RFID Adoption Timing: The Application of Option Pricing Model

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Abstract

This paper aims to investigate the characteristics of RFID adoption and find a feasible way to decide the optimal adoption timing for RFID adoption. Due to the significant investment of this technology, RFID implementation could be considered in two stages -- internal and external adoption. Hence, a stage option pricing model (OPM) can be applied to calculate the optimal adoption time in the internal stage for the highest profit to the company. In this paper, we adopted OPM to solve the first stage internal adoption timing decision. Implications on the external adoption were also presented as a rational reference to managers.

1. Introduction

Radio Frequency Identification (RFID) is one of the most promising technologies and has been predicted to be a replacement technology for bar code in identifying and tracing goods in the future [1-3]. However, most potential adopters are still considering, but not adopting, this technology due to the inherent problems associated with this technology. These organizations, which have chosen to take the wait-and-see attitude, will lose the first mover advantage, including the early revenue, the first market place and long-run market share [4]. Nevertheless, on the other hand, they will not have to face the high cost and uncertainty of the technology. To strike for a balance, it would be desirable if an optimal timing could be calculated for RFID adoption decision.

In the context of technology adoption decision, the widely adopted and validated technology acceptance model (TAM) [5-7] could be used to predict RFID adoption using two constructs -- the perceived usefulness and the perceived ease of use [8]. Though TAM gives a good evaluation to the future technology adoption, it does not consider an organization's investment issues from the financial perspective. Consequently, TAM cannot suggest to practicing managers of any hint on the optimal time for the best savings to adopt RFID.

In addition to TAM, one qualitative analysis technique, real option analysis (ROA), has also received much attention when it is applied to the technology adoption. Though ROA is derived from financial options and has been used widely in investment analysis, IS researchers have also adopted this approach to examine the timing issue of the new technology adoption. To date, their findings based on ROA include: boundary condition and uncertainty influence the timing of the technology investment [9], industry attributes have an effect on the adoption timing of e-commerce [10], technology attributes can affect adoption timing of new technology [11], a continuous-time stochastic model proposed can determine the optimal timing for managerial adoption for two incompatible and competing technologies [12].

This paper aims to investigate the characteristics of RFID adoption and find a feasible way to decide the optimal adoption timing for the RFID adoption. Due to the complexity and costs associated with the technology, RFID project could be adopted in two stages - internal adoption and external adoption, with the former stage acts as the requisite of the latter one. In this staging process, the early internal adoption can bring in business benefits and serve as a fundamental infrastructure as well to base its second stage external adoption, which focuses on the connection to the supply chain of the company's trading partners. Using option pricing model (OPM), we propose a practical approach to decide the adoption time for the internal stage to bring the highest profit to the company. Implications for the external adoption will also be discussed.

2. Research Background

2.1 RFID Technology

FRID is a technology to identify or track objects with tags through radio frequency [1]. Basically, RFID technology is composed of three major components: RFID tag, RFID reader and transmitting information. RFID tag is a microchip with an antenna embedded, or put on as a label, in a product to transmit product data to a remote reader. The tag can be active or passive, depending on whether it has its own power and the ability to broadcast information. In addition to product identification and tracking, tags can also be used to sense, monitor, and record environmental changes, such as temperature, moisture and exposure to light [13]. RFID reader is used to capture data stored in tags for further transmission to a computer for processing. Many readers do not only have reading capability, but also have written capacity to update data stored in certain kind of tags. Information transmitted in the RFID systems could range from a serial number to more sophisticated database [13], depending on what have been embedded in the tags when the products were manufactured [14].

As compared to a bar code system, the advantages of a RFID system include the absence of line-of-sight problem, the ability to read tags in batch and information retrieval from a distance. Due to the unique capacity of RFID, its business applicability could be more diversified to include supply chain management, product or asset identification, logistics and transportation, healthcare, customer service, theft and waste prevention, personal and asset status application, etc. [1]. Specifically, RFID finds its widest application in the manufacturing industry. So far, many manufacturers have adopted RFID to support quality control, eliminate the need for manual continuing, deliver significant benefits in operations, improve product flow, enhance the productivity measurements, reduce employee theft, and improve picking accuracy [15]. In the logistic sector, RFID can be used to manage warehouses to improve visibility of goods movement throughout the transportation, which subsequently could possibly trim warehouse labor by 20%, slash inventory by 25%, boost sales by 3% to 4% [16] and gain more opportunities to cooperate across enterprise boundaries in supply chain [13].

Despite all these benefits, RFID, however, has not been widely adopted. Although Wal-Mart and Department of Defense of US have mandated their top 100 suppliers (out of a total of 10,000 and 43,000 respectively) to experiment and adopt RFID, this scale (1% and less than 1% respectively) only represents an insignificant number of their supplier base [16]. The sluggish adoption of RFID could include the concerns of cost, technology and standard [14]. The cost of a RFID tag, which could now be lowered to 20 U.S. cents, is still much more expensive than the anticipated 5 cents for a justifiable adoption. Besides the tag cost, there are also costs for hardware, software, and development.

The second adoption issue relates to the problem of reading distance and accuracy [2]. The incompatibleness of standards across different countries and areas may be the third hindrance for RFID adoption [13, 14, 17]. Fortunately, the establishment of second-generation standards, Gen 2, is expected to attract global tag makers to the market, resulting in increased competition and lower prices.

2.2 Stage Option analysis

Traditional Net Present Value (NPV) analysis has been widely used to evaluate finance projects by discounting their future cash flows with proper rates. Nevertheless, this technique, which was originally designed for fixed asset investment, has some limitations when applied to evaluate new technology projects [18]. Firstly, it holds an unrealistic assumption for new technology that future revenue is known for sure and the discount rate is fixed. Secondly, it neglects the future opportunities and flexibility new technology project brings and options for corrective actions, including implementation or termination that cannot be captured by NPV. Fortunately, researcher introduced ROA to IS field to evaluate new technology investment.

Real option theory is an extension of financial option theory to options on real assets. Finance option is the right but not the obligation to buy or sell a stock or other underlying asset at a particular price within or at a specified period of time [19]. ROA aims to identify and specify the options embedded in strategic investments [20]. The underlying asset of real option is not financial stock, but real asset [18]. The option offers an asset owner with embedded flexibility, but not the obligation, to change the asset's configuration [21]. From the perspective of real option, uncertainty is no longer considered as negative [22, 23], but considered as an opportunity that allows more flexibility, which coincides with the reality of new technology investment, particularly those multi-stage large-scale projects [24].

Stage option, which is one type of real option, suggests that investors should make small investments first, followed by large investments, to avoid big risk and provide more time for organization learning [25]. The first stage, though initially intends for accurate resource planning and project tracking, could later create more alternatives for future decision in the second stage. These alternatives include the options to abandon, change scale, or switch to other utilities based on the costs-benefits assessment according to the business and environment changes.

Previous studies of stage option usually focused on the flexibility of the second stage, i.e., whether or not to exercise the option [26]. To evaluate the flexibility embedded in real option, researchers have applied different option pricing models (OPM), which include Binomial model, Black-Scholes (B-S) model, and their extensions, for such investigations. Of all these OPMs, the B-S model and its variants are found most popular due to their simplicity. In the B-S model, the value of a call option can be calculated using the following formula:

$$C = SN(d_1) - Xe^{-Rf(T)}N(d_2) \quad (1)$$

$$d_1 = (\ln(S/X)) + (Rf + \sigma^2/2)*T)/(\sigma\sqrt{T}) \quad (2)$$

$$d_2 = d_1 - \sigma\sqrt{T} \quad (3)$$

Where:
C — Value of a call option;
S — Value of option's underlying risky asset;
σ — Volatility, the standard deviation of the expected rate of return on S;
X — Option's exercise price;
Rf — The risk-free interest rate;
T — Option's time to maturity or expiration; and
$N(d_i)$ is the standard normal distribution function and *i* is the index of *d,* the substitute variable.

Although the B-S model is simple to use, its application in real option analysis still has many problems. First, could this technique, which was designed to evaluate assets that can be traded in a financial market, be used to analyze non-traded assets such as IT project? Second, the assumption of risk-neutral in B-S model, which is against the reality of risk-aversion of most executives, may not find its support in the new technology adoption. Third, IT costs do not fluctuate like financial assets, thus making the parameters in the B-S model difficult to estimate based on past prices. For all these problems, quite a few IS researchers have already proposed solutions for rectification, therefore, making this model feasible for evaluating IT adoption.

2.3 Previous OPM Research in IS field

In 1991, Dos Santos employed Margrabe's exchange option model to value an IS project of a new technology. He argued that the greatest value of a new technology project does not come from the initial project, but from future-stage projects after having the experience and learning from the initial project [27]. His findings demonstrated that future investment values are difficult to capture using the traditional NPV model while option analysis can greatly improve the value estimation of a new IT project. Following the work of Dos Santos, Kumar's research on new IT investment and OPT provided a new insight into the understanding of an IT investment decision. His research examines the correlation between project risk and the option values of new IT investment using the B-S model and Margrabe exchange models. From the results of the B-S model, Kumar concluded that it was not always attractive (in terms of option values) to select a riskier second stage project, yet the result from Margrabe's exchange model indicated that option values could either increase or decrease with an increase in project risk [28].

Taudes derived a new option named the "software growth option" in his research. It is created by IS functions in a software system that can be used in applications brought into operation at certain implementation decision points when found beneficial. This new option represents the possibility, at certain future decision points, of bringing new functions from a current IS system into future-stage investment. Taudes' research adopted OPT formulae from the B-S, Margrabe, Geske, and Carr models, and evaluated the value of the software growth option embedded in a IS system [21]. The findings of this study concluded that in some cases the embedded option value can outweigh the negative static net present value and therefore make the investment economically justifiable. His research lays the foundation for valuing software platforms.

Undertaking the same kind of OPT research but from the perspective of a practitioner, Amram et al. provided a good illustration and explanation of why real options are applicable in IT project valuation, and of how to use option thinking to measure the value of IT projects. Their paper provides clear guidelines for realizing the benefit of a real IT option. They also argued that option analysis can help managers to capture and formalize their intuition, and create a sophisticated disciplined decision-making process [20].

Taudes et al. also employed the B-S model to solve a real business case problem of whether to continue using SAP/2 or switch to SAP/3 in a central European company. In this study, Taudes compared different valuation techniques, NPV, decision tree-based NPV, and OPM, and discussed their respective advantages and drawbacks. At last, he demonstrated the practical advantages of employing OPMs in the case studies. After including the option value of future potential e-business usage, which can be provided by SAP/3 but not by SAP/2, the upgrade investment is economically justified. The evaluation error caused by inaccurate parameter estimation is resolved by sensitivity analysis and the model is proven to be robust enough in this case. The conclusions from this work show that OPT can lead to a better-structured and more objective decision-making process. The research has given more detailed examination about the application of OPM. However, it did not study the timing of the option implementation although it has been mentioned in his paper [18].

Chang et al investigated the adoption timing of e-commerce and demonstrated that the timing for a company to introduce e-commerce depends on uncertainties regarding future cash flows and the opportunity costs associated with using e-commerce, which depend on industry sectors. Some industry sectors have low uncertainty and high jump behavior and companies in this industry should launch e-commerce early. The companies in the high-uncertainty industries with low jump behavior should wait before they can future information [10]. Besides the industry attribute, researchers also examined the effect of the technology properties on the adoption timing. Whether a new technology can bring very-high positive cash flow immediately after system implementation has been proved to be the main determinant for the adoption time by numerical analysis. Early investment should be preferred if the project can bring high and quick benefit. Otherwise, the adoption should be delay [11].

Kauffman and Li have analyzed the timing strategy for the adoption of two incompatible and competing technologies using a continuous-time stochastic model. The result suggests the deference of investment until the technology's probability to become successful in the marketplace and its critical mass has reached a critical threshold [12].

These studies about adoption timing can help managers to make their investment strategy, especially when the company competes with other rivals or faces two competitive alternatives. Nevertheless, it is still hard to decide when the company should implement the technology project definitely. Benaroch and Kauffman studied the exact timing of the technology deployment in a real bank, Yankee 24 in New England. They found the particular network infrastructure of the bank brought itself the options about the expansion of the point-of-sale debit services. When to exercise the option is the question they studied. They first confirmed that the major assumptions of B-S model based on the underlying economics of capital budgeting in a competitive market are also reasonable in technology adoption. They motivated the usage of B-S model whether the underlying asset is traded or not due to the correction of the market. Then they solved the optimal adoption timing by using approximate B-S model. Their studies give a formal theoretical grounding for the validity of B-S option pricing model in evaluation of IT investments [29].

In the follow-up research, Benaroch and Kauffman stated another factor, a project's idiosyncratic risk, can be introduced into the model because it may decrease the option value of an investment opportunity. Nevertheless, they also provided a fact that the optimal adoption timing did not depend on the particular value chosen of this parameter in their case by sensitivity analysis. Therefore, the application of B-S model is still valid for the timing issue in IS investment [30].

However, their research findings can not generalize to RFID project. Yankee 24 is a special case because it already had the infrastructure network, naturally providing the options for the expansion project. RFID is a new and revolutionary technology without existing infrastructure to support or provide an option. Thereby, further research is necessary to investigate the optimal adoption timing for RFID.

3. Optimal Investment Timing in Stage Options

3.1 Stage Option Analysis of RFID

Traditionally, stage option is applied to help to decide whether or not to conduct the investment of the second stage. Instead of studying the flexibility of the second stage [26], we try to solve technology adoption timing problem by broadening the application scope of stage option. RFID is a promising, yet risky, new technology that, like many other types of IT, has no guarantee of commercial success. Obstacles are everywhere: technological effectiveness, RFID tags costs, equipment costs, reengineering costs, diffusion rates, competing formats, competing technologies, privacy, and other concerns. Given these uncertainties, the adoption of RFID by a company would normally take place in stages. The initial stage, called the internal stage, will involve only part of the company's business, followed by a subsequent stage of extending the technology to remaining business and strategic partners, forming 2-staged investment of RFID. The internal stage will build infrastructure of RFID that is required to implement the technology. The infrastructure will also help to broaden the application scope of RFID in the external stage.

From an option perspective, the investment of the internal stage can be regarded as option-creating [20], providing options for the second stage not only for whether to adopt it, but also different times to adopt it. Investing in the external stage is just like the action of exercising the option. Thereby, to investigate the optimal investment timing becomes the corresponding question to find out the optimal option-creating time, i.e., when to create the option may have the highest option value?

After the construction of the internal stage, companies possess the options of different times for the second stage adoption. The uncertain time for option-exercising suggests an American call option, not a European one. American option can be exercised at any time point no later than the maturity. For each time point, there is a corresponding European option maturing at that time with other conditions unchanged. If there is no dividend-payment and the exercising cost is fixed, the value of American option is equal to the last corresponding European option, indicating exercising the option in advance is not the optimal decision [31]. It seems that it will be better for a company to delay their action, either exercising or abandoning, of the option. However, in RFID adoption context, things are more complex. Later adoption of RFID will delay revenue earned in early years, tending to be a kind of loss, which was theoretically considered by researchers as the dividend paid of the underlying asset [29, 30]. Therefore, the delay decision will not be optimal due to the "dividend paid" here. In addition, the revenue losing in this case is a continuous process and it is hard to find the last dividend payment date. Furthermore, the exercising cost will be declining rather than fixed with the obviously dropping expenditure of RFID technology in the future. Strictly speaking, it is not a dividend-paid American option of which dividend payment is discrete and exercising cost is always fixed.

3.2 Model Development

As the standard B-S model can not be directly applied to solve our decision problem, therefore we proposed a variant of B-S model in our research based on one assumption. We assume that the revenue loss occurs discretely for the convenience of the calculation of the underlying asset value.

As discussed earlier, there are five parameters in B-S model that affect the option value -- the value of the underlying asset and the volatility of it, the option's exercise price, the risk-free interest rate and maturity time. The volatility of the value of the underlying asset and the risk-free interest rate will not be affected within a big time of period. Because the maturity time will affect the option value directly, we will keep it as one consideration. The possible values of the underlying asset corresponding to different times of option-creating may be different. So will the option's exercise price. Therefore, we consider the option-creating time as the second dimension to consider. Based on this analysis, a two-dimension table can be drawn with the column referring to different option-creating time and raw the expiration time of the option.

As depicted in Table 1, the option value of each cell can be calculated by using the standard B-S model with the five aforementioned parameters estimated in a way discussed in latter section. The profit, i.e., option value minus cost for each cell could also be subsequently calculated. Here, the imagined European options maturing at different time may have different exercising cost to imitate the declining cost of RFID. The scope of the value for t and T will be determined and confined based on the reality of the company.

Table 1 An Approach to Calculate the Optimal Investment Timing

Profit		Option-Creating Time					
		t_1	t_2	…	t_a	…	t_n
Option Maturity Time	T_1						
	…						
	T_b				The highest profit		
	…						
	…						
	T_m						

Comparing the profits in each cell, the highest one(s) can be found and the determinant time point for option-creating time t_a can be confirmed. The model can be express in equation forms as following:

$$t_a, T_b = \underset{\substack{t_a \in \{0, t_1, \dots t_n\} \\ T_b \in \{T_1, \dots, T_m\}}}{\arg\max} [(P_{t_i,T_j} - X_{t_i}) * e^{-Rf*t_i} - \sum_{t_l=0}^{t_i} D_{t_l} * e^{-Rf*t_l})]$$

$$(i=1,2\dots,n;j=1,2\dots,m; 0<t_1<\dots<t_{n-1}<t_n; 0<T_1<\dots<T_{m-1}<T_m; \text{and } t_i<T_j) \quad (4)$$

$$P_{t_i,T_j} = S_{t_i} N(d_1) - X_{T_j} e^{-Rf(T_j - t_i)} N(d_2) \quad (5)$$

$$S_{t_i} = S_0 * e^{Rf*t_i} - \sum_{T_k=t_i}^{T_j} D_{T_k} * e^{-Rf*(T_k - t_i)} \quad (6)$$

$$d_1 = (\ln(S_{t_i} / X_{T_j})) + (Rf + \sigma^2/2) * (T_j - t_i)) / (\sigma\sqrt{T_j - t_i}) \quad (7)$$

$$d_2 = d_1 - \sigma\sqrt{T_j - t_i} \quad (8)$$

Where

t_a — The optimal adoption time for the first stage bringing the highest present option value;

T_b — The maturity time for the second stage bringing the highest present option value;

P_{t_i,T_j} — The value of the imaged European options created at time t_i and expired at time T_j;

X_{t_i} — The option-creating cost at time t_i;

D_{t_l} — The dividend paid/ the discrete loss at time t_l, $t_l < t_i$;

S_{t_i} — The underlying asset value at time t_i;

X_{T_j} — The option exercising cost at time T_j;

D_{T_k} — The dividend paid/ the discrete loss at time T_k, $T_k < T_j$;

σ — Volatility, the standard deviation of the expected rate of return on S;

Rf — The risk-free interest rate;

t_i — The investment time of the first stage;

T_j — The maturity time of the real option, also the dividend payment time;

i— The index for the timing of the first stage, *i=1,…n;*
j— The index for the timing of the second stage, *j=1, ….m;*
N (d_x) is the standard normal distribution function and *x* is the index of *d*, the substitute variable.

3.3 Result Interpretation

Based on the proposed model, the optimal option-creating time t_a is the optimal adoption time for the first stage, due mainly to its ability to bring in the highest profit during the whole project. As the functions of value in the row and the column are not monotonic, thus suggesting that there may be other values near or equal to the highest one, which in turn provide a multi-solution to the decision. Consequently, RFID adoption timing ought to evaluate other factors, rather than simply relying on the profit return of the investment. This includes the other determinant time -- the corresponding option maturity T_b.

By definition, we know that the maturity time does not equal to the exercising time as options offered may be abandoned. This scenario is identical to financial option that its option holder may exercise the option at the maturity time, or may not execute it when the market stock price at that time is lower than the exercising price. Unfortunately, the difference of maturity and the exercising time is either ignored or used interchangeably without any differentiation, which subsequently causes confusion in ROA research. In IT adoption, the possibility to abandon or exercise the options are critical due to the high uncertainty associated with technology development. Actually, the possibility to abandon or exercise and the uncertainty of the future condition are the most important factors that produce the option value we care about. Therefore, T_b cannot be viewed as the optimal adoption time for the second stage. Nonetheless, T_b can provide the managers with a good reference on whether to adopt or abandon the investment in the second stage before this maturity date.

3.4 Parameter Estimation

Researcher has recommended “market valuation” approach as an approximation rather than other methods for its convenience and simplicity [21]. With this approach, each parameter has its special estimation questions and format for their different properties. For example, it is rather straight forward to determine a time scope for the adoption t_n and the maturity of the option T_m based on the prediction of RFID development and the company’s strategy. Like previous research, half a year can be used to divide the time scope into several time of periods [29, 30], “creating” the dividend payment date at the end of each period. Dividend payment refers to the revenue loss for the delayed adoption. D_{t_i}, is the revenue lost during the course of waiting for the first stage implementation and D_{T_k} for the second stage, which, nevertheless, can also be estimated easier by market research data. Based on these estimates of the expected revenues, the present value of the underlying asset, S_0, can be produced.

The investment of the first stage will be the cost to create the option compared with the option value. The predicted investment for the external stage is considered as the exercise cost of the option, denoted as X_{T_j}. We provided a RFID cost evaluation framework to measure the cost, including hardware cost, software cost and implementation cost, in another separate paper [32]. The volatility of the rate of return of the underlying asset σ can be estimated by interview, brainstorming of the managers. Based on their RFID-related plans, different scenarios regarding the adoption environment can be used to calculate the variance using percentile estimation for normal distribution. Past data of similar project, such as, Electronic Data Interchange (EDI), can help to modify the estimate.

4. Future research

There are a few areas our research can be extended. First, the timing for RFID adoption is determined by more than five parameters specified in the B-S model. Therefore, more investigations need to be performed to evaluate the model’s applicability in the IS research domain. Second, the model we proposed is a variant model instead of an original one, therefore, rigorous mathematical proof needs to be performed to validate the fundamentals of this variant model. Third, empirical data needs to be collected to validate the suitability of the model's application in technology adoption. Most probably, a longitudinal study would be more appropriate in this regard.

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