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# Impact of Security Risks on Cloud Computing Adoption

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***Abstract*—Cloud computing has been a paradigm shift in the information technology domain. It offers potential benefits to users in terms of instant availability, scalability and resource sharing, while potentially posing security issues. Especially, recent events like Amazons system failure increased the concerns related to cloud computing[1]. Given these security and reliability concerns , we explore the optimal decision rule for moving certain IT function to public clouds. We formulate the problem as an entrepreneurial decision for an optimal stopping time at which the entrepreneur shall migrate to the cloud computing paradigm. Two different models are presented. Recognizing that an important and specific issue related to different computing paradigm is the potential "security" risk posed by each technology, we consider security risks in both models. The first model approaches the optimal adoption problem from assessing the cloud computing adoption under project value uncertainty. The entrepreneur has the timing flexibility and solves his optimal adoption decision under uncertainty. The optimal adoption rule obtained is a threshold strategy. A firm should adopt the cloud computing only if the value from the adoption exceeds the threshold level. The second model builds on a comprehensive assessment of two different computing paradigms. The entrepreneur can either keep the traditional on-site computing paradigm or migrate to the cloud computing paradigm. His problem is to make the paradigm shift optimally. We model such a problem as optimally swapping two "risky" assets, which refer to benefits of the traditional on-site computing paradigm and those of the cloud computing paradigm. The term "risky" captures the fact that actual benefits can only be resolved through time, and thus estimates of benefits are embedded with uncertainty. We obtain the optimal swapping rule as a threshold strategy, defined in terms of the two benefit ratio. A firm should only shift the part of its business to the cloud computing service if the ratio, the benefit from the cloud computing paradigm over that from the traditional on-site computing paradigm, exceeds the threshold. In both models, both the extent of riskiness (i.e. uncertainty) and the significance of security risks (both in terms of potential occurrence probability and the severity of damage) affect the threshold level, thus the entrepreneurial adoption decision.**

[1]Web chaos as Amazon cloud failure crashes major websites and Playstation Network goes down AGAIN, April 22, 2011. <http://www.dailymail.co.uk/sciencetech/article-1379474/Web-chaos-Amazon-cloud-failure-crashes-major-websites-Playstation-Network-goes-AGAIN.html>

## I. Introduction

Cloud computing has been a paradigm shift in the information technology domain. Third-party providers are increasingly providing storage and computational resources to their customers through services (software as a service, SaaS) such as Google Docs and Gmail, underlying platform (platform as a service, PaaS) such as Microsoft Azure, and underlying infrastructure (infrastructure as a service, IaaS) such as Amazon's Elastic Compute Cloud (EC2). The market for these services was estimated at around USD 17 billion in 2009, and is forecast to reach USD 44.2 billion by 2013 [7]. The enthusiasm for cloud infrastructures is not only present in the business world, but also extends to government agencies. Federal Chief Information Officer(CIO) Vivek Kundra of United States recently released Federal Cloud Computing Strategy (February 8, 2011) document [8] calling for about a quarter of federal IT spending committed to cloud systems. While cloud computing offers potential benefits to users in terms of instant availability, resource and information sharing, it potentially poses security issues. According to a report brought out by Trend Micro, cloud computing moves servers outside the traditional security environment, making them easier to access by cyber criminals who will try to manipulate the connection to the cloud or attack the data centre. In a study by Spinola [10], it cited that GTRA (Government Technology Research Alliance) research showed that the most common concern about implementing cloud programs was security and privacy, a finding supported by an IDC study of 244 CIO's on cloud computing where 75% of respondents listed security as their number one concern. Moreover, recent Amazon's system failure, affecting thousands of businesses and major websites, highlighted the risks involved when companies rely on so-called cloud computing.

Cloud computing gives cloud customers access to completely different levels of scale and economics in terms of the ability to scale very rapidly and to operate IT systems more cost-effectively than traditional on-site computing infrastructures. As a cloud computing end-user, he obtains the benefits

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of the infrastructure without the need to implement and administer it, and could directly add or remove capacity almost instantaneously on a pay-as-you-use basis. The pharmaceutical firm Eli Lilly's successful utilizing Amazon's web service for immediately scaling up computing capacity to crunch the huge volume of data of a potential world-class drug within an hour provides a real world example of cloud computing advantages.

Observing the considerable benefits of cloud computing over conventional in-house (on-premise) application deployment, the question for every business boils down to "when and what IT functionality to migrate to cloud computing". The problem is akin to outsourcing, with the very specific issue of security. A recent study by Tak et.al. [6] tries to answer "Move or Not to Move to Cloud'" from economics perspective. They identify a comprehensive set of factors affecting the costs of a deployment choice (in-house, cloud, and combination), and use NPV (Net Present Value)-based cost analysis for adoption recommendations. Due to the complexity of quantifying associated security risk encountered with deployment choices, they do not include the risk factor in their current version of analysis.

In this paper, we respond to the decision problem, "When and What IT functionality to Move to the Cloud Computing'", confronted with cloud customers. Following Tak et.al. [6], we provide the analysis from economics perspectives. We approach the problem with two distinct models. The first model is an assessment of the cloud computing adoption under uncertainty, and the second model is to obtain optimal swapping of one computing paradigm for the other computing paradigm through a comprehensive assessment of two different paradigms under uncertainty. To perform the latter, we monetize potential "Savings" of one deployment choice over the other, and "Savings" is termed "Benefits" in our model analysis.[2] Different from Tak et.al. [6], we consider the estimated "Benefits" to stochastically evolve over time since we recognize that actual benefits can only be resolved as time progresses[3], for example, cloud pricing can change over time. We consider "Security" risks in both models. For the second model, each deployment choice is associated with its own security risks. The security risk would cause a negative jump (downward jump) for the adoption value (or benefits) because a security event would bring damages to enterprises. We model this negative jump expected from security risks by a Poisson process. In both models, the entrepreneur obtains his optimal adoption/migration rule by solving the optimal stopping time at which the entrepreneur shall migrate to the cloud computing paradigm. Both models suggest a threshold strategy as the entrepreneurial optimal adoption/migration rule. For the first model, a firm should adopt the cloud computing only if the value from the adoption exceeds the threshold level. For the second model, a firm's optimal migration rule is hinged on the level of benefit ratio. The benefit ration is defined as the benefit from the cloud computing paradigm over that from the traditional on-site computing paradigm. A firm should only shift the part of IT functionality to the cloud computing service if the ratio exceeds the threshold level. We find that in both models, the extent of riskiness and the significance of security risks (both in terms of potential occurrence probability and the severity of damage) have substantial impact on the threshold level, thus the entrepreneurial adoption decision.

[2]This is the same as identifying cost and cost factors affecting the deployment choice. "Savings" are just "Negative Costs Difference" between two different deployment choices.

[3]This is similar to the analysis of Tak et.al. [6] which considers standard deviation in their cost estimate.

### A. Contribution of the Study

Our study contributes to the literature by shedding lights on two issues:

1) How does the uncertainty of estimated benefits or adoption value impact the entrepreneurial decision of optimal migration to cloud services?
2) How does the significance of security risks associated with each computing paradigm, both in terms of potential occurrence probability and the severity of damage, affect the managerial decision of moving to cloud services?

The characteristics of an IT functionality does matter the entrepreneurial decision of migration to cloud services. From the analysis of our first model, given the constant adoption cost and the fact that the whole project value is the most that a firm will lose from security events, we find that the entrepreneur will tend to migrate to the cloud computing paradigm sooner if he anticipates that the adoption may accompany with a high probability of security events and/or substantial loss expected from potential security events. In addition, holding all else being equal, the higher the uncertainty of project value from cloud computing adoption, the later an entrepreneur will move the IT functionality to such a computing paradigm. Next, from the second model, "Swapping of Two Risky Assets", an IT functionality with potential huge benefits promised from the cloud computing paradigm does not necessarily support the earlier migration to the cloud services since the uncertainty and the security risks embedded in two different computing paradigms will impact the threshold level, defined by the benefit ratio of two computing paradigms.

## II. First Model: Optimal Adoption of Cloud Computing Paradigm under Uncertainty

We start with a simplified model focusing on the optimal adoption rule if the adoption presents uncertain project value as well as the potential security risks.

### A. Model Process

We assume the value from the cloud computing adoption are governed by a mixed Brownian/jump process:

$$dX(t) = \alpha X(t)dt + \sigma X(t)dW_1(t) - X(t)dL_1(t),\ X(0) = x \tag{1}$$

where $\alpha$, the growth rate, $\sigma$, the volatility, are both constants, $W_1(t)$ is a standard Weiner process, and

$$dL_1(t)_{(\lambda_1,\phi_1)} = \begin{cases} \phi_1, & \text{with probability } \lambda_1 dt \\ 0, & \text{with probability } 1-\lambda_1 dt, \end{cases} \tag{2}$$

with $\lambda_1$ being the mean arrival rate of the loss during an interval $dt$, and $\phi$ ($0 \leq \phi_1 \leq 1$) being the size (here referred to as a fixed percentage) of the loss caused by the sudden data loss security breach/ service unavailability.[4] We assume $dW_1(t)$ and $dL_1(t)$ are independent, i.e., $\mathrm{E}[dW_1(t)dL_1(t)] = 0$. Under this specification, it implies that (1) the project value from cloud computing adoption is always non-negative, and (2) the most that a firm will lose from the potential security events is the whole project value.

### B. Entrepreneur's Problem and Solution

Given the uncertain project value evolution (1), the entrepreneur solves his optimal adoption time (i.e., optimal stopping time in the terminology of control theory) that maximizes his expected discounted project value from cloud computing adoption by paying cost $K$:

$$F(x) = \sup_{\tau \geq 0} \mathrm{E}\left[e^{-\mu t}\left(X_x(\tau) - K\right) 1_{\tau < \infty}\right] \tag{3}$$

where $\mu$ is the rate of return required by the entrepreneur.

The solution to (3) is given in the following theorem.

*Theorem 1:*

$$F(x) = \begin{cases} \frac{K}{\beta-1}\left(\frac{x}{\hat{x}}\right)^{\beta} & x < \hat{x} \\ x - K & x \geq K \end{cases}, \tag{4}$$

where

- $\beta$ is the positive root of the characteristic equation $\frac{1}{2}\sigma^2\beta^2 - \frac{1}{2}\sigma^2\beta + \alpha\beta + \lambda_1(1-\phi_1)^{\beta} - (\mu + \lambda_1) = 0$.
- $\hat{x} = \frac{\beta}{\beta-1}K$.

*Proof:* Proof Sketch.

Assuming that the function $F(x)$ is sufficiently smooth, $F(x)$ solves the following variational inequality (V.I.) as a consequence of dynamic programming:

$$\begin{cases} \frac{1}{2}F''(x)x^2\sigma^2 + \alpha x F'(x) + \lambda_1 F(x)[(1-\phi_1)x] \\ \qquad -(\mu+\lambda_1)F(x) \leq 0 \\ F(x) \geq v - K \\ [F(x) - (x-K)]\left[\frac{1}{2}F''(x)x^2\sigma^2 + \alpha x F'(x)\right. \\ \qquad \left. + \lambda_1 F(x)[(1-\phi_1)x] - (\mu+\lambda_1)F(x)\right] = 0 \\ F(0) = 0;\; F(x) \geq 0;\; F(x) \quad \text{has linear growth at infinity.} \end{cases} \tag{5}$$

Next, it can be verified that the solution by (4) satisfies V.I. (5). ∎

By Theorem 1, we observe that $\hat{x} = \frac{\beta}{\beta-1}K$, the adoption trigger, is inversely related to the size of loss and the mean arrival rate of loss. That is, the higher the mean arrival rate of loss and the larger the size of loss, the lower the threshold value is required for triggering the cloud computing adoption. In other words, given the entrepreneur will lose the whole project value at most, the entrepreneur will attempt to shift to cloud computing paradigm sooner than later if he anticipates the probability of negative events is high and the loss is substantial. In addition, the higher the uncertainty, the higher the adoption trigger value is. That is, an entrepreneur would adopt the cloud computing later if the value obtained from cloud adoption is highly uncertain/volatile.

[4] $\phi_1$ itself can be modelled as a random variable.

## III. Second Model: Optimal Swap of Two Risky Assets

We continue with a more advanced study. In this modelling scenario, the entrepreneur can either keep the traditional on-site computing paradigm or migrate to the cloud computing paradigm. His problem is to make the paradigm shift optimally. To be able to perform the analysis of optimal shifting from one computing paradigm to another computing paradigm, we need to identify the value associated with these two different computing paradigms. However, instead of directly identifying the value of implementing each computing paradigm, we monetize potential "Savings" of one deployment choice over the other, termed "Benefits" in our model analysis. The sources of potential benefits of the cloud computing paradigm and the on-site paradigm are provided in the following section.

### A. Sources of Potential Benefits for Cloud Computing vs. On-Site Computing

We propose the following potential sources of benefit for cloud computing adoption based on the study from Gartner Inc. and other studies. They include:

1) Better Optimization of Operational Expense: Cloud computing offers a pay-per-use model for hardware and software functionality and does not charge for the features that come with software but not used.
2) Better Optimization of Capital Investments: Cloud computing takes away the task of infrastructural deployment and makes technology, platform or software readily available commodities; therefore, by obtaining cloud computing services, enterprises could have lower investment costs in hardware, software and real estate.
3) Better Speed and Flexibility of Implementing Business Changes: The elasticity and use of shared resources inherent in the cloud computing paradigm makes enterprises faster to achieve a business objective and easier to respond to the support of implementing necessary business changes.
4) Better Concentration on Achieving Business Objectives: Cloud service providers would take care of the IT matters; therefore, procuring could computing services could have enterprises focus on their primary business matters, for example machinery manufacturing, financial services, film delivery...etc.
5) Better Scalability: With cloud computing, enterprises get access to a broadening market of service providers that can satisfy their needs without investing in establishing those services inside their own enterprises.
6) Lower Cost/Risk/Time in Starting a New Business Model: Cloud computing enables small enterprises to get access to the IT services that were too expensive with the on-site paradigm, because many of them could not afford all the needed breadth of their own IT (along with their own hardware, software and human resources).

7) Lower Entry Barriers: Cloud computing sets lower entry barriers with its pay-per-use model and theres a lower need to invest in its own full-breadth IT infrastructure.

All of these sources have positive impacts on business values either through the cost reduction, securing more business opportunities due to better business development, or timely responding to market needs and better resource allocation.

On the other hand, we also identify the following potential sources of benefit for on-site computing adoption, consisting of:

1) Better Support for Unique Requirements Specific to the Particular Enterprise: On-site computing paradigm gets used to the customization of its users requests, while cloud computing broadly practices same- for-all services.
2) Better Control in Data Security and Application Ownership: Through on-site computing paradigm, enterprises have full control over their own business data, and at the same time, the application ownership is less threatened since the code and applications remain on-premises rather than stored in the cloud, with which the enterprises do not have the control power.
3) Better Control in Service Reliability and Quality: Unlike clouding computing paradigm in which service providers control over these issues, enterprises enjoy full powers in managing their service reliability and ensuring service quality with on-site computing adoption.
4) Better Coping with Regulatory Requirements and Responding to Risk Management: On-site computing paradigm has developed, over half a century, a more or less comprehensive set of best practices, standards, certifications and tools to manage risks and cope with the regulatory requirements.

As mentioned above for the case of adopting cloud computing paradigm, these sources have positive effect on the entrepreneurial values.

Before presenting our model, we clarify two points regarding input parameters for the model. First, when evaluating “what part of IT functionality to shift to cloud computing (equivalently, what cloud computing services to use)”, we shall only select the related factors for assessment. In addition, there is a major concern of sudden loss of data, security breach and service unavailability over the cloud computing adoption, which would render a significant loss to the enterprises. To incorporate this random negative event of adopting cloud computing services, we would subtract this potential negative impact from the benefit expected.

In the following section, we characterize the processes of potential benefits for cloud computing and on-site computing paradigms with uncertainties respectively.

### B. Processes for Potential Benefits

*1) Process for Potential Benefits of Cloud Computing Deployment:* We assume the benefits for the cloud computing adoption are governed by a mixed Brownian/jump process:

$$dX(t) = \alpha X(t)dt + \sigma X(t)dW_1(t) - X(t)dL_1(t),\ X(0) = x \tag{6}$$

where $\alpha$, the growth rate, $\sigma$, the volatility, are both constants, $W_1(t)$ is a standard Weiner process, and

$$dL_1(t)_{(\lambda_1,\phi_1)} = \begin{cases} \phi_1, & \text{with probability } \lambda_1 dt \\ 0, & \text{with probability } 1-\lambda_1 dt, \end{cases} \tag{7}$$

with $\lambda_1$ being the mean arrival rate of the loss during an interval $dt$, and $\phi_1$ $(0 \leq \phi_1 \leq 1)$ being the size (here referred to as a fixed percentage) of the loss caused by the sudden data loss security breach/ service unavailability. We assume $dW_1(t)$ and $dL_1(t)$ are independent, i.e., $\mathrm{E}[dW_1(t)dL_1(t)] = 0$. The reason we model the process as a geometric Brownian motion is that we measure the benefit as the advantage of the cloud computing adoption over the on-site adoption which shall be constrained in the non-negative value.

*2) Process for Potential Benefits of Traditional On-Site Computing Deployment:* We assume the benefits for the on-site computing adoption are governed by a mixed Brownian/jump process:

$$dY(t) = \nu Y(t)dt + \zeta Y(t)dW_2(t) - Y(t)dL_2(t),\ Y(0) = y \tag{8}$$

where $\nu$, the growth rate, $\zeta$, the volatility, are both constants, $W_2(t)$ is a standard Weiner process. We assume $dW_2(t)$ and $dL(_2t)$ are independent, i.e., $\mathrm{E}[dW_2(t)dL_2(t)] = 0$. We assume the two Wiener processes, $W_1(t)$ and $W_2(t)$, are correlated with $\mathrm{E}[dW_1(t)dW_2(t)] = \rho dt$, and

$$dL_2(t)_{(\lambda_2,\phi_2)} = \begin{cases} \phi_2, & \text{with probability } \lambda_2 dt \\ 0, & \text{with probability } 1-\lambda_2 dt, \end{cases} \tag{9}$$

Before proceeding further, we comment that the randomness (measured by Brownian motion) between the benefits of the cloud computing adoption and those of traditional on-site computing deployment can be uncorrelated, and in this case, we simply specify $\rho = 0$.

### C. Entrepreneur’s Problem and Solution

The entrepreneur’s problem is to find an optimal stopping time at which he should exchange the benefit from the on-site computing adoption for that from the cloud computing adoption. That is

$$F(x,y) = \sup_{\tau\geq 0} \mathrm{E}\left[e^{-\mu\tau}\left(X(\tau) - Y(\tau)\right)1_{\tau<\infty}\right] \tag{10}$$

where $\mu$ is the rate of return required by the entrepreneur.

We state the solution of (10) in the following theorem.

*Theorem 2:*

$$F(x,y) = \begin{cases} \hat{c}^{-\beta}(\hat{c}-1)\left(\frac{x}{y}\right)^{\beta} x & \frac{x}{y} \leq \hat{c} \\ x - y & \frac{x}{y} \geq \hat{c} \end{cases}, \tag{11}$$

where $\beta > 1$ is the positive root of the characteristic equation.

The theorem indicates that the entrepreneur shall shift to the cloud computing paradigm if the ratio, the benefits of cloud computing adoption over those of the traditional on-site computing deployment, exceeds the threshold $\hat{c}$. The threshold level, $\hat{c}$, is related to the degree of uncertainty embedded in the benefits of each computing paradigm and the significance of security risks (both in terms of potential occurrence probability and the severity of damage). In other words, ignoring any of these issues may lead to a non-optimal move.

## IV. Conclusion

In this study, we aim to identify the optimal rule of migrating to the cloud computing paradigm for enterprises from economics perspectives. We propose models based on the application of the option pricing theory and the concepts of exchanging one risky assets for anther risky assets used in financial pricing. Under the assessment of single technology adoption under uncertainty, we find that given the entrepreneur will lose the whole project value at most, the entrepreneur will attempt to shift to cloud computing paradigm sooner than later if he anticipates the probability of negative events is high and the loss is substantial. The "SWAP" model also identifies that the degree of riskiness (randomness) from the identified benefits and the extent of security risks will affect the entrepreneurial adoption decision. If one ignores any of these factors, he may shift the IT functionality to the cloud computing paradigm non-optimally.

A concrete monetization model for the benefits of both computing paradigms, the cloud computing deployment and the traditional on-site computing deployment, is crucial to the successful implementation of "SWAP" model presented in this study. Therefore, this will be one of our future research directions.


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