Methodological Improvement for the Economic Assessment of Public R&D Programs

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ABSTRACT

Korea has rapidly increased R&D investment over the last few decades and the intensity of R&D investment is among the highest in the world; however, there are serious concerns about R&D performance and R&D efficiency. This study is to improve the economic assessment methodology regarding a feasibility study for national R&D programs that are thought to be one of the most prominent ways to enhance R&D efficiency. In order to improve the methodology of economic assessment, a few of important factors such as technical or market uncertainty, spillover effect, and R&D contribution ratio should be covered in the model. The focus of this article is technological and market uncertainty that has a close relation with strategic flexibility and utilization potential to increase the value of R&D programs. To improve the current linear and definitive R&D process, a new framework with strategic flexibility is suggested, in which the result of economic assessment that considers technological and market uncertainty is reflected in planning. That kind of feedback process is expected to enhance the value of the program/project as well as R&D efficiency.

KEYWORDS: R&D efficiency, economic assessment, feasibility study, real option, technological risk

1. INTRODUCTION

Korea spent 43.9 Trillion Korean Won (37.9 billion US$) on R&D in 2010 which puts Gross Domestic Expenditure on R&D (GERD) at 3.74% of GDP and is one of the highest levels in the world. Korea has also increased R&D invest in ment at one of the fastest annual rates of growth in recent years (although considerably below that of China) and exceeds that of other advanced countries. The volume of Korean R&D expenditures is rapidly catching up with the level of expenditures in the UK and France; the annual growth rate of business R&D is around twice the OECD average. The Business Enterprise Expenditure on R&D (BERD) is now among the highest in the world and is

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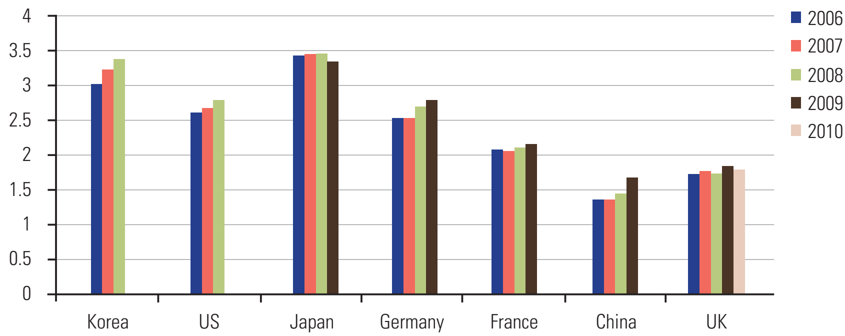
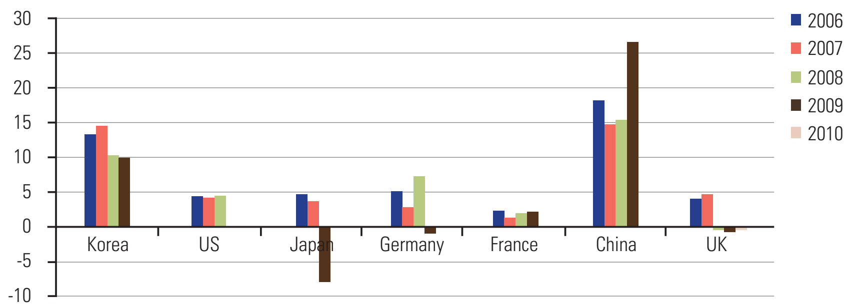
indicative of the emergence of Korean leaders in industrial technology areas such as information and communication technology, automobiles, shipbuilding, and steel (OECD 2009).

FIGURE 1 R&D Intensity (Gross Domestic Expenditure on R&D as a percentage of GDP, %)



Source: OECD, Main Science and Technology Indicators, 2011-1

FIGURE 2 Growth Rate of R&D Expenditure (%)



Source: OECD, Main Science and Technology Indicators, 2011-1 MEST, Korea

Although the intensity of R&D investment is among the highest in the world, there is a serious concern about R&D performance and R&D efficiency in Korea. The quantitative performance of Korean R&D investment is so significant that the number of scientific publications doubled in six years from 11,324 in 1999 to 23,048 in 2005. Korea is now in 11th place with 39,848 publications in 2010 (3.4% of the global total); however, the qualitative performance has not been fully matched with the quantitative performance. One of the important qualitative performance indicators (citations per paper) has improved gradually from 2.8 in 2005 to 3.5 in 2009. However, the ranking of the indicator remains markedly lower than the number of papers published.

There are several reasons for the disparities between the publication and citation rates that include database and language biases and the differences in publication behavior in different scientific fields. However, even if these are taken into account, it is likely that many Korean scientists fail to publish groundbreaking and original research that might be cited by international peers (OECD 2009).

Patent data also show similar tendency with the publication data in terms of quantitative and qualitative performances. Even though patents have been used as the most familiar R&D performance indicator, they are not as important as the commercialization or technology trade, because a patent is just a throughput and not the outcome. As one of the main commercialization indicators, technology transfers reveal the handicap of the Korean innovation system. Spending 13.2 billion

US$ in 2009, Korean government earned only 29 billion KRW \(25.2 million US$) from R&D investment through technology transfers. According to the Korean Industrial Property Office (KIPO), the rate of licensing of Korean universities and public research institutes remains below the US (two thirds) and the royalty per licensing is 1/80 of that of the US (KIPO 2011).
The technology trade data also corresponds with that of technology transfers. The Korean trade volume in technology was only 8.2 billion US$ in 2008 and below that of representative advanced countries (5.6% of the US and 15.4% of UK).

TABLE 1 Publication Performance of S&T Articles

	2006	2007	2008	2009	2010
Number of Articles	28430	27407	35624	38647	39843
Share (%)	2.89	2.78	3.05	3.24	3.37
World Ranking	11	12	12	11	11

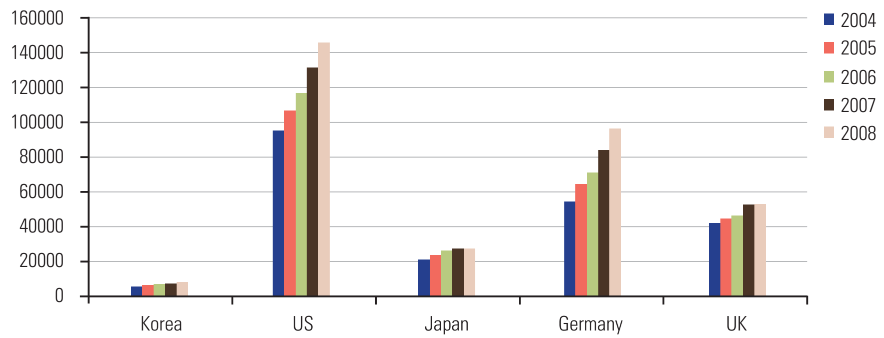
Source: MEST, Korea

TABLE 2 Citation Performance of Published S&T Articles

	2006	2007	2008	2009	2010
Citation per Article	2.79	2.93	3.1	3.29	3.47
World Ranking	30	31	31	30	30

Source: MEST, Korea

FIGURE 3 The Volume of Technology Trade (millions US$)



Source: MEST, Korea

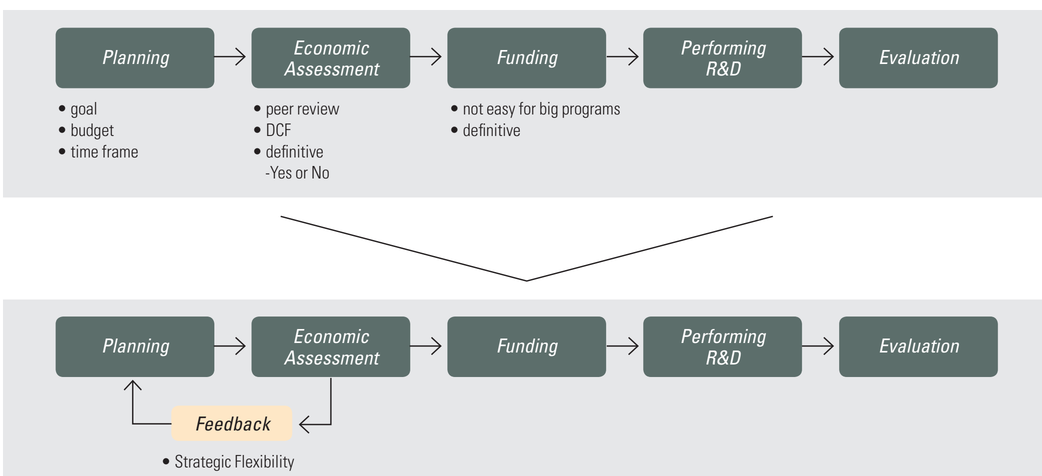
In order to improve the qualitative performance and efficiency of the Korean R&D investment, many policy tools should be considered that included reinforcement of the promotion programs for commercialization and redesign of the incentive mechanism for technology transfer. Among those policy tools, improving the prior decision making system is one of the most prominent ways, because R&D efficiency could be increased clearly by saving the money from nonviable R&D programs. For applied research with obvious applications for commercialization, the most critical procedure in the decision making process is economic assessment. Economic assessment is now required as a core element of evaluation in the formal R&D decision making process of Korea (i.e. preliminary feasibility assessments of R&D programs/projects), especially when the size of investment exceeds a certain

amount (50 B\). Some problems remain such as uncertainty, spill over, and technology contributions even though the formal economic assessment procedure for the Korean public R&D programs has a long history of methodological development.
Among those problems, the focus of this article is the uncertainty that is closely related to the concept of strategic flexibility in R&D planning. This stated, Hwang and Jeong (2007) showed that the value of an R&D program could be increased by imposing strategic flexibility under the given uncertainty.

2. UNCERTAINTY AND STRATEGIC FLEXIBILITY

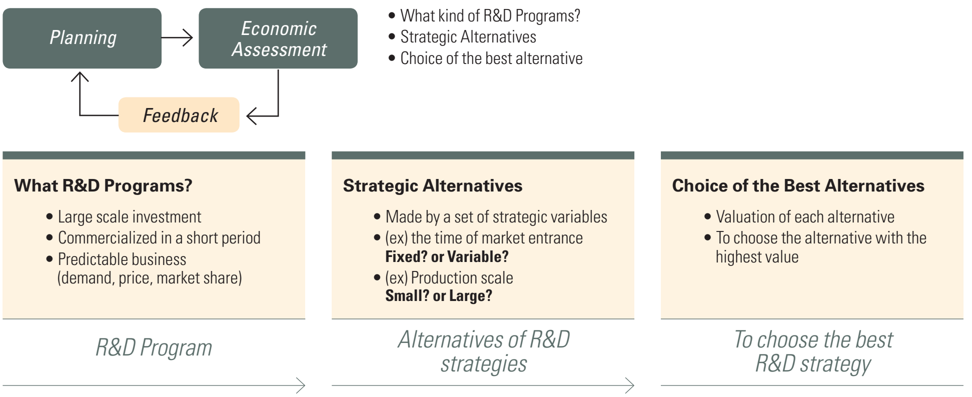
The current R&D process in Korea is linear according to Hwang and Jeong (2007). As the first step, goals, budgets, and the duration of the R&D programs/projects are planned and a feasibility assessment is conducted if the size of the program is over a certain amount (now 50 Billion Korean Won (43.5 million US$). The economic value of a program/project is mainly evaluated by the discounted cash flow (DCF) method and the overall evaluation is determined by peer reviews through various committees. Once the feasibility of the R&D investment is verified through the feasibility assessment, the process directly moves onto the next stage without providing feedback to the planning stage. Usually, the feedback is given to the planning stage only when the plan is unfeasible. Even in this case, the feedback is only a kind of comment on the problems identified during the evaluation stage. However, this is fundamentally different from the suggestion of Hwang and Jeong (2007) that evaluation and planning should be systematically combined to choose a superior strategy. In this respect, the current R&D evaluation processes are inflexible and definitive.

FIGURE 4 Improvement of R&D Process with Strategic Flexibility: a Feedback Structure from Economic Assessment to Planning



A program or a project obtains budget if it is evaluated as feasible; however, in this case strategic flexibility has not been incorporated into the process through an option-based approach. Usually a large amount of investment for the whole stage is allocated to the program/project at the budgeting stage, based on the assumption that the program/project will proceed to the completion stage without suspension. Decision makers are usually conservative in immediately deciding whether a huge amount of money should be invested for a large-scale program and is why often some big programs face difficulty in obtaining a sufficient budget. Meanwhile, the program/project would continue once the budget is allocated unless it would not make any critical failure, which means that the mechanism is considerably definitive. Of course, the budget allocated can be increased or decreased depending on the results of the "Investigation, Analysis, and Assessment of National R&D Projects"; however, the range is rather limited and the budget adjustment is made quite conservatively. Performance evaluation such as the "Investigation, Analysis, and Assessment of National R&D Projects" is conducted in a stepwise manner and is past-oriented focused on what went well in the past. Vonortas and Hertzfeld (1998), Vonortas and Lackey (2003), and Neufville (2003) also showed the importance of flexible decision-making in large-scale R&D projects.

FIGURE 5 Framework of the Feedback System in the Consideration of Strategic Flexibility



By adding strategic flexibility into the currently rigid R&D process, it is possible to enhance the value of an R&D program/project and R&D efficiency. In the improved R&D process (during the planning stage) once the preliminary program/project goals, budgets, and program/project periods are determined, economic values are estimated to choose a flexible strategy to enhance the program/project value. The results of the preliminary planning are reflected in the next round of planning. Strategic decision includes optimal investment timing, stages of the decision-making, and the kind of additional options. After the second-round of R&D program/project planning, the investment plan that includes the strategic flexibility is fixed and the process proceeds to the next stage of budget allocation. The budget is allocated only for the investment approved during the first-stage of decision-making since the key component of strategic flexibility is decision-making made in a stepwise manner. Therefore, compared with the entire budget requirement that is estimated based on the assumption that the project proceeds to the end, the size of investment is relatively small at first and makes budget allocation easier. If it is possible to allocate the budget by stage throughout the R&D process and if it is supported by the R&D management system, more creative ideas for research can be selected and implemented. The overall efficiency of the national R&D programs/projects greatly increases if selected programs/projects of good performance proceed to the next stage.

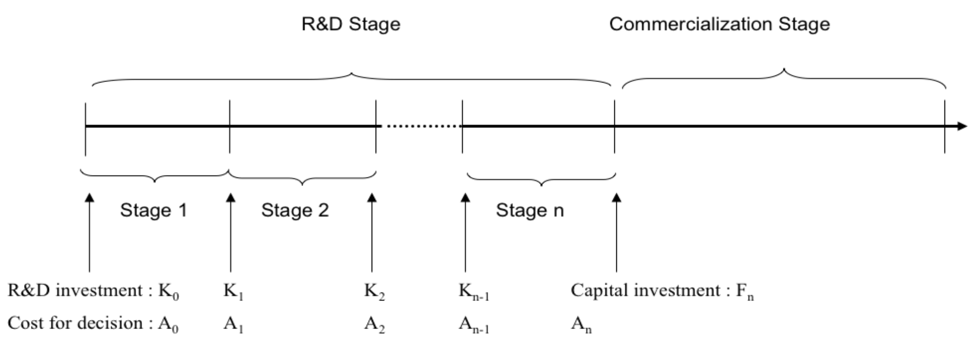
3. METHODOLOGIES

Economic assessment with strategic flexibility under given uncertainty could be conducted by the real option approach. The option pricing method was developed by Black and Scholes (1973) and Merton (1973), it was suggested immediately for an alternative investment decision-making method by Myers (1977) and later evolved into widely used valuation methods for the investment decision-making with various strategic flexibilities by Geske (1979) and Kester (1984). Trigeorgis (1996) presented a long summary of literature in regards to real options by type of strategic flexibility, methodology, and application field.

3.1 Simulation Approach

Among various real option approaches, Hwang and Jeong (2007) suggested a type of Monte-Carlo simulation approach and conducted a real case study. This approach is one of the most powerful methodologies when there are many uncertain variables within a complex decision-making structure. Assuming that the value of a program/project follows a geometric Brownian motion (GBM), Hwang and Jeong suggest a procedure to adopt a superior strategy by estimating the value of strategic options through simulation. In this study, the authors present a whole process of choosing the best investment strategy that considers multi-stage options that are powerful but very simple compared to the models suggested by Ottoo (1998) and Cassimon et al. (2004). In general, if decision-making steps are increased, the value of a project enlarges because flexibility also increases. On the other hand, we have to consider various inefficiencies since the multi-stage options will increase the cost for information collection and additional analysis (including cost of feasibility assessment) for decision-making. Decision makers should look into the impact of those positive and negative factors on economic valuation and provide the most desirable decision-making stages in the R&D program/project.

FIGURE 6 R&D Valuation Structure with Multiple Stages under Uncertainty



At a glance, this multi-stage decision-making may seem to be similar to the current performance evaluation system. However, there is a fundamental difference between them because multi-stages in the newly suggested process are designed to add strategic flexibility while those in the present system are usually only set to correspond with the fiscal years. Multi stages in the newly suggested process could be appropriately selected according to how many decision-making steps there are all or how long the R&D should be conducted. A present assessment system is focused on the past performance in each stage of assessment; however, a new decision-making process focuses on adopting a strategy based on future-oriented decision criteria. It helps decision makers choose a superior strategic structure that enhances the value of R&D program/project, updating the prospect of the program/project by collecting new information at every stage and recalculating the economic value.

If the new approach would be used more extensively in the future, various strategies including the options of postponement, scaling-down, or scaling-up should be considered in the model. Even after the commercialization stage, economic valuation should be able to be conducted in consideration of various strategies like project postponement, scaling-down/scaling-up, project disposal, and project diversification to identify superior flexibility.

The procedure of economic valuation is as follows.

Firstly R&D investment, facility investment after commercialization, and unit cost of the output are estimated. We can either use the estimates directly assuming they are quite accurate with low uncertainty or express them as a stochastic process and include them in the simulation considering the uncertainty.

Cash flows are obtained through the estimation of market share, output price, and market size. These variables (with some uncertainty) could be represented by stochastic processes with their estimates are obtained by simulations. The equation for cash flows is as follows.

(1) $\pi = m_t(p_t - c_t)D_t - F_t$

Where is market share (a stochastic process), is output price (a stochastic process), is market size (a stochastic process), is unit cost (a stochastic process), and is fixed expenditure at time t.

Cash flows are calculated according to the equation (1), if the variables are determined or generated by the stochastic process. The distribution of a cumulative value is obtained after generating cash flows. At each simulation, net present value (NPV) at the start of commercialization is calculated using weighted average cost of capital (WACC). A distribution that consists of calculated values is the value distribution at the start of commercialization.

After obtaining a value distribution at the start of commercialization, the program/project value during the R&D period is estimated using a risk-neutral stochastic process because it calculates the program/project value by risk-neutral valuation. The program/project value is assumed to follow GBM in that this process is often used for modeling the stock price and the value is essentially similar to the value of the company or the investment plan.

(2) $dS = \mu S dt + \sigma S dz$

Where is the stock price or the value of underlying asset, and is the expected growth rate, while is the volatility of the stock price or the value of the underlying asset.

GBM can be changed through Ito's lemma as follows.

(3) $d\text{In}S = (\mu - \frac{\sigma^2}{2})dt + \sigma dz$

Equation (3) represents that follows a generalized Wiener process and the change of in the time interval from 0 to has a normal distribution as follows.

(4) $\text{In}S_T - \text{In}S_0 \sim \Phi[(\mu - \frac{\sigma^2}{2})T, \sigma\sqrt{T}]$

The mean and variance can be estimated because represents the program/project value at the commercialization time. The volatility only has actual meaning in that this task is conducted to confirm the risk-neutral stochastic process during a R&D period. If there is no other information for volatility, it could be a good alternative to estimate it from the cross-sectional value distribution at the start of commercialization.

For risk-neutral valuation, the variable of expected growth rate is changed into the risk-free rate, new stochastic process (a risk-neutral stochastic process) is confirmed by substituting the estimates of the volatility and then the distribution of risk-neutral value is generated. Here a risk-neutral stochastic process is represented as follows.

$$(5)\ dS = r_f S dt + \sigma S dz$$

The reason why a complex procedure is needed is that there exists no market to inform the program/project value objectively. It is impossible to estimate the program/project value from cash flow in that there is no cash inflow at the R&D stage. The market exists and is proposed for information of the asset price in the case of financial assets. This research assumes that asset value can be estimated at a cost of decision-making 'A' at each decision-making stage instead of the market (if it is needed).

The economic value considering flexibility can be estimated by a backward induction (Jeong, 2006). The profit at each decision-making stage (which is combined with exercise of these options) can be calculated after the distribution of a risk-neutral value is obtained by simulation. A program/project is continuously progressed in the case of the abandoning option if the value exceeds the R&D investment cost at the corresponding stage. A program/project is terminated if it does not exceed. The equation for the economic value computation is expressed as follows.

$$(6)\ ROV = \hat{E}\{Max\{Max\{\ldots Max \begin{Bmatrix} Max\{S - F_n - A_n, 0\}e^{-r(\tau_n - \tau_{n-1})} \\ -K_{n-1} - A_{n-1}, 0 \end{Bmatrix} \ldots\}e^{-r(\tau_1 - \tau_0)} - A0, 0\}\}$$

3.2 Analytic Approach

The simulation approach has merit in that it could handle a complicated decision structure with multi-stages and many uncertain variables; however, it does not include technological uncertainty in the model and only cover market uncertainty. The 2 stage real option model suggested in this article could be a good alternative in which both of market and technological uncertainty are simultaneously considered. For simplification, we consider only 2 stages in the model; the first stage for doing R&D and the second for preparing market launching and capital investment.

Let V0 be the value of underlying asset at time t=0, which means the summation of present values of Free Cash Flow (FCF). Also let Z be a binary random variable for representing success (Z=1) or failure (Z=0) of a R&D program. Finally let S be the market value of the business conditional on successful market launching of the R&D program that is assumed to be a stochastic process with Geometric Brownian Motion (GBM). Then, at any time t the value of the underlying asset V=SZ, where S and Z are assumed to be independent.

In the 2-stage model, the value of the compound option can be written by backward induction as follows.

$$(7)\ C = e^{-rt_1} E[max[e^{-r(t_2 - t_1)} max(V_2 - X_2, 0) - X_1, 0]]$$

Because Z and S are independent,

$$\begin{aligned}(8)\ C &= e^{-rt_1} E[max[e^{-r(t_2 - t_1)} max(S_2 Z_2 - X_2, 0) - X_1, 0]] \\ &= e^{-rt_1} E(Z_2) E[max[e^{-r(t_2 - t_1)} max(S_2 - X_2, 0) - X_1, 0]] \\ &= pe^{-rt_1} E[max[e^{-r(t_2 - t_1)} max(S_2 - X_2, 0) - X_1, 0]]\end{aligned}$$

In derivation (8), p is the probability for success of the R&D program and considered as a diversifiable or idiosyncratic risk. Putting p aside, the other part of the last formula of (8) has the same value as a call on call (CoC) compound option if all related variables are also the same.

Letting Ccall be the value of the call on call option, we can write down the last formula as follows.

(9) $C = p\ C\,call$

Geske (1979) derived the value of Ccall analytically, for which there are many commercial or free computer programs providing the calculation formula.[1]

4. CONCLUSION

This improves the economic assessment methodology regarding feasibility studies for national R&D programs that is thought to be one of the most prominent ways to enhance R&D efficiency. In order to improve the methodology of economic assessment, a few important factors such as technical or market uncertainty, spillover effect, and R&D contribution ratio should be covered in the model. Among those factors, the focus of this article is technological and market uncertainty that have a close relation with strategic flexibility and the ability to increase the value of R&D programs.

To improve the current linear and definitive R&D process, a new framework with strategic flexibility is suggested in which the result of an economic assessment that considers technological and market uncertainty is reflected in planning. That kind of feedback process is expected to enhance the value of the program/project and R&D efficiency.

This new framework focuses on selecting the best strategy to enhance the value of the program/project after the consideration of various strategies. Strategic decision includes choosing investment timing, the number of decision-making stages, and additional options to consider after decision-making.

The model suggested in this article could be applied to an R&D program/project that is near commercialization or is predictable about future market conditions such as profitability. The economic valuation of R&D program/project (whose commercialization is still far away) is difficult to be covered by this model because a future market related to basic research programs cannot be accurately forecasted.

This study presents a methodology that identifies the best strategy among possible strategies and makes a strategic decision accordingly; however, it does not assume that we consider all the possible variables and all the possible conditions of these variables in an attempt to identify an optimal strategy. As result, the methodology presented in this study is limited to identifying a superior strategy and not the optimal strategy in general. The theoretical verification of the optimal R&D implementation strategy remains a topic for future research.

[1] $C_{call} = S_0 N_2(a_+, b_+; \sqrt{t_1/t_2}) - X_2 e^{-rt_2} N_2(a_-, b_-; \sqrt{t_1/t_2}) - X_1 e^{-rt_1} N(a_-)$,where

$$a_+ = \frac{\ln(S_0/S^*) + (r + \sigma^2/2)t_1}{\sigma\sqrt{t_1}}, \quad b_+ = \frac{\ln(S_0/X_2) + (r + \sigma^2/2)t_2}{\sigma\sqrt{t_2}}$$

$$a_- = a_+ - \sigma\sqrt{t_1}, \quad b_- = b_+ - \sigma\sqrt{t_2}$$

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