Determining When to Adopt Advanced Information Technologies: A Multi-Stage Real Option Analysis

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Abstract—**Nowadays, the development of advanced information technology (IT) is rapid. Adopting such advanced IT products in an organization has been considered as crucial to establish an effective competitive strategy. However, determining the best time to implement a particular advanced technology is critical. In this study, the optimal adoption time to implement advanced new technologies is suggested. We recommend implementing expensive advanced new technologies in several stages and apply a multi-stage option pricing model to calculate the optimal solution, that is, to generate the maximum profit and the corresponding timing for each stage. The implications of such timing are interpreted as rational references for practitioners.**

Keywords*- *Advanced information technology; adoption timing; implementation; option pricing model; real option

INTRODUCTION

Information technology (IT) has rapidly developed and has been applied in the business sector in the past decades. Moreover, new advanced technologies continue to develop, such as radio frequency identification (RFID), 3D printing, cloud computing, big data, and other technologies. Research has shown that the successful application of advanced IT can benefit numerous aspects of the business sector, including supply chain management, product management, logistics and transportation, customer service application, and healthcare [1]. The advantages of advanced IT have attracted many companies and industries to adopt and apply such technology. For example, the rapid development of cloud computing has been applied to biology to improve the efficiency of calculations [2], to architecture to enhance multidisciplinary and collaborative research [3], and to business to increase supply chain innovation [4]. However, the appropriate time to adopt IT is the most important decision for managers due to the problem of "productivity paradox" of IT. Increase in productivity is always accompanied by huge investments. Maintaining competitiveness and reducing risks as well are critical. On the one hand, companies have to wait for a technology to mature and for its cost to be attractive. On the other hand, a wait-and-see attitude results in losing the first-mover advantage [5]. Therefore, deciding the optimal adoption time for an advanced IT is highly desirable for many companies.

Although the well-accepted technology acceptance model (TAM) [6] helps companies decide on their adoption decision, this model mainly focuses on the individual acceptance of a technology and does not consider the financial perspective of a company. In the present study, real option analysis (ROA) is applied to include financial information to predict optimal adoption time. Real option is derived from finance option. Its underlying concept involves viewing opportunities as options to take future actions that coincide with the characteristics of IT projects, in which future investment may have several options after the first stage or the pilot stage is implemented. Compared with traditional financial analysis approaches such as net present value (NPV) analysis, ROA is more suitable for advanced IT adoption because it can capture future opportunities and the flexibility of new technologies as well as provide options for corrective actions, including implementation or termination. Therefore, previous information system (IS) researchers have successfully adopted this approach to examine technology investment in general and optimal timing in particular. They have investigated topics such as boundary condition and uncertainties, which influence the timing of a technology investment [7]; industry attributes, which affect the adoption timing of e-commerce [8]; the effects of technology attributes on adoption timing [9]; the use of a continuous-time stochastic model to determine the optimal timing for the managerial adoption of two incompatible and competing technologies [10]; and decision-making regarding the deployment of software platforms [11].

The present study investigates the manner in which companies can determine the optimal adoption time for advanced IT. An implementation of advanced IT in stages was previously recommended because of the complexity and costs usually associated with such process [12, 13]. Each stage can draw business benefits and serve as a requisite for the next stage. We use an option pricing model (OPM) to propose a practical approach for deciding the adoption time for the first stage and to provide insights into implementing the second stage from a financial perspective.

This paper is organized as follows. First, we review related research on real options theory. Second, we analyze stage options and develop our estimation model for optimal technology adoption timing followed by a discussion of the model and its implications. Finally, we present our conclusions and future research directions.

RESEARCH BACKGOUND

OPMs have been introduced into the management information systems (MIS) field to evaluate real options brought by new technologies. Although the application of such models in real option may violate their original assumption, they can still provide a different perspective of the uncertainty to IT project managers through quantitative analysis. In addition, OPMs can be used to solve problems in project management in addition to simple option valuation because of their flexibility. In general, the application of ROA in IT investment can be classified into three categories: IT project valuation, IT investment timing, and other IT project management issues.

IT Project Valuation Using ROA

IT project valuation refers to the valuation of an IT investment, that is, whether a firm should invest on a certain IT project. In 1991, Dos Santos [14] used Margrabe's exchange option model to evaluate the implementation of new IS technologies. He argued that the main value of a new technology project would not come from the initial endeavor but from future projects that would benefit from the overall learning experience [14]. His findings demonstrated that future investment values would be difficult to estimate when the traditional NPV model was used and that option analysis could significantly improve the overall value estimation of a new IT project. Building on this previous work, the research of Kumar [15] on IT investment and OPM provided new insights into the understanding of an IT investment decision. It examined the correlation between the project risk and option values of new IT investment using the Black–Scholes (B–S) model and Margrabe's exchange model. The results of the B–S model showed that in terms of option values, selecting a riskier second-stage project was not always attractive; meanwhile, the result of the Margrabe's exchange model indicated that option values could either increase or decrease with an increase in project risk [15].

Taudes [16] presented a new procedure called "software growth option," which represented the possibility of bringing new functions from a current IS system into a future stage investment at certain future decision points. He adopted the OPM formulae from the B–S, Margrabe, Geske, and Carr models and then evaluated the value of the software growth option embedded into an IS system [16]. He concluded that in some cases, the embedded option value outweighed the negative static NPV, and thus, made the investment economically justifiable. This research lays the foundation for the valuation of software platforms.

Amram et al. [17] conducted the same kind of OPM research from the perspective of practitioners and provided a good explanation for the applicability of real options to IT project valuation. They used option thinking to measure the actual value of IT projects and provided clear guidelines to realize the benefit of a real IT option. These researchers also argued that option analysis could help managers capture and formalize their intuition and then create a sophisticated and disciplined decision-making process [17].

Taudes et al. [16] used the B–S model to solve the real business problem of a central European company of whether to continue using SAP/2 or to switch to SAP/3. They compared different valuation techniques, namely, NPV, decision tree-based NPV, and OPM, and discussed the respective advantages and drawbacks of these techniques. After the option value of future potential e-business usage was included, which was possible with SAP/3 but not with SAP/2, upgrade investment was economically justified. The evaluation error caused by inaccurate parameter estimation was resolved through sensitivity analysis, and the model was proven to be sufficiently robust. These researchers demonstrated that OPM could lead to a better-structured and more objective decision-making process. However, they did not study the actual timing of option implementation, although this issue was raised in their research [11].

Kumar [18] found that unlike financial options, real option values could either increase or decrease with the increase of risk in a project. Later studies differentiated the risks that could be resolved by action from the risks that required hedging, and presented a framework for assessing the business value of IT infrastructure [15, 19]. Other frameworks or models derived from ROA can help in IT project evaluation; they include the framework of strategic actions [20] and models that account for uncertainty in the costs and benefits associated with investment opportunity [21], among others. Recently, researchers used ROA to evaluate the investment of RFID in a supply chain [22].

IT Investment Timing Using ROA

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In some cases, the concern of managers is not whether to adopt but when to adopt a technology. *IT investment timing* refers to the optimal time for adopting a certain IT investment that can return the highest value. It is an extension of IT project valuation based on the calculation of the option value to solve the timing problem by comparing the value of a project at different times and then selecting the optimal time. McGrath [23] argued that boundary condition and uncertainty would influence the timing of a technology investment.

Benaroch and Kauffman [24] studied the exact time of technology deployment in the ATM network, Yankee 24, in New England. They found that the particular network infrastructure of the bank provided the option to expand point-of-sale debit services. The researchers studied the best time to exercise this option. First, they confirmed that the major assumptions of the B–S model based on the underlying economics of capital budgeting in a competitive market were also reasonable in technology adoption. They encouraged the use of the B–S model regardless of whether the underlying asset was traded or not because of the correction of the market. Second, they determined the optimal adoption time by using an approximate B–S model. Their studies provided formal theoretical grounding for the validity of the B–S OPM in evaluating IT investments. In their follow-up research, Benaroch and Kauffman [25] showed that another factor, namely, the idiosyncratic risk of a project, should be introduced into the overall model because it might decrease the option value of an investment opportunity. However, they also showed that in their case, the optimal adoption time did not depend on a particular value of this parameter. Therefore, the application of the B–S model remains valid for the timing issue in IS investment.

Chang and Hung [8] investigated adoption timing and demonstrated that the best time for a company to introduce e-commerce depended on uncertainties regarding future cash flows and opportunity costs associated with using e-commerce, which depended on industry sectors. Companies in industry sectors with low uncertainty and high jump behavior should launch e-commerce early. By contrast, companies in high-uncertainty industries with low jump behavior should wait until they can obtain future information.

Several researchers believe that adoption time can be determined by whether a new technology can create a high positive cash flow immediately after its implementation. Early investment should be preferred if the project can bring high and immediate benefits. Otherwise, adoption should be delayed [9]. Kauffman and Li [10] analyzed the timing strategy for adopting two incompatible and competing technologies by using a continuous-time stochastic model. Their results suggested the deferment of investment until the probability of a technology to become successful and its critical mass reached a certain threshold. Zhu and Weyant [26] attempted to integrate game-theoretic models of strategic market interactions into a real option approach to analyze IS investment decision. Timing and ordering were included in the model. Their results showed that competition led to early exercise and aggressive investment behavior. A recent study found that present-biased managers would be more likely to exercise options with a low net payoff, high volatility, and small risk-free discount rate at an early time and a growth option in its life when the project was performing well [27].

The aforementioned literature provides insights into the optimal timing for advanced IT. However, some research findings cannot be generalized easily to other technologies. For example, Yankee 24 is a special case because the infrastructure network that provides the option for the expansion project already exists. Most advanced ITs are relatively new and have no existing infrastructure and feasible option. Therefore, further research is necessary to investigate the optimal adoption time for these technologies.

IT Project Management Using ROA

In addition to IT project valuation and IT investment timing, other applications of ROA are used in IT project management. Keil and Flatto [28] examined the escalation of commitment using options theory. They argued that traditional theories of escalation behavior provided an incomplete view, and thus, they applied options theory to demonstrate that some projects, which might otherwise be regarded as cases of unwarranted escalation, actually involved situations in which escalation would be warranted. Options theory offers new theoretical insights that challenge traditional assumptions but complement existing theories on escalation behavior. Fichman et al. [29] analyzed several options with real cases. They argued that real options would not only be a new approach to valuate IT investments and determine their timing but also provide a new manner of managing and structuring IT projects. A conceptual model of the determinants of the option value associated with IT investment was developed. The effect and interaction of the factors, technology strategy, organizational learning, innovation bandwagons, and technology adoption on the option value were studied [30].

Grenadier and Weiss [31] developed a model of optimal investment strategy for a firm confronted with a sequence of technological innovations by using ROA. The model yielded four investment strategies: laggard, leapfrog, compulsive, and buy-and-hold. Another framework was provided to justify the application of ROA in IT investment based on two criteria: technology switching costs and nature of competition, which formed four categories. This previous study argued that different real option models should be adopted for each category with a real case [32].

McGrath [23] extended ROA to technology-positioning projects and asserted that the option value could be amplified by investments to shift boundaries, ideally in manners that would be idiosyncratic to the firm. In the follow-up research, McGrath examined the initiation of technology-positioning investments through ROA and provided a method to access uncertain projects that could approximate option value by scoring a series of statements. This approach integrated technological and strategic considerations [33].

Risk management is another topic in project management. Dewan et al. [34] investigated the risk–return relationship of IT investment and demonstrated that IT capital investment could make a substantial contribution to overall firm risk. Moreover, IT return was associated with a substantial risk premium. Benaroch [35] proposed a methodology for planning the creation of specific operating options designed to maximize the value of a technology investment by considering the risks that underlay that investment. Afterward, the research presented an approach to manage IT investment risk to make a rational choice; such options could optimally control the balance between risk and reward [36]. Along with other researchers, he validated risk-option mappings for choosing particular real options embedded into an investment to control risks by empirically testing 50 IT investments and demonstrating that the use of formal real option models to control risk would be necessary [37].

Stage Option Analysis of Advanced IT

Advanced ITs do not necessarily guarantee commercial success. Obstacles are everywhere, including technological effectiveness, costs, diffusion rates, competing formats, competing technologies, privacy, and other concerns. Implementing an advanced IT project in a single stage is difficult because of these uncertainties. Stages of implementation are necessary to reduce risk. In this research, the implementation of advanced IT is divided into two stages for convenience. The first stage aims to build the necessary infrastructure, whereas the second stage involves the complete implementation of the advanced IT.

Stage Options and the B–S Model

Real option theory is the extension of financial option theory to options on real assets. A finance option is the right to buy or sell a stock or any other underlying asset at a particular price within or at a specified period [38]. ROA aims to identify and specify the options embedded into strategic investments [17]. The underlying asset of real options is not financial stock but real assets [11]. The option is offered to an asset owner, but not the obligation to change the configuration of the asset [16]. From the perspective of real options, uncertainty is no longer considered negative [39, 40], but an opportunity that provides flexibility. This flexibility is necessary for investments in new technology, particularly when multi-stage large-scale projects are undertaken [32].

A multi-stage option, which is a specific type of real option, suggests that investors should make small investments first to avoid high risk and provide a long time for organizational learning [41]. Although initially used for accurate resource planning and project tracking, the first stage can provide alternatives for future decisions that will be made during the second stage. These alternatives include the options to abandon, change scale, or switch to other utilities based on the cost–benefit assessment according to changes in the business environment

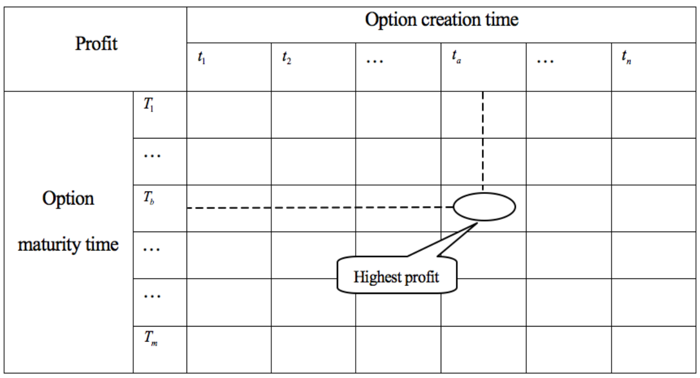
Previous studies on stage options have usually focused on the flexibility of the second stage, that is, whether an option should be exercised [42]. To evaluate the flexibility embedded into real options, researchers have applied different OPMs, including binomial models, B–S models, and their extensions. Among these OPMs, the B–S model and its variants are the most popular because of their simplicity. Only five parameters are required in a B–S model to calculate the option value, namely, the value of the underlying assets, the volatility of the underlying assets, exercise price, risk-free interest rate, and the maturity time of the option (refer to the appendix for the model specification). Although the assumptions of the B–S model, such as traded assets and risk neutrality, may not be satisfied in real option analysis, researchers have already proposed solutions to rectify and verify, thereby making this model feasible for evaluating IT adoptions [24, 25].

Model Development

From a real option perspective, investment during the first stage of advanced IT can be regarded as option-creating [17], that is, it provides options for the second stage, such as optimal timing or whether to adopt a technology at all. Investing during the second stage corresponds to exercising the option in a financial contract. Therefore, finding the optimal time becomes the most important issue, such as “when does exercising the option create the highest option value?”

After option creation during the first stage, companies have the option to choose different points in time to adopt the second stage. The uncertain time for option-exercising suggests an American call option and not a European one. American options can be exercised at any time before their maturity. For each time point, a corresponding European option matures exactly on the expiration date. If no dividend payment is made and exercising cost is fixed, then the value of an American option is equal to the last corresponding European option, which indicates that exercising an option in advance is not the optimal decision [43]. Therefore, companies seem to be better off delaying their action by either exercising or abandoning the option. However, in an advanced IT adoption context, considerations are more complex because a late adoption will delay potential revenue. This action can be regarded as a kind of loss, which corresponds to the lost dividend paid by the underlying asset [24, 25]. Therefore, the decision of whether the option should be delayed will not be optimal because of the "dividend paid" in this case. In addition, the losing revenue is a continuous process, and determining the due date for the last dividend is difficult. Furthermore, the exercising cost will decline instead of remain constant because of the continuously dropping costs of advanced IT technology. Strictly speaking, a real option for technology investment is not an American option with discrete dividend payments and fixed costs.

The standard B–S model cannot be directly applied to solve our decision problem; hence, we propose a modification based on the assumption that revenue loss occurs discretely. This assumption, which can be loosened, is made for the convenient calculation of the underlying asset value.



The optimal timing for creating an option t_a can be easily found by comparing the profits in each cell.

Figure 1. Approach to calculate the optimal adoption time.

As discussed earlier, the five parameters in a B–S model affect the option value, that is, the value of the underlying asset and its volatility, the exercise price of the option, the risk-free interest rate, and maturity time. The volatility of the underlying asset value and the risk-free interest rate will be unaffected for a long period. Maturity time directly affects the option value, and we consider it to be the first dimension in our model. The potential values of the underlying asset at various times of option creation may differ. Moreover, the exercise price of the option may also be different. Therefore, we consider the option-creating time as the second dimension. In Figure 1, the columns indicate different option-creating times t_n, whereas the rows T_m denote the expiration time. The option value of each cell can be calculated using the standard B–S model with the five aforementioned parameters. The profit, that is, the option value minus the cost, can be easily calculated for each cell. In this study, European options maturing at different points in time may have various exercising costs to imitate the declining cost of advanced IT. The respective scopes of the values for t and T will be determined and confined based on the environment of a company.

Parameter Evaluation

The main parameters in the model can be estimated easily using a "market valuation" approach, which is convenient and relatively simple [16]. In this approach, each parameter has its special estimation procedure and format for different properties.

For example, determining a time scope for the adoption t_n and the maturity of the option T_m is straightforward based on the prediction of advanced IT development and the strategy of a company. As adopted in previous research, half a year can be used to divide the time scope into several periods [24, 25], with the dividend payment date at the end of each period. In this case, dividend payment refers to the loss of revenue caused by delayed adoption. D_{t_i} is the revenue lost during the course of waiting for the first stage that should be implemented, and D_{T_k} is the loss from the second stage, which can also be estimated using market research data. The present value of the underlying asset S_0 can be easily calculated based on the aforementioned estimates of the expected revenues.

The investment for the first stage will be the cost to create the option compared with the actual option value. The predicted investment for the second stage is considered as the exercise cost of the option and is denoted as X_{T_j}. The cost includes all the hardware, software, and implementation costs. The volatility of the rate of return of the underlying asset σ can be estimated through interviews with managers. Different scenarios regarding the adoption environment can be used to calculate the variance based on advanced IT-related plans through percentile estimation for normal distribution. Previous data of similar projects, such as the implementation of electronic data interchange (EDI) or enterprise resource planning (ERP), can help improve estimates.

Discussions and Implications

Our multi-stage real option model helps company managers decide when they should adopt advanced IT. The optimal option creation time t_a is the optimal adoption time for the first stage based on an estimation of the profit for the total project. However, the functions in the rows and columns are not monotonic; hence, more than one optimal solution possibly exists. In our model, the corresponding option maturity T_b helps managers choose the "optimal but real" solution among possible ones.

The maturity time of an option is not equal to its exercising time because options may be abandoned. With financial options, the option holder may exercise his/her right at maturity time or he/she may not execute it at all when the market stock price is lower than the exercising price. Disregarding the difference or using maturity and exercising time interchangeably will cause confusion in ROA research. In advanced IT adoption, the possibility of abandoning or exercising the option is critical because of the high uncertainty associated with technology development. In fact, the possibility of abandoning or exercising and the uncertainty of the future condition are the most important factors that produce the option value. Therefore, T_b cannot be regarded as the optimal adoption time for the second stage. Nonetheless, T_b can provide managers with a good reference on whether to adopt or abandon the investment during the second stage before the maturity date.

This research contributes to advanced IT implementation in both practical and academic applications. The adoption timing of advanced IT is a critical problem for most companies working with partners in a supply chain. The proposed model can help managers make justified strategic decisions. We identify the time for an advanced IT adoption, particularly during the first stage. Company managers can benefit from this approach when they make strategic plans for their companies. The adoption time for the first stage can be easily calculated. Moreover, the maturity time for the decision of the other stages can be provided as a rational reference. In addition to the model parameters proposed in this research, other factors during the decision-making process, such as technology maturity, internal requirements, and the adoption environment of the overall supply chain, must be evaluated by company managers before they make their final decision. For the academic contribution of this work, we continuously extend the application of the multi-stage real option approach to a wider scope to solve the adoption timing issue, which further research on stage options and IT investment. In addition, this research highlights the applicability of using OPM to explain advanced IT implementation decisions.

CONCLUSIONS AND FUTURE RESEARCH

In this study, a multi-stage real option analysis is proposed to assess the optimal timing of advanced IT adoption. We present a feasible approach based on the B–S model with two dimensions, namely, the implementation time for the first stage and the maturity of the option. By applying the procedures of the B–S model, we can easily calculate the highest profit and its corresponding implementation time. The optimal adoption timing of advanced IT can be solved by finding the optimal option-creation time.

This research has several limitations. First, it only focuses on the financial perspective and does not consider the general adoption environment in the whole supply chain. The network effect of advanced IT technology may change the strategy of a company, and subsequently, the adoption timing of advanced IT. The lock-in effect of advanced IT has also not been considered in this research. As far as the model is concerned, several potential improvements exist. For example, more variables are required in addition to the five parameters specified, and perspectives other than the financial one must be considered. Moreover, additional longitudinal studies must be performed to validate the model. Finally, advanced IT adoption timing is more complicated in reality. For example, some companies cannot determine the appropriate timing for adopting RFID based only on their needs; that is, powerful downstream or upstream partners may require them to participate in an RFID supply chain [13]. If companies depend significantly on their partners, then the adoption time for the first stage of advanced IT implementation becomes mandatory, and the model proposed in this research is not applicable.

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APPENDIX

In the B–S model, the value of a call option can be calculated using the following formulas:

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

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

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

where
C — the value of a call option;
S — the value of the underlying risky asset of the option;
σ — volatility, the standard deviation of the expected rate of return on S;
X —exercise price of the option;
Rf —risk-free interest rate;
T —time to maturity or expiration of the option; and
$N(d_i)$—standard normal distribution function, and *i* is the index of *d*, which is the substitute variable.
The model can be expressed as follows:

$$t_a, T_b = \underset{\substack{t_a \in \{0, t_1, \dots t_n\} \\ T_b \in \{T_1, \dots, T_m\}}}{\arg\max} [(P_{t_i, T_j} - X_{t_i}) * e^{-Rf * t_i} - \sum_{t_l = 0}^{t_i} D_{t_l} * e^{-Rf * t_l})], \quad (4)$$

(i=1,…n-1,n; j=1,…,m-1,m; $0 < t_1 < \dots < t_{n-1} < t_n$;

$0 < T_1 < \dots < T_{m-1} < T_m$; and $t_i < T_j$)

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

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

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

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

where

t_a —the optimal adoption time for the first stage, which brings the highest present option value;

T_b —the maturity time for the second stage, which brings 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-creation cost at time t_i;

D_{t_l} — the dividend paid/ 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 that exercises cost at time T_j;

D_{T_k} — the dividend paid/ 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 for the first stage;

T_j — the maturity time of the real option, also the dividend payment time;
i— the index for the timing for the first stage, i=1,…n;
j— the index for the timing for the second stage, j=1, ….m; and
N (d_x)—the standard normal distribution function, and *x* is the index of *d*, which is the substitute variable.