare the (perceived or predicted) value of retaining internal IT with the (perceived or predicted) value of losing this legacy and acting as a cloud consumer. Moreover there is clearly value in having the ability to wait (preserving the option) to migrate. It is possible to use a direct utility driven approach to compare the relative values of these approaches, but phrased this way it seems natural to consider the problem as a switching problem. That is, there are many switching models that frame choices in terms of having the option to stay, migrate, and to wait. Such models provide valuations of the options that take account of the time value of money, uncertainty and volatility of values and predictions, and risk appetite. In the cloud migration situation it is natural to explore the security issues in terms of the restrictions and uncertainty they bring to the different valuations. This appropriately positions security concerns in the context of the business valuation and decision.

III. Real Options

An option is a right, but not an obligation, to take an action on the underlying asset. An option may have an expiry date, on which an action must be taken upon the underlying asset, or it may be perpetual, that is without an expiry date. A call option is the right to buy the underlying asset, while a put option is the right to sell, at a predetermined price. There are two forms of option: financial option and real option, depending on whether the underlying asset is a financial asset (e.g. stock) or real asset (e.g. real estate, projects and intellectual property).

The decision to invest will depend on many factors and it can be complex to determine when the conditions are correct. This will not only depend on the current conditions but our perception of future conditions and how we value money. Real option theory provides a formal framework for exploring these decisions.

The scenario we are considering here (Figure 2.) is a company running its traditional IT services (i.e. invests in IT assets) and these services have some business value, at this moment in time. The company sees the possibility of an alternative IT investment by using a cloud service, again offering some business value.

The question that the company is faced with is should they switch from their internal IT to Cloud? They may have heard about cost or business value arguments from others – the question they need to frame is when the conditions are right for them. The question itself can vary it could refer to moving their applications onto a cloud platform or it could be replacing one of their current applications with one provided by a cloud service.

Clearly, the decision depends on the costs and potential business value that the cloud delivers. As cloud is unproven, and outside of the companies control, there will be significant uncertainty that this value can be delivered without security incident. As with all emerging technologies cloud will be subjected to various risks (technical, legal, and policy) along with an unknown likelihood that vulnerabilities will be found. In other words, this business value is subjected to uncertainty arises from exposure to Cloud, and this must be taken into account when deciding to switch. If the value that Cloud promises exceeds that of current IT facilities and the switching costs, then one may choose to migrate.

Within this section we start by looking at net present value and discount rate as a way of assessing the value of an investment. We then look informally at the factors involved in making a decision to switch to the cloud. Lastly we explore how we put these factors into a real option model and what this model tells us about the decision.

A. *Net Present Value*

Net Present Value (NPV) is the difference between the present value of the asset and the capital expenditure to acquire this asset, in today's money. If the NPV for a prospective investment is positive the investment will be profitable and is acceptable; if the NPV is negative the investment will lose money and should be rejected. NPV tells us whether an investment would make money or not, but does not capture a valuable characteristic of many investment decisions, that is the option to defer a decision, as it assumes that decision cannot be deferred. This flexibility gives rise to two important and valuable opportunities, that is: (1) time value of money, and (2) circumstances might change, such as the economic landscape, the costs of acquiring an asset or the value of an asset, or allow us time to gather information that as not available earlier, which is highly valuable in decision making, clearing doubts and uncertainties.

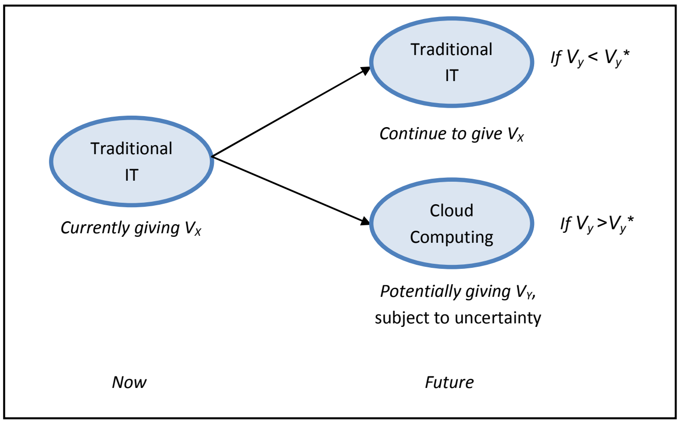


Figure 2. User will only consider opting for Cloud if the value that it promises exceeds the optimum critical value (which comprises value derived from current IT asset and swtiching costs, see section *D*), where the uncertainty around the value expected from Cloud is critical.

B. *Discount Rate and the value of money*

Each company will value money in different ways and in our model we represent this as a discount rate, which capture individuality based on their income pattern and attitude. Discount rate is related to income stream, and is based (in part) on psychological or subjective elements of comparative marginal desirability, that is the marginal preference for present over future. This preference is called time preference or human impatience [16]. So, discount rate can be thought of as a measure of impatience of an individual company, in other words, how much a company values its current state over its distant future.

Individual's impatience depends on the entire income stream, beginning from now, till indefinitely into the future, which has mainly the following three characteristics:

1) Size (measured in unit of money): of expected income stream. Small income, with everything else equal, tends to have high discount rate, i.e. value current more than distant future; whilst large income tends to have low discount rate, i.e. value its distant future more.

2) Expected distribution: how that amount is distributed across time, e.g. increasing, decreasing, constant or a mixture. Increasing income tends to give higher preference for present over future. This expectation of future growth makes one impatient to realize the preference in advance. One may borrow money now and repay with future income. That is high discount rate. Decreasing income tends to give lower preference for present over future, hence low discount rate.

Two different individuals or business entities that both have exactly the same income distribution may well have different degree of impatience. For example, if they both have increasing income, one may have 10% discount rate, while the other have 5%. If that increasing income is replaced by decreasing income, the discount rate for the former may fall from 10% to 6%, while the later may fall from 5% to 4%, for example. It is relative. Many estimation approaches are available, but we will not cover in this paper.

If we treat the size and the distribution simultaneously, we observe that smaller size of income will be more sensitive to the type of distribution, compared to large income. For a poor man, a slight change will suffice to enhance or diminish his impatience, while a rich man would require a larger change for him to feel any effects.

3) Stability: of that income stream. If current income is secure, and future income is uncertain, then one would have low impatience for the money now, but higher impatience for the money in the future. If current income is uncertain, and future income is secure, then one would have higher impatience for the money now, but lower impatience for the money in the future. If the risk is distributed uniformly, uncertainty on income stream tends to raise impatience.

TABLE I. OTHER QUALITATIVE FACTORS THAT MAY INFLUENCE INDIVIDUAL COMPANY'S DISCOUNT RATE.

Discount rate is high when	Discount rate is low when
Focus on short-term	High degree of foresight
Take high risk	Take low risk
Habit of spending freely	Habit of thrift
Shortness of life	Expecting longevity
Care less about continuity	Care about continuity
Easily influenced by trend: e.g. fashion retail	Independent from trend influence: particularly true for commodity

Besides these main three characteristics, discount rate can be influenced by other qualitative factors that constitute to attitude, such as foresight, self-control, habit, expectation of life, business continuity, easily influenced by trend or not. The influence of these factors on impatience is summarized in TABLE I.

Typically, a large mature company may have low discount rate; late start-up may have medium discount rate; while a new start-up may have a high discount rate. Not only the maturity of a company has typical discount rates, the types of industries, and the size of business may have their own range of discount rate. Figure 3. illustrate discount rates for examplar business entities where they typically fall onto. As before each individual company will have a different discount rate compared to the other. But if all the factors change in the same way, their discount rate may raise or fall in the same direction, though the magnitude might be different. Discount rate increases along with the decrease of income size and instability (*y*-axes), and/or the increase of risk appetite (*x*-axes). For example, a SME IT startup may have a higher discount rate due to near term focus (current market trend, and this trend may change fast), shortness of life (unsure about longevity) and care less about continuity (what is important is its current survival). On the other hand, oil, gas, mining and commodity may have a low discount rate, as they have high regard on its future existence and income. They also have high degree of foresight, expectation of long life, care about continuity and independent from the influence of fashion. It is not only the type of industries that matters, but also at what stage a particular company is in, e.g. start-up or established. Large established technology company with very large income, though influenced by technology trend, may have a low discount rate, due to is stage of maturity, and also income size, hence valuing its future existence significantly. On the other hand, small local businesses, though established, but due to its small or micro size of income, they may have relative higher discount rate, valuing current state more than distant future.

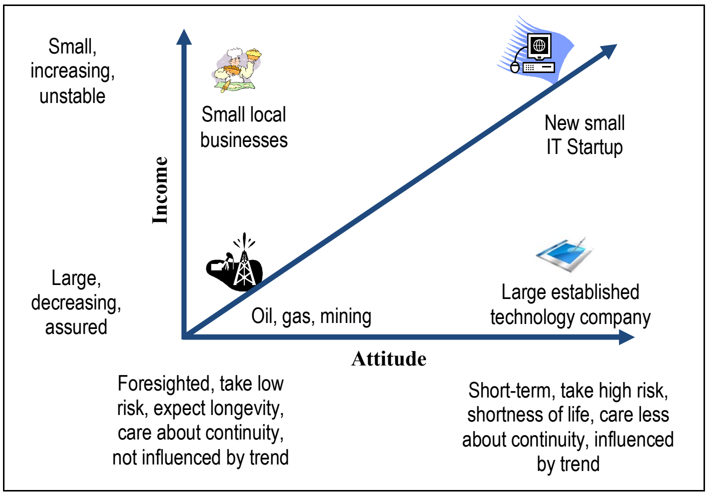


Figure 3. Discount rate captures individual characteristics such as income patterns and attitude unique of a company.

C. Relating Costs, Benefits and Uncertainties to Real Option

The value of a deferred investment option, $F(V)$, is the value of either asset value, V, less present value of cost, $PV(K)$ or 0 (if the return of investment is negative, you will choose to take no action), whichever is greater. It can be thought of as potential payoff. That is a company can value its ability to move to the cloud at some later point *F(V).*

$$\boldsymbol{F(V)} = \mathbf{max}\begin{cases}\boldsymbol{V - PV(K)} \\ \mathbf{0}\end{cases} \tag{1}$$

The value of an asset is normally thought of in terms of how much cash flow it generates. The value of computing facilities, V, can be thought of as the benefit from cost savings or business value generated by improving efficiency and effectiveness of a process, leveraging on Cloud flexibility, for example. A cloud service may bring value to the company in that it may allow them to improve their processes [17] or bring additional reliability alternatively it may bring value by being cheaper than running the internal IT service.

For many companies the value generated by a cloud service will be the new business processes that are supported. In large companies IT departments are often perceived as slow in responding to updating IT services to support new business processes. Here a business may see the value in that they can pick a service that supports their needs. This lack of agility is often due to the governance processes that an IT department must perform on introducing change to ensure reliability. From a security perspective we need to ensure that security is also seen as part of the Cloud adoption decision. For a well-run large enterprise the Cloud may be seen as adding additional uncertainty around Cloud value due to the inherent exposure.

On the other hand, for a SME with less IT resources and expertise, Cloud may be seen as offering better security hence better value. Using the Cloud here could be perceived as offering better protection for customer's data (perhaps personal sensitive data) along with more reliable service delivery and hence offering increased value through better reputation, customer trust, efficiency, ability to handle peak demand etc.

Cloud services claim to bring benefits of scale as resources and IT processes are shared across multiple companies and these should be reflected the speed of the IT operations as well as in cost reductions. A company's assumption in looking to switch into the cloud is that the cloud service provider will pass on these cost savings.

In considering cost we need to look at the switching cost as well as the operational costs. These costs will include redundancy or redeployment costs for IT staff along with costs associated with disposing of physical assets. The exact nature of the costs will depend on whether the decision is to switch the IT infrastructure or to switch a service supporting part of the business. As well as costs associated with shrinking the current IT provision there may be additional costs associated with using cloud such as linking a cloud service into other applications, training staff to use a new application or adapting business processes.

Given the nature of Cloud, the gross business value that it will generate is subject to some uncertainty, and it might depend on market condition at that time, and how the overall cloud ecosystem emerges In general, we can regard risks (policy and organizational, technical and legal) and vulnerabilities as uncertainty associated with benefits. For instance, *loss of governance*, *isolation failure*, *management interface compromise*, *insecure or incomplete data deletion* and *malicious insider* can be considered as uncertainty.

The risk of *lock-in* that encumbers portability and interoperability that make migration difficult may be seen as cost, as well as uncertainty, similarly as per *compliance risk*. This model looks at the costs of switching from IT to Cloud, it can be extended to include a return path, which is moving from IT to Cloud, and then return to IT [18]. If services have a high degree of lock-in they have less incentives to run their service well and respond quickly to vulnerabilities and attacks.

A less predictable but potentially large cost is due to security incidents. Security incidents may be somewhat unpredictable but will be more prevalent with systems that are not designed and run with security in mind. Occasional large extremely costly security incidents may occur; for example in damaging a company's reputation as customer information is leaked. The potential security risks will differ for each IT service due to the different data and business processes being supported. Different types of companies will also have different risk profiles – some will be attractive to attackers whereas others may lack robustness as their business processes are tightly intertwined with the IT provision. In this way security can bring a huge degree of uncertainty into the decision. A company may feel they have a good understanding of the risks associated with their IT, security policies and processes however, they may feel that they lose this understanding as they rely on a service provider.

The way a company sees the decision will vary depending on its current legacy, its ability to raise capital and its attitude towards risk. For example, a very young IT startup will have little legacy IT and the cost of moving to cloud will be minimal. They are unlikely to have a well developed security strategy and will worry less about their reputation – the speed of getting their product out will dominate their decisions. Compare this to a large enterprise; they will have a large IT legacy meaning change will be costly. They will feel they understand their risk profile and be very concerned about their reputation. Each of these companies will see the move to cloud in very different ways but the real options model allows us to explore the decision in both cases.

D. Cloud Switching Decsion as Real Option

Our opportunity to adopt Cloud is analogous to a perpetual call option i.e. it has no expiry date, unless that project is otherwise subject to government regulation or institutional arrangements. In this case, there are techniques in option theory that can be adopted. Here, we restrict our example to a perpetual call option [1].

A company that is currently using traditional IT, X, will continue to receive a net constant payoff or value derived from existing IT infrastructure in the future, V_X, as long as the company continue to use this asset. Given the discount rate, r, the present value is, $PV(V_X)$, where

$$PV(V_X) = \frac{V_X}{r} \tag{2}$$

That is the value of net pay off (benefits less costs such as operational and incident) derived from existing IT infrastructure in today's value. The alternative investment in using a cloud service offers us a potentially different payoff (for the reasons previously discussed) of, V_Y .

A company will not only need to consider the total costs of moving to cloud in today's money, $PV(K)$, and the total business value, V_Y, but also need to consider net payoff derived from current asset in the future (discounted to today's value), $\frac{V_X}{r}$.

$$F(V_Y) = \max \begin{cases} V_Y - PV(K) \\ \\ \frac{V_X}{r} \end{cases} \tag{3}$$

One should only consider adopting a Cloud service if the net Cloud value less the present value costs ($V_Y - PV(K)$) is greater than the net present value of future benefit derived from current IT facility ($\frac{V_X}{r}$). This involves a view on the future value of money and perceived uncertainty around Cloud value, which are critical to the decision.

TABLE II. COSTS AND BENEFITS GIVEN CURRENT IT FACILITIES AND POTENTIALLY NEW CLOUD INFRASTRUCTURE.

User's current state: traditional IT		**User's state in the future: option of using Cloud**	
B_x	Benefit received from using IT	B_y	Benefit received from using Cloud
P_x	Penalty for exiting IT	C_y	Initial capital to set up facility Cloud
O_x	Cost of operation and maintenance	O_y	Cost of operation and maintenance
I_x	Security incident cost when using IT	I_y	Security incident cost when using Cloud
r	discount rate	r	discount rate
V_x	Net value (benefit less costs) provided by IT $V_x = S_x - O_x - I_x$	V_y	Net value (benefits less costs) provided by Cloud $V_y = S_y - O_y - I_y$
		σ_y	Uncertainty associated with B_y

Suppose that we can summarize the costs and benefits as in TABLE II. and if we can put a number on each of them (though it can sometime be challenging). Net value generated from current IT asset, is gross benefits received less all the costs incurred by, e.g. operation and incidents. Similarly, for the net value that the new Cloud asset might be generating. Amazon Web Service provide resources and tools in that help businesses quantity the economic benefits and cost of Cloud services it offers [19], which could be used to populate some of the value in TABLE II.

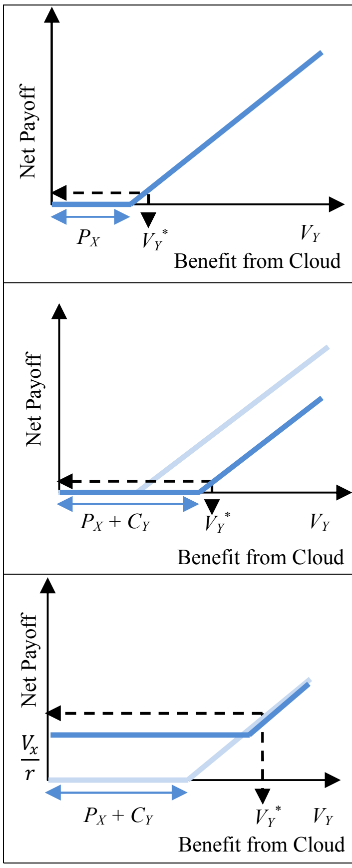
When thinking of ceasing an old facility and moving into a new facility, other irreversible costs that we need to consider are the cost of exiting the old facility (P_X), and also, the initial capital to set up the new facility (C_Y). Therefore, one will only adopt cloud if the value Cloud promises less the total switching cost is greater than that of existing IT (4).

$$V_y - (C_y + P_x) > \frac{V_x}{r} \tag{4}$$

Hence, the total value to give up (i.e. switching cost) is the sum of the cost of acquiring Cloud services, and exiting existing IT and the value that existing IT is expected to continue to generate in the future. Rearranging (4), we have the condition minimum value for V_Y in order to switch. We describe this baseline threshold value as V_Y^*.

$$V_Y^* > \frac{V_x}{r} + (C_y + P_x) \tag{5}$$

Figure 4. shows the effects of benefits derived from existing infrastructure and irreversible cost on the critical value, V_Y^*.



From (5), we know that the critical threshold for benefits generated from Cloud must exceed, in this case, the penalty of exiting IT, and we assume there is no cost associated with using the Cloud. As shown in the figure, V_Y^* needs only exceed the penalty cost, for that particular Net Payoff on the *y*-axes.

Now, let's consider there are costs associated with acquiring Cloud, that pushes V_Y^* away to the right, which implies that Cloud should generate greater amount of benefits, should one be considering adopting Cloud.

If the existing IT facilities is generating benefits as long as it exist, then V_Y^* will be pushed even further away to the right, hence higher benefits from Cloud is expected if that company were to adopt Cloud. The bigger the value of $\frac{V_x}{r}$, the bigger the critical value, V_Y^* , will be.

Figure 4. Effects of irreversible costs ($P_x + C_y$) and benefits derived from existing infrastructure, $\frac{V_x}{r}$, on the value of new investment option, $F(V_Y)$.

Equation (5) describes the baseline threshold that Cloud should satisfy should one were to adopt Cloud. However, each individual will have their own optimum threshold unique to their type of business, attitude towards risk and perception towards uncertainties inherent in Cloud. So, how do we determine that optimum critical value?

E. Option Value, Optimum Threshold and Investment Decision

Option value is simply potential payoff from the new investment, or opportunity cost. Real option theory states that the value of an investment option, $F(V)$ is (full derivation can be found in [2]:

$$F(V) = aV^{\beta} \tag{6}$$

where β is

$$\beta = \frac{1}{2} - \frac{(r-\delta)}{\sigma^2} + \sqrt{\left(\frac{(r-\delta)}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}} \quad , \quad > 1 \tag{7}$$

β will depend on discount rate, r, dividend yield, δ, and uncertainty, σ, (ranges from 0 to 1) associated with V_Y. Recal that r is a description of individuality based on type of company and risk appetite, while σ is uncertainties around value of Cloud. And a is

$$a = \frac{V_y^* - (C_y + P_x + \frac{V_x}{r})}{{V_y^*}^{\beta}} \tag{8}$$

The optimum threshold for adopting Cloud is then, V_y^*,

$$V_y^* = \frac{\beta_+}{\beta_+ - 1}\left(C_y + P_x + \frac{V_x}{r}\right) \tag{9}$$

The perceived uncertainty surrounded Cloud, and discount rate characterizing type of income and attitude towards investment decision will be unique for each company. These values are encapsulated by β. V_y^* must always be a factor $\left(\frac{\beta_+}{\beta_+ - 1}\right)$ bigger than the switching costs $\left(\frac{V_x}{r} + (C_y + P_x)\right)$. Because β is always bigger than 1, therefore $\frac{\beta_+}{\beta_+ - 1}$ is always bigger than 1.

That confirms that V_y^* is always bigger than the switching cost. By substituting (7-9) into (6) and rearranging them, we get the formula for pricing or valuing the investment option as,

$$F(V_y) = \frac{1}{\beta_+ - 1}\left(C_y + P_x + \frac{V_x}{r}\right)\left(\frac{V_y}{V_y^*}\right)^{\beta} + \frac{V_x}{r} \tag{10}$$

This tells us the value of such investment opportunity.

As uncertainty increases, the critical threshold increases (Figure 5.). If the value that Cloud promises is subject to high uncertainty, a higher threshold of return is desired, to cushion the high level of perceived risks. It is also more sensitive when the uncertainty gets higher.

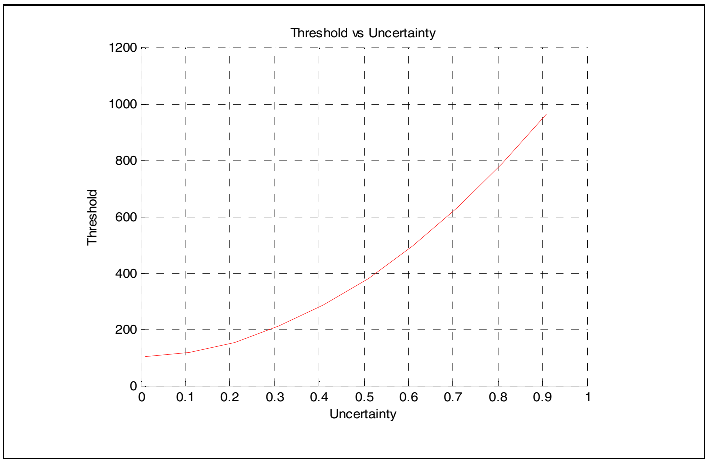


Figure 5. As uncertainty increses, the optimum threshold for expected Cloud value, V_y^*, increases and rises faster.

F. Real Option Space

Real option technique not only allows us to quantitatively describe the expected value of an investment option, by its cost and benefit, and uncertainty, but also encapsulating the nature of individuality in decision making, based on unique company characteristics. These allow individual company to draw their own decision boundary by calculating their own unique optimum threshold. Figure 6(a) shows examplar investment projects A to F, quantify by cost, benefits (x-axes) and uncertainty (y-axes) on the value that each project might bring. Project A has low cost and high benefits, and low uncertainty, indicating that project A will almost certain be profitable, whereas project C, has high uncertainty and at the borderline of profitable, indicating that project C is a high risk investment with little profit, if it does succeed.

Now, how do we decide which project to take on or not? Factors that are affecting the decision boundary of invest now or later, i.e. optimum threshold, are one's expectation on the profit, their attitude towards investment and how much they value their future. A company that has large consistent income and value their future a lot with low discount rate may have smaller "invest now" decision region, favouring investment options of low uncertainty and high profitability such as project A (Figure 6. (b)). A new small startup that has small inconsistent income and focusing on current survival and has aptitude for risk would have a high discount rate, hence a larger "invest now" region. While favouring low risk and high profitable project A, it would also take on project B of higher uncertainty, though relatively less profitable (Figure 6. (c)). If that company values its future even lease, increasing its discount rate, its renewed decision boundary might even engulf project C. The higher the discount rate, the more impatient one would like to realize an investment option for its expected profits, making the "invest now" region larger by including investments of higher uncertainty, and squeezing others regions like "invest later" even smaller.

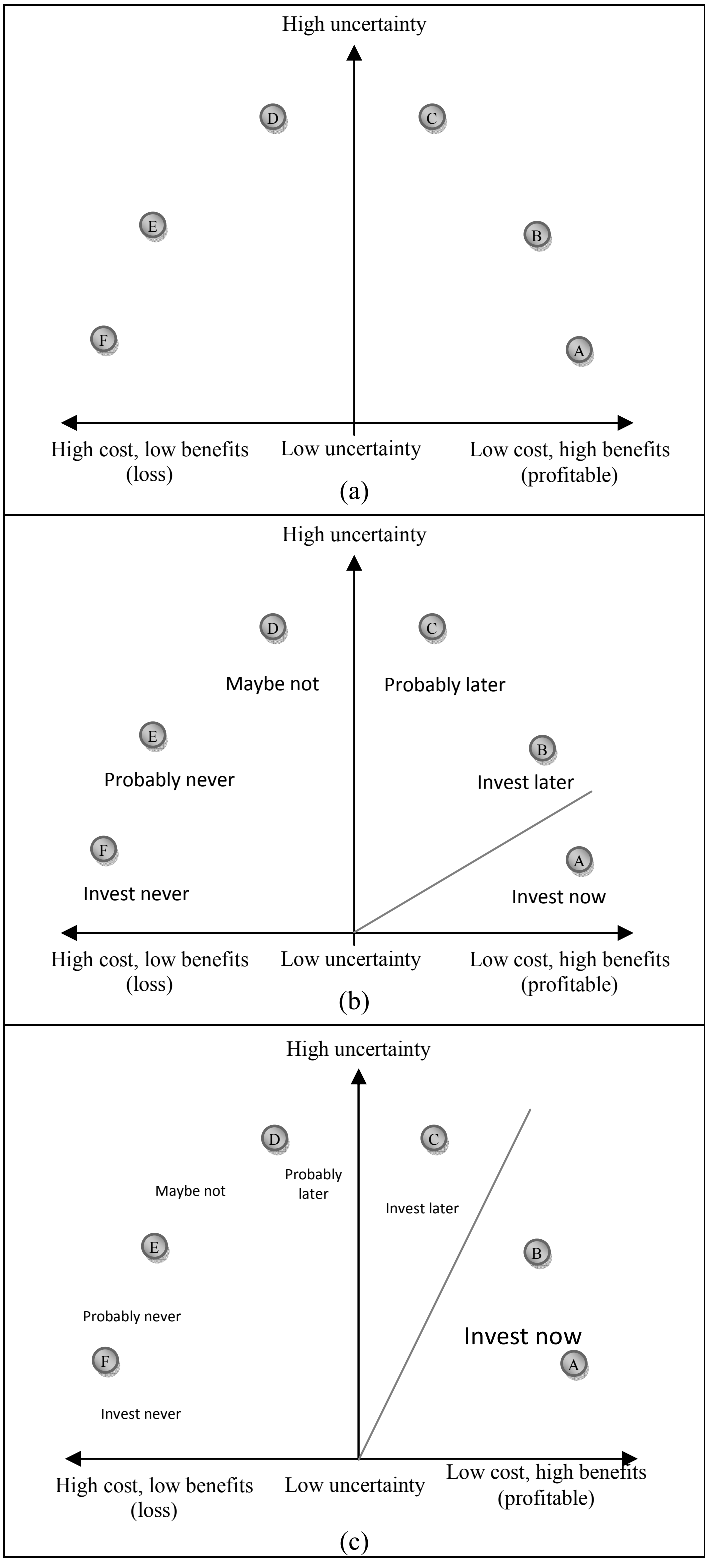


Figure 6. (a) Real option technique allow potential investments (represented by circles) to be placed in cost/benefits and uncertainty space. (b) Encapsulating the nature of individuality based type of business and attitude toward risk taking unique to a company, affecting the decision boundary. Companies with low discount rate tends to favour projects with low uncertainty and high profitability. (c) Companies with high discount rate tends to increase the size of "invest now" taking on proejcts with higher uncertainty, squeezing "invest later" and other regions smaller.

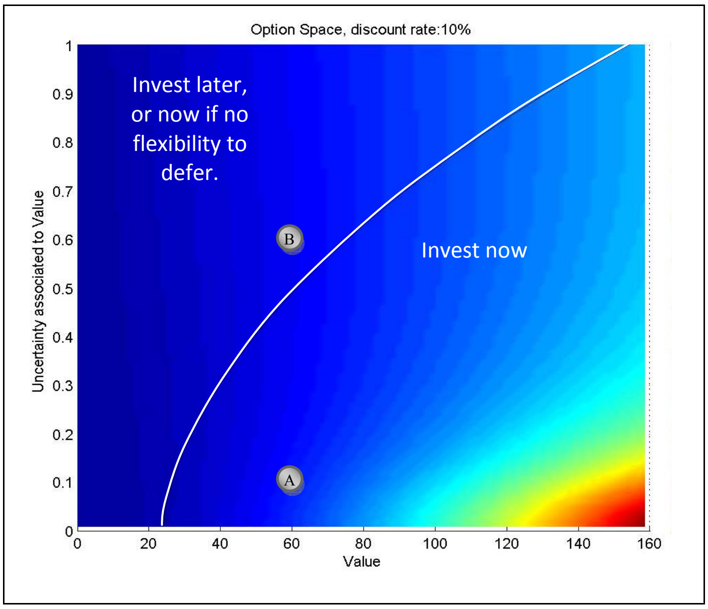
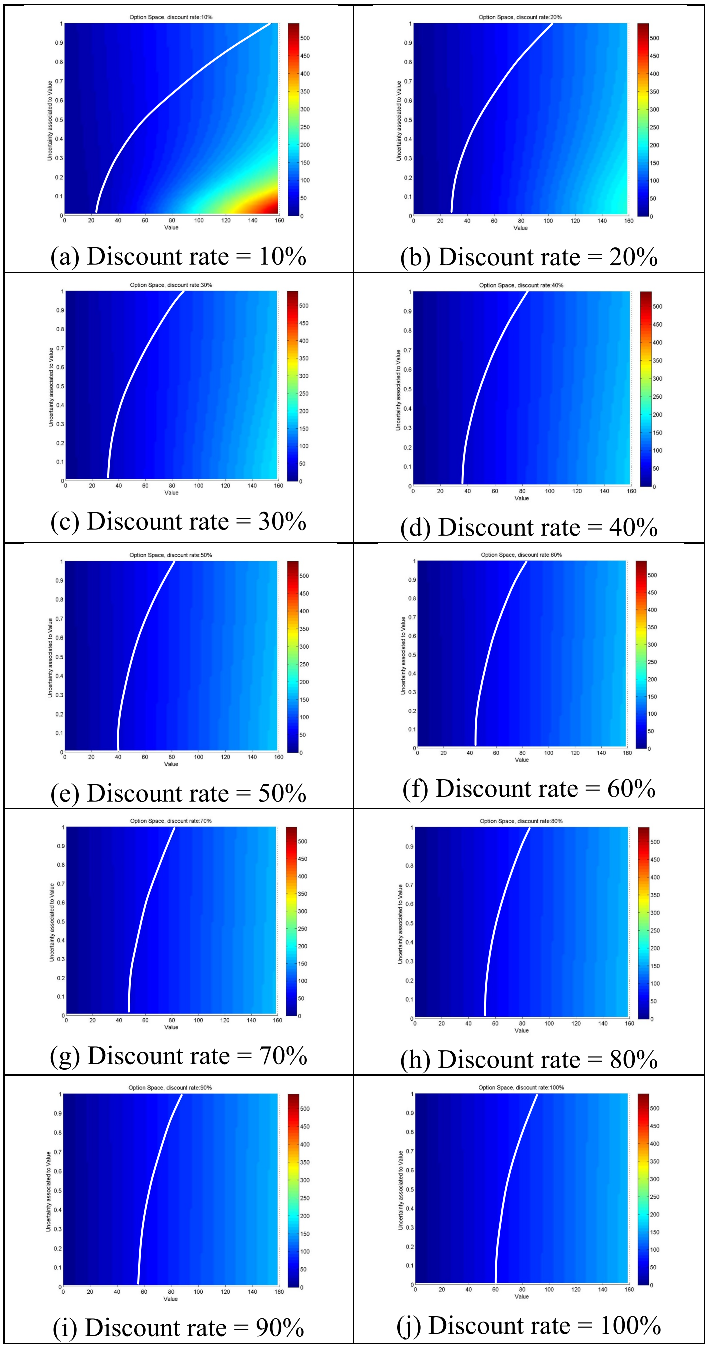


Figure 7. Option space showing optimal investment decision boundary under uncertainty, given a specific discount rate at 10%. Background colour indicating the value of investment option, red has higher value than blue.

We are interested in the effects of how differences in discount rate (and the value of money) and uncertainty affect the investment space and optimal threshold, and hence decisions made. We have used equations (6) to (10) to generate a view of the decision space, which by fixing costs and benefits variables (C_y, P_x and V_x), and varying uncertainty, σ and discount rate, r. In doing so we can explore the way changes in these factors affect the decision. Figure 7. shows a numerical example of the model desibcribed. The background colour shows the value of having that option, red is high, blue is low, but above zero. The curve is the optimum threshold given certain uncertainty at specific discount rate, in this case, is 10%. If the investment proposal under consideration fall into the right region, the model suggests that you can invest now as its potential profitability has exceeded the optimum threshold. For example, if company Z which has a discount rate of 10%, and has two potential investment projects A and B. Project A has the value of 60 (profitable) and a perceived uncertainty of 0.1 (low risk), then for this company, it should consider investing in project A, but may save project B for later review, even though project B has similar profitability but with perceived higher risk (uncertainty = 0.6). On the left of the optimum curve, it is invest later region, or invest now if there is no flexibility to wait, as the option has got some value (represented by the colour) in the future and is not zero.

Figure 8. shows that increasing discount rate (from 10% to 100% - in reality, hardly a discount rate of 100% will be used, we have included for the sake of completeness) pushing the optimum boundary towards left. The effect is the inclusion of potential investments of higher uncertainty, and progressively investments of higher value, reflecting the explanation in Figure 6. Note that the background colour on bottom right changing from red to blue, as discount rate goes higher. That is, the higher the discount rate, the less a company would value their future money, as a higher percentage is discounted. The

£100, say, in one year's time, with discount rate of 80%, would only worth £55.56 to you today; or £90.91 if your discount rate is 10%.



(a) Discount rate = 10% (b) Discount rate = 20%

(c) Discount rate = 30% (d) Discount rate = 40%

(e) Discount rate = 50% (f) Discount rate = 60%

(g) Discount rate = 70% (h) Discount rate = 80%

(i) Discount rate = 90% (j) Discount rate = 100%

Figure 8. Increasing discount rate pushing the optimum boundary towards left. The effect is the inclusion of potential investments of higher uncertainty, and progressively of higher value.

G. Discussion

Here we have explored the simplest form of a real option. Other categories of options [20] [21] are: option to alter operating scale (expand or contract), option to abandon, staged investment (looking at risks and return of any stages within an investment cycle), and multiple interactions option. Cloud adoption initiatives may be multistage, where management can decide, at any stage, whether to expand, to scale back or to abandon, depending on the profit, growth, uncertainty, and economic landscape at that point of time. This is an example of compound options where the decision made at one stage will affect the other stages, or may generate new stages. Staged investment (compound options) can be either sequential or simultaneous. Instead of considering the investment as a binary option, we may have to think of it as a binary tree, where future option is dependent on previous decision. For example, Cloud procurement may need to be exercised first, before a company can move any services into Cloud, that is sequential option, whereas, a company may move their helpdesk services to Cloud independently (or simultaneously) with, say, customer relationship services to Cloud, this is simultaneous option. Or, it can be a combination of both. Another example is that as a company moves more services to the cloud their internal IT organization looses the ability to scale efficiently and the costs of those things they wish to keep in house increases.

The key input for real option analysis, as we described in the main text is uncertainty (or volatility in finance term). Two important elements to consider here are: 1) say, if cloud migration is thought of a multiphase investment, then, we will expect uncertainty from multiple sources that need to be considered separately when evaluating the option value. 2) Uncertainty from multiple sources will change in time, due to technology advancement, the market landscape or the stewardship environment enforced by regulatory bodies.

We have described a real option model applied to a company's decision to move an IT service or platform into the cloud. The model can also be used by potential service providers trying to understand how those in their target segment may act. This will help them develop strategies for price, terms and conditions, assurance information and interoperability. The switching model could equally be applied to a software company looking to become a cloud service provider – the analysis of costs would change but the methods for dealing with uncertainty remain.

H. Conclusions

Cloud services are just starting to emerge and as they do so companies are faced with the problem that the cost structures look attractive but they have uncertainties that they will get a good reliable service. Security and business continuity concerns are perhaps two of the biggest drivers for uncertainty. In this paper we propose the use of real option theory as a way of enhancing decision making.

The real options approach to decision making helps then understand the impact of this uncertainty allowing them to value their ability to move later as the picture becomes clearer. Understanding the options space can provide a quantitative description of investment proposal, and a continuum of decision space along with a decision boundary matches the unique characteristics of the company described by their income patterns and risk appetite.

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REFERENCES

[1] Timothy A. Luehrman, “Strategy as a Portfolio of Real Options”, Harvard Business Review, Vol. 76, pp. 87-99, September-October 1998.

[2] Robert S. Pindyck, “Irreversibility, Uncertainty, and Investment”, Journal of Economic Literature, Vol. XXIX, pp. 1110-1148, 1991.

[3] Suto, H., Alleman, J. and Rappoport, P. “An Investment Criterion Incorporating Real Options”, Communications & Strategies, IDATE, Vol. 1(70), pp. 45-66, 2008.

[4] E. Romer, “Asymmetric Buyer-Seller Relationships and Real Switching Options”, 7th annual Real Options Conference, July 2003.

[5] Y. Chen and A. Bharadwaj, “An empirical analysis of contract structures in it outsourcing”, Information Systems Research. Vol. 20, pp. 484-506, 2009.

[6] P. Mell and T. Grance, “NIST Cloud Computing Program”. [Online] Jan 2011. [Cited: 22 Jun 2011.] http://csrc.nist.gov/publications/drafts/800-145/Draft-SP-800-145_cloud-definition.pdf.

[7] “Cloud UK: Paper One: Adoption and Trends 2011”, Cloud Industry Forum, 2011.

[8] ISO 27000 series of standards for information security and security management. [Online] www.27000.org.

[9] L.A. Gordon and M.P. Loeb, “Managing Cybersecurity Resources: A Cost-Benefit Analysis”, McGraw Hill , 2006

[10] B. Schneier, Security ROI. Schneier on Security blog. [Online] 2 Sept 2008. http://www.schneier.com/blog/archives/2008/09/security_roi_1.html.

[11] Y. Beres, D. Pym and S. Shiu, “Decision Support for Systems Security Investment”, IEEE/IFIP, Network Operations and Management Symposium Workshops, 2010.

[12] R. L. Keeney and H. Raiffa, “Decisions with Multiple Objectives: Preferences and Value Tradeoffs”, Wiley, New York, Reprinted, Cambridge Univ. Press, New York (1993), 1976.

[13] A. Beautement, R. Coles, J. Griffin, C. Ioannidis, B. Monahan, D. Pym, A. Sasse and M. Wonham, “Modelling the Human and Technological Costs and Benefits of USB Memory Stick Security”, Springer, 2009.

[14] C. Ioannidis, D. Pym and J. Williams, “Investments and Trade-offs in the Economics of Information Security”, Financial Cryptography and Data Security 2009, LNCS 5628. pp. 148-162, Springer, 2009.

[15] S. Shiu, A. Baldwin and C.-Y. Yam, “Institute of Information Security Professionals Workshop on Cloud Stewarship Economic Technical Report”, in press.

[16] H. Fisher, “The Theory of Interest,” Library of Economics and Liberty. [Online] 1930. [Cited:] http://www.econlib.org/library/YPDBooks/Fisher/fshToI.html.

[17] V. Kundra, Stanrdard foster innovation. NIST Cloud Forum 2010 *http://csrc.nist.gov/groups/SNS/cloud_computing/documents/forumworkshop-may2010/nist_cloud_computing_forum-kundra.pdf*

[18] Y. Khwaja, ”Should I Stay or Should I Go? Migration Under Uncertainty: A Real Option Approach”, Public Policy Discussion Papers 002-10, Economics and Finance Section, School of Social Sciences, Brunel University, 2002.

[19] [Online] Amazon. [Cited: 09 09 2011.] http://aws.amazon.com/economics/.

[20] L. Trigeorgis, “Real Options: An Overview”. [book auth.] E. S. Schwartz and L. Trigeorgis. Real Options and Investment under Uncertainty: Classical Readings and Recent Contribution, The MIT Press, 2001.

[21] P. Kodukula and C. Papudesu,” Project Valuation Using Real Options: A Practitioner's Guide”, J. Ross Publishing, 2006.