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Using Real Options Pricing to Value Public R&D Investment in the Deep Seabed Manganese Nodule Project

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Abstract This paper seeks to measure the monetary value of technical development in the deep seabed manganese nodule mining by applying the compound option model (COM). The COM is appropriate for the project in terms of its decision-making structure and embedded uncertainty. The estimation results show that the deep seabed mining project has more economic potential than shown by the previously obtained results from the discounted cash flow (DCF) analysis. In addition, it is reasonable to invest in the project taking the various uncertainty factors into consideration, because the ratio of the value to the cost of the project is far higher than one. This information can be utilized in national ocean policy decision-making.

Keywords Real option pricing, compound option model, technology valuation, deep seabed manganese nodule project

I. Introduction

Many countries and firms have conducted extensively investigations in deep seabed minerals and have developed deep seabed mining technologies to compensate for the lack of minerals on land and occupy the leading position in resource competition. In particular, Korea has struggled with the poor endowment in mineral resources on land and, thus, has depended on mineral supplies from overseas. Korea imports almost 100 percent of four strategic metals – nickel, cobalt, copper, and manganese – contained in manganese nodules and used in various industries such as steel, chemical, telecommunication, and power generation. This high dependence of metals

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import has been the barrier to develop the Korean economy and made it vulnerable to external environment.

In addition, market conditions for metal trading has recently become more difficult for importers as the demand increased from emerging economies such as BRICs (Brazil, Russia, India, China) where the industry has developed rapidly. Thus, the Korean government has promoted investment activities in overseas mineral resources development projects in order to address this fundamental problem, and it is natural for the government to evaluate deep seabed mining ventures as a possible alternative to secure the stable long-term procurement of strategic metals. So, deep seabed exploration has become an important national ocean policy.

The Korean government has carried out pioneer activities in the international seabed area located in the Northeast Pacific Ocean since the beginning of 1980s. Upon completion of these activities, Korea filed for registration as an investor with the sole license to develop manganese nodule mining in the Clarion-Clipperton (C-C) zone, approximately 2,000 km southeast of Hawaii, covering 75,000 km^2 and corresponding to about three-fourths of the area of South Korea. As a registered pioneer investor, Korea has thus obtained the exclusive rights to carry out activities in this area for future commercial mining production.

High technologies are required for deep seabed mining: exploring manganese nodules buried in the deep sea, mining them under high water pressure and smelting them. The costs of research and development (R&D) for those technologies are enormous and could burden the government's limited budget. Conservative decision-makers may be reluctant to appropriate enough funds from the government budget for an R&D project that may take a long time to show results and bears various uncertainties.

The main purpose of this study is to assess the value of the R&D project in deep seabed mining technologies by employing a real options approach. The findings could help a more rigorous economic analysis by taking account of the concept of technology valuation, which has not been considered in previous marine resource development projects. The rest of this paper is organized as follows. Section 2 presents the real options approach, a suitable method for the valuation of R&D investment. Section 3 describes an application of the theory to the deep seabed mining R&D project problems. Some concluding remarks are presented in the last section.

II. The Real Options Pricing Approach

Projects are typically analyzed based on their expected cash flows and discount rates at the time of the analysis. Calculated net present value or the ratio of benefit to cost is a fiducial value to assess its economic validity. The expected cash flows and the discount rates at the time of the analysis change over time, so does the net present value (NPV). This discounted cash flow (DCF) technique favors short-term projects for relatively certain markets rather than long-term and relatively uncertain projects since it assumes that expected cash flows and discount rates at the time of the analysis. Large-scale long-term risky projects such as deep seabed mining could be undervalued in this framework; so a more flexible approach is needed to deal with future uncertainties. Many studies have critiqued the DCF techniques for capital budgeting (e.g., Dixit and Pindyck, 1994; Lint and Pennings, 1998).

Investors are able to handle uncertainties induced from the underlying asset as market conditions change by using options. The real options approach is derived from the concept of financial options, which allows investors to defer a decision on a financial transaction, but at a pre-set price. An option provides the holder with the right to sell or buy a specified quantity of an underlying asset at fixed price (referred to strike price or exercise price). Options help investors, who do not know how underlying asset prices change in the future, to hedge or limit risks from future volatilities and uncertainties.

The basic idea of the real options approach is to transfer sophisticated option pricing models used in financial market theory, first proposed by Black-Sholes (1973), to the valuation of risky R&D projects (Perlitz et al., 1999). Financial investors can derive more profit by buying an option rather than purchasing stocks the first time. Likewise, real option, a decision right to keep or stop investment at each decision-making step, brings more profit to R&D investors, rather than keep investment as initial plan, because they can react to changes in the project environment. The most important characteristic of the real options approach is that it interprets the flexibility embedded in an investment project as an option.

Table 1 Comparison of call option on a stock and on an investment project

Input variables	Call option on a stock	Call option on an investment project
Underlying	Current stock value	(Gross) present value of expected cash flows
Exercise price	Fixed stock price	Present value of investment cost
Time to expiration	Fixed date	Time until opportunity disappears
Risk	Stock value uncertainty	Project value uncertainty
Interest rate	Riskless interest rate	Riskless interest rate

A basic financial option pricing model uses five different input variables: the underlying, the risk, the exercise price, the riskless interest rate and the time to maturity. The analogy between financial and real option input variables is shown in Table 1, and by using this analogy, the option value can be assessed for a project that has operational flexibility.

The real options approach has been diversely applied to value the technologies of R&D projects (e.g., Kemna, 1993; Perlitz et al., 1999; Kim et al., 2014). Perlitz et al. (1999) provides the application procedures of real option approach to technology valuation of large-scale risky project like a biotechnology development. Specifically, the real options approach can be useful for valuing the project for mineral resources development (Costa Lima and Suslick, 2006; Ajak and Topal, 2015). Real options pricing is appropriate for valuing R&D project for large-scale resource development bearing uncertainty in aspects of theoretical validity and the number of related research cases.

The types of real options are various, and researchers can develop new real options, as circumstances require. One can distinguish different kinds of real options as follows (Copeland and Keenan, 1998; Edlson, 1999; Perlitz et al., 1999):

- the option to defer an investment project
- the time to build option
- the option to abandon an investment project
- the option to contract, expand or temporarily shut down an investment
- the growth option
- the option to staged investment

The first thing to do in analyzing an investment is to find out, which real options belong to the investment project. Among those various real options, the growth option is appropriate to value the technology for resource development project with great growth potential. For the long-term and risky projects, like a deep seabed mining project, R&D is a prerequisite throughout the chain of interrelated projects, and opens up future growth opportunities. Commercialization decisions can be made only after the technology-related uncertainty is resolved in the R&D phase. In other words, the growth option is the value of opportunity for a firm to grow through investment in commercialization based on the outcome of R&D investment. Therefore, one may take the R&D investment to be a ticket to the investment opportunity. For this reason, the R&D option is considered as a growth option in this study.

III. Application to R&D Project for Deep Seabed Mining

The entire period of the project on mining manganese resource in deep seabed is composed of three stages, according to the suggested development scheme of the Korea government. Figure 1 shows the structure of the deep seabed mining project. According to this plan, the development in the basic technique to commercialize will have been completed in the first period, from the end of 2012 to 2015. The second period, from 2016 to 2022, covers preparations for commercial production. Actual commercial production will begin in the last period, from 2023 to 2052.

Multi-stage R&D projects generally contain a series of embedded options based on technological and market uncertainty. Undertaking an R&D project gives management the right, but not the obligation, to commercialize a product if and when the R&D effort is successful and the economics of producing and marketing the product are attractive. Although an R&D project viewed in isolation may have negative NPV, the options to commercialize the result are often extremely valuable.

Figure 1 describes the R&D phase's three-stage program for deep seabed mining that illustrates two options, learning and growth opportunities following the initial investment. The first call option is written on the value of the first investment opportunity with a time maturity of T_1 (2016 - 2013 = 3 year). The exercise price of the first option (X_1) is equal to the present value of the investment cost required for a pilot plant testing. If the first option is exercised, then the company will receive a second call option with a time maturity of T_2-T_1 (i.e., 2023 - 2013 = 10 year). The first option is a compound option since it is the completion of the first investment that provides another option. *S* is defined as the present value of cash inflows following the second investment (X_2) from its start.

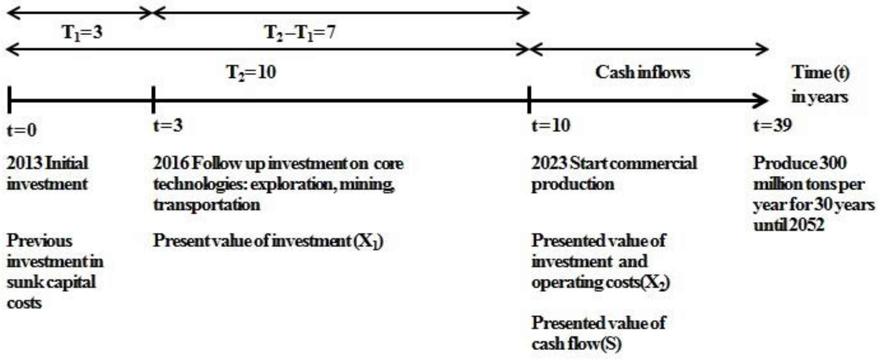

Figure 1 Structure of the project

A compound option can be valued analytically using Geske's valuation approach, which is based on the Black-Scholes formula. Kemna (1993) and Perlitz (1999) applied Geske's formula to real option valuation. Geske's formula is as follows, (Geske, 1979):

$$C = S\,M(a_1, b_1; \sqrt{T_1/T_2}\,) - X_2 e^{-rT_2} M(a_2, b_2; \sqrt{T_1/T_2}\,) - e^{-rT_1} X_1 N(a_2)$$

Where,

$$a_1 = \frac{ln(S/S^*) + \frac{1}{2}\sigma^2 T_1}{\sigma\sqrt{T_1}} \quad , \quad b_1 = \frac{ln(S/X_2) + \frac{1}{2}\sigma^2 T_2}{\sigma\sqrt{T_2}}$$

$$a_2 = a_1 - \sigma\sqrt{T_1}\,, \quad b_2 = b_1 - \sigma\sqrt{T_2}$$

$N(\cdot)$	Univariate normal distribution function
$M(a,b;\rho)$	Bivariate normal distribution function with a and b upper integral limits for each variable and correlation coefficient ρ
S^*	Critical value of the project above which the first call option will be exercised.
S	Present value of the cash inflows of the commercial production as of year T_2
σ	Volatility of the present value of commercial venture
X_2	Present value of the capital expenditures of the commercial venture as of year T_2
X_1	Present value of first year capital expenditure of the pioneer venture as of year T_1
r	Risk-free interest rate

The aforementioned R&D process can be rephrased as follows. The government supports research activities in new technologies to develop the mining of manganese nodule resources buried in deep seabed. It will cost X_0 which is mostly used to develop core technologies for mining and metallurgical processing. Subject to the successful completion of the first stage R&D, decision makers have the option to carry on with construction of a pilot plant in the sea by making a further investment of X_1. After completion of the pilot plant, testing, in the beginning of year T_2, to start the commercial production, X_2 should be invested. In this process, X_0 correspond to option value of first stage R&D.

On the other hand, the value of S^* is the minimum value of the project which makes it possible to invest in initial resource development project. If C_0, the first option value, is larger than X_1, then the second option can be exercised; thus S satisfying $C_0 = X_1$ is S^*.

$$C_0 = S\,N(d_1) - X_2 e^{-r(T_2 - T_1)} N(d_2) = X_1$$

Where,

$$d_1 = \frac{\ln(S/X_2) + (r - \frac{1}{2}\sigma^2)T_2}{\sigma\sqrt{T_2}}, \quad d_1 = d_2 - \sigma\sqrt{T_2 - T_1}$$

That is, S* satisfies the following equation,

$$S * N(d_1) - X_2 e^{-r(T_2 - T_1)} N(d_2) - X_1 = 0.$$

Table 2 The values of input variables

Variables	Definitions	Values
T_1	Time to maturity of the first option	3
T_2	Time to maturity of the second option	10
d	Discount rate	8.0%
r^f	Return rate of risk-free asset	9.5%
σ	Volatility of metal (nickel, copper, cobalt and manganese)	109.06%
X_1	Present value of first year capital expenditure of the pioneer venture as of year T_1	KRW 3,413.7 bil.
X_2	Present value of the capital expenditures of the commercial venture as of year T_2	KRW 18,501.6 bil.
S	Present value of the cash inflows of the commercial production as of year T_2	KRW 28,811.3 bil.
S^*	Critical value of the project above which the first call option will be exercised	KRW 4,384.1 bil.
X_0	Previous investment in sunk capital costs (as of 2013)	KRW 249.6 bil.

Table 2 summarizes input variables. Among the input variables in Table 1, some figures need detailed explanations. Measuring the volatility (σ) of the investment project could be a controversial point. In most R&D cases, no historical volatility data is available and no method can be used to solve this problem completely. In natural resource investment problems, such as for copper and oil reserves, a commodity market (for example, the London Metal Exchange (LME)) data can be used to estimate the volatility. In deep seabed mining, the extracted products mainly consist of four metals – nickel, copper, cobalt and manganese.

The first two metals are being traded in the international commodity market, but the other two metals are not. In most studies dealing with natural resources, one or two commodity prices are considered as having a stochastic process. However, it makes the problem too complicated to assume the price of four metals as stochastic variables. Furthermore, commodity market data for cobalt and manganese are not available. Therefore, instead of modeling the metal price process directly, the average standard deviation of the equity value of 68 metal and mining companies in US for five years (2007-2011), provided by Damodaran (2013), is used in the present study as a proxy variable for volatility.

S, X_1 and X_2 are calculated from the DCF chart in the 2013 government report on deep seabed mining (Korea Institute of Ocean Science and Technology, 2013). The discount rate (8.0%) is a used vale in financial feasibility analysis, reflecting the social discount rate noticed by the Korean government and the risk of international development business. The value of return rate of risk-free asset (r^f) is also an analyzed value in financial feasibility analysis, and this figure – 9.5% – reflect the expected inflation rate (about 3%) and premium for tied capital investment for a long time (about 2%, same as the average United States Treasury spread over the past 20 years).

The estimation results show that the option value of R&D for mining deep seabed manganese nodules is approximately KRW 25.8 trillion as year of 2013, so the net present value (NPV) of the R&D project for deep seabed mining is calculated at about KRW 25.6 trillion by subtracting the sunk cost (amount of previous investment) from the value of growth opportunity. However, the NPV from simple DCF approach is computed at approximately KRW 1.8 trillion as year of 2013. The difference between NPVs from the real option approach and the DCF approach is substantial, and this gap shows that if only the DCF result is used as a decision criterion, a conservative planner is apt to undervalue the potential possibility of the project.

Three (negative, standard, positive) scenarios of the move of future metal price are considered for sensitivity analysis, in view of the fact that the expected metal price is a key part of financial return and its prediction is very difficult. Table 3 presents the results of the sensitivity analysis for the metal price. The value of R&D project tends to increase as the expectation of metal price becomes positive.

Table 3 Results of the sensitivity analysis (as year of 2013) (Korean Won)

Metal price scenarios	Value of the R&D project
Pessimistic condition	12,749 billion
Intermediate condition	25,800 billion
Optimistic condition	36,835 billion

IV. Concluding Remarks

Deep seabed mining has been considered as an alternative source for the supply of major strategic minerals. However, many technical problems for deep sea mining still remain unresolved, and a huge amount of R&D investments is required in order to start commercial production. Deep seabed mining is vulnerable to various uncertainties, and a more flexible decision-making process is needed to start lucrative commercial production. So, to successfully proceed with a long-term and risky project, it is essential to devise a stepwise plan to continuously check out the economic feasibility. However, the traditional investment decision method, DCF, does not consider this step-by-step decision-making process in valuation.

In this paper, the real options model is applied to R&D valuation instead of the standard DCF method. Especially, a compound option pricing method is used in consideration of the three-stage R&D plan. The estimation results show that deep seabed mining project has more economic potential than the previously obtained results from the DCF analysis would show. In the first period, the value of technology of the project is estimated at KRW 25.8 trillion, and the NPV of deep seabed mining projects based on the compound option-pricing model is estimated at approximately KRW 25.5 trillion (at the beginning of 2013).

These figures are quite high even as the project contains various uncertainty factors. Since this estimated option value is obtained based on forecast data, sensitivity analysis was also performed in order to assess the uncertainty from the future market conditions of metal prices. The value of the R&D project for deep seabed mining is still large in the case of a negative scenario. Therefore, we could expect to earn considerable profit from a sustainable and stable development project of manganese nodule mining. Even though the value of the R&D project is estimated to be very substantial, enormous investment is needed over the next 10 years to start commercialization of the minerals. It is, therefore, difficult to attract private funds. Consequently, the public sector needs to keep playing a key role in this R&D phase before commercialization.

In conclusion, unlike other studies on natural resources investment, this study focuses on the R&D phase, and uses a compound option pricing technique to assess the characteristics of long-term risky project. This real options approach is expected to be used more often in R&D valuation as it provides more useful information to decision-makers. The study only includes accounting costs, but does not include social costs (e.g., environmental impact on the deep seabed ecosystem). Clark and Neutra (1987) point out that deep seabed mining activities have a substantial impact on the deep seabed ecosystem, so the environmental impact should be considered into marine resource development. Further research may improve the economic analysis of marine resource development project by considering the external costs.

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