An Alternative Real Option Approach to R&D Project Assessment

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Accepted June 18 2008

Abstract

An organization can take diversifying actions to reduce the total risks of project portfolios. For an R&D project, the overall level of risk could be reduced with better management and/or appropriate diversifying. In this paper, we develop an alternative real option approach to assess R&D projects in consideration of diversifying investments. The distinguishing feature of our model setting is that two major uncertainties of R&D investment, i.e., the market and technological risks, are combined to generate a specific underlying process of R&D projects. The net present value rule and traditional real option methods are applied in evaluating R&D projects. It is found that the outcomes of the traditional real option methods would be affected by evaluators’ expectation upon the market or technological outlook. The proposed method incorporating diversification effect could lead to more reasonable assessments for R&D projects since the influence of R&D firms’ subjective views could be resolved. The value-creation effect from diversifying actions has been examined through the numerical analyses. The results indicate that better management for R&D investment diversification will increase the project value.

Keywords: R&D project, diversification, real options

1. Introduction

A technology firm faces two types of risk, similar to stock investor: unique risk and market risk. The former is associated with the activities of an individual business and is reducible through diversifying actions. However the latter that correlates to the industry or technology category cannot be reduced through diversifying. As suggested by Boer (2000, 2003), systematic reduction of unique risk could be applied as a tool for a successful R&D. Because risks characteristics for R&D projects are usually idiosyncratic, these risks cannot be offset completely by a duplicate portfolio of other assets. Although all the risk of R&D projects could not be hedged fully, firms still attempt to reduce the total level of risks due to the common risk-aversion characteristics. Boer (1998, 2000) pointed out that a manufacturer can reduce the unique risk of R&D projects by taking diversified investments such as, investing in other similar projects and joining exploring syndicates. Thus it is worthwhile to study how such diversifying actions could influence the fair valuation of an R&D project. The purpose of this article is to evaluate the value of R&D projects with the option pricing approach adopting the diversifying actions.

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The real option approach has been widely applied to the valuation of R&D projects since real R&D options are usually embedded in projects or processes. Researchers recognized that the traditional DCF model (such as NPV rule) could not catch the value of managerial flexibility embedded in an R&D project. Even some reasons for reluctance in the employment of real option approach for an R&D project are elucidated (Hartmann and Hassan, 2006; Paxson, 2001). The advantage of real option method that captures such flexibility value has been proposed in the literature (e.g. Morellec and Zhdanov, 2005; Boer, 2000, 2003; Jensen and Warren, 2001; Perlitz et al., 1999). Especially for the technological projects with higher uncertainties, the adoption of real option method is explicitly superior to the traditional DCF models (e.g. MacMillan et al., 2006; McGrath and MacMillan, 2000; Morris et al., 1991; Mitchell and Hamilton, 1988). For an R&D project, the more uncertainties associated with the future revenue streams of a project investment, the higher value of the managerial flexibility would be (Dixit and Pindyck, 1994). Additionally, Santiago and Vakili (2005) proposed a simple decision model to examine how the increase in uncertainty and variability impact the overall value and the value of management flexibility in R&D projects, giving a conclusion that increased variability in general increases the value of the project. Typically, there are five types of managerial flexibility, namely, defer option, abandonment option, expansion option, contraction option, and switching option (Trigeorgis, 1998).

With respect to the application of real option theory in assessing R&D programs, many studies utilized the Black-Scholes model (BS model) or Cox-Ross-Rubinstein model (CRR model) to evaluate R&D projects (Bowman and Moskowitz, 2001; Carter and Edwards, 2001; Boer, 2000; 2003; Miller and Arikan, 2004; Lewis et al., 2004). However, some assumptions of the aforementioned models should be relaxed for the valuation of technological projects. For example, it is assumed in the BS model that the rate of returns of the underlying asset follows lognormal distribution which is not the usual characteristics in an R&D context. Angelis (2000) proposed an alternative method to assess real R&D option values relaxing the lognormal-distribution assumption. The no-arbitrage condition, which is another crucial assumption in the BS model or in the CRR model, is ignored in the literature related to real R&D option value. Theoretically, the real option method is based on contingent claims analysis. It is required for this approach that the project’s risk could be replicated completely by the portfolio of some other traded assets (Dixit and Pindyck, 1994). Because the risks of R&D projects usually are idiosyncratic, such replications could not be carried out. Therefore, many studies assumed that firms have risk-neutral attitude toward R&D projects with proper discount rates (Dixit and Pindyck, 1994; Simth and Nau, 1995; Trigeorgis, 1998; Huchzermeier and Loch, 2001; Bollen, 1999). Although not all risks for an R&D project could be duplicated completely with other assets, firms would take diversifying actions to reduce the risk while implementing an R&D project. Diversification effects on an R&D project has been emphasized in the studies of Boer (2000, 2002, 2003), but an appropriate evaluation method incorporating such the effect has not yet been explored. This study will attempt to fill this gap. The main purpose thus is to develop an alternative real option method for R&D projects considering the diversifying actions. We would also compare the results with the traditional NPV rule and real option method. It is found that, under the incorporation of diversification effects, the proposed valuation method could yield more reasonable outcomes. Numerical analyses will be done to demonstrate the traditional real option methods might over-evaluate or underestimate of R&D projects values. It should also be noticed that that better management for diversification could increase the R&D projects values.

The remainder of this paper is arranged as follows. The diversifying actions for an R&D project will be discussed in Section 2. Section 3 is devoted to develop a new valuation approach incorporating the diversification effect for an R&D project. A simplified risk model describing the R&D evolution process is established in this section. In section 4, some
numerical examples are provided to illustrate the proposed model. The difference among the proposed method and the traditional ones are shown. Furthermore, special management implications are drawn as well. Finally, conclusive remarks are presented in the last section.

2. Diversifying action of R&D firm

2.1 The source of uncertainty

An R&D firm means the one that is carrying on R&D investments in order to increase its market value. R&D firms will face diverse types of risks when proceeding with an R&D investment. Various kinds of uncertainty sources regarding to R&D investments could be synthesized into two types, namely, technological uncertainty and market uncertainty (MacMillan and McGrath, 2002). The technological uncertainty refers to whether new technology can work, whether complementary technology could be ready in time, and what technological standards will dominate the market. The market uncertainty involves the issues of whether there is enough potential market demand, or whether product price will change in the future. These uncertainties will influence potential revenue streams of R&D firms indirectly or directly. Incorporating both the technological and market uncertainties, Raynor and Leroux (2004) have proposed a conceptual model of how to offers a strategic thinking for optimal allocation of technology investment. The technological risk is referred to as unique one in the study of Boer (2000). The study emphasized the importance of separating unique and market risks in applying options theory to R&D projects, and suggested that the unique risk could be analysed using estimated probabilities from historical database and the market risk could be modelled by well-known financial tools. Since the unique risk and the technological risk have similar characteristics, in this article, we use the technological and market risks as two major kinds of risks for an R&D project.

2.2 Diversification effect on R&D

Markowitz (1952) and his followers have demonstrated that investors can take diversifying actions to eliminate the unique risk. However, there is an obvious distinction between financial and technology portfolio, that is liquidity. Since most financial assets could be traded with limited transactional friction, diversification could be achieved over various classes of securities. Diversified portfolios of technology assets are much more challenging to assemble and to liquidate than portfolios of either securities or businesses. It may be difficult to obtain through buying and selling as claimed by Boer (2002). Nevertheless, diversification in the R&D portfolio can help us in maximizing the value for a given level of risk.

A firm should take proper actions to mitigate negative influence caused by those aforementioned risks. But R&D firms have no way to dodge the market risk which can be affected by the product price or the conditions of market demand. However they could diminish the technological risk of an R&D project through project diversifications. Taking an investment of exploratory oil well as an example, an enterprise could reduce the technological risk by investing in different exploitation case or by ways of joining drilling syndicates (Boer 2000). Thus R&D firms could make a constructive action to abate the losses caused by unfavourable situations in practice. Analogous to diversified investment of stock market, a firm could invest simultaneously in the rival companies developing the same technologies or taking R&D projects with substitutive technology. That is, diversifying action means that R&D firm can invest in a wide variety of projects so that exposure to the risk of a particular R&D project could be limited. In other words, diversifying actions could be done by investing in other assets with a payoff pattern that offset exposure to a particular source of risk. When unfavourable situations do take place, a firm could obtain additional rewards to compensate its losses. Magnitude of such compensatory reward obtained in unfavourable situations would
express the diversification effect. In other words, through the investment in other R&D projects, an R&D organization is just mimicking in holding another asset, and would get compensatory reward while unfavourable situations occur. The net effect of such diversifying behaviours would be regarded as obtaining the asset, which is similar to insurance. So a firm could be compensated for potential losses through holding such assets. The diversification effect could be measured by magnitude of the compensatory reward.

3. Valuation framework

3.1 Set-up of risk model

In this paper, both market and technological risks are regarded as major R&D risk source. The market risk involves the uncertainty of the future revenue streams that are related to projects itself briefly. Technological risk may involve the extent in which the R&D projects might be failed, or in which the developed technology might be replaced by other new dominant technologies after successful commercialization. In order to consider the market and technological risks jointly, the evolution of an R&D project should be modelled as a stochastic process influenced simultaneously by these two uncertainty factors. In a typical model setting, the market risk always is treated as the only factor describing the evolution of R&D project and the technological risk is regarded as an independent variable which could be estimated with evaluators’ judgment or historic data (e.g. Santiago and Vakili, 2005; Boer, 2003; Bowman and Moskowitz, 2001). In other words, these studies assume that the technology risk is independent from market one. However the two risk factors may correlate positively each other. For example, a bull stock market may stimulate better R&D performance because the project participators will receive greater bonuses in this situation. Since both risks in an R&D project can occur simultaneously at the same time, all states occurring in the same period should be combined. It may be more suitable and comprehensive for the valuation of R&D projects to incorporate the fact that an R&D firm may encounter simultaneously both the uncertainties into the framework setting. A simplified two-phase model would be applied to describe such a process as exhibited in Figure 1. The first phase is devoted to the R&D for new technology. Assume that there are two states of nature, i.e., success and failure, in the first phase before an R&D project is completed. If being failed in the first phase, the R&D project will be discontinued, and its solvency value will be left to \( V_s \) \( (V_s < V_0) \). On the other hand, if the outcome is successful in this phase, a firm could invest further for commercialization. In the next phase, a firm will encounter another risk type, that is, the commercialized technology may be replaced by another new technology. Two states in this phase are therefore defined. One of the states is unfavourable, in which the commercialized technology is replaced, and the market is dominated by other substitutive technologies. The other one is favourable, in which the commercialized technology can establish product standards and dominate in the market. Thus the distinguishing feature of our model setting is that two major uncertainties of R&D investment are combined to generate a specific underlying process of R&D projects. Such the setting would become more reasonable since the both risks may not need to be treated as ones that take place in different periods. Although the model setting is more complex, it may more closely approximate the real world.

The conventional treatment on building the market risk for an R&D project is analogous to financial options. Typically, it is supposed that price or rate of returns of underlying asset follows a specific stochastic process. The option value could be derived according to no-arbitrage pricing theory. However, R&D projects usually do not have the corresponding underlying assets as the financial options do. Thus the general treatments usually assume that the future revenue or net present value (NPV) associated with the R&D program follows a specific stochastic process. A certain linkage relationship between this evolution process and
the market condition or the average industrial stock price is also assumed. Therefore the stochastic process of the revenue streams could be established according to the characteristics of industrial stock price or market demand. For example, it could be assumed that there is a reasonable relation between the revenue volatility of R&D project and that of industrial stock price (Bowman and Moskowitz, 2001; Boer, 2003). With the historical database, we can estimate the growth rate and volatility of revenue streams for an R&D project. By this way, a suitable stochastic process describing the market risk could be established. In this research, it is assumed that the market risk of an R&D project follows a Binomial tree. We will use $\sigma$ to denote the volatility of the revenue of an R&D project and $\delta, 1/\delta$ to denote the upward and downward multipliers for the Binomial tree respectively.

Because uncertainty comes from both the market and technological risks, there are four possible states at the end of the first period, i.e. successful R&D in better market situation, failed R&D in better market situation, successful R&D in worse market situation and failed R&D in worse market situation. The initial revenue associated with R&D projects is supposed to be $V_0$. The four states could be expressed respectively with symbols as $(\delta V_0, S), (V_s, F), (V_0 / \delta, S)$ and $(V_s, F)$, where the first variable in parentheses represents the magnitude of revenue; $S$ and $F$ denotes the success and failure of R&D respectively. If R&D is completed successfully, a firm could choose to commercialize the new technology or not to, depending on market condition at that time. Otherwise, this R&D project would be terminated. Once the new technology commercialized decision is made, a firm must put further in the investment cost. The firm will face other risk associated with technology replacement in the second phase. If new superior technologies appear and replace the existing technology, the existing market share would be affected. We assume that the market revenue would be reduced down to a specified proportion of original scale, $\theta$, if such the unfavourable situation occurs. Consequently, there will be eight states at the end of the second period, as shown in Figure 1. They are $(\delta^2 V_0, D), (\theta \delta^2 V_0, R), (V_0, D), (\theta \delta V_0, R), (V_0, D), (\theta V_0, R), (V_0 / \delta^2, D)$ and $(\theta V_0 / \delta^2, R)$ respectively, with the first variable in parentheses denoting the magnitude of revenues; $D$ representing the situation in which the existing technology could be dominant in the market, and $R$ denoting that it is replaced by other dominant technologies.

![Figure 1: The simplified stochastic process of an R&D project](image-url)
3.2 Valuation method

Theoretical development of option valuation in financial economics has laid the foundation for the extension of option pricing approach to the evaluation of investment projects embedding some managerial flexibilities. The traditional NPV method assumes an investment project will be operated continuously until the end of the pre-estimated investment duration. The valuation criterion is based on the present value of expected future revenue streams and investment cost input through discounting procedure with a risk-adjusted rate, i.e.

$$\text{NPV} = \sum_{t=0}^{T} \frac{E[\tilde{C}_t - I_t]}{(1 + r_{adj})^t}$$ \hspace{1cm} (1)

where $\tilde{C}_t$ is cash inflow in period $t$, $r_{adj}$ is a discount rate adjusted for risks associated with the investment, $T$ is expected duration of the investment, $I_t$ is the required investment cost in period $t$, and $E[\cdot]$ is the expectation operator with respect to subjective estimated probability. The NPV rule, which suggests the investment opportunity with discounted cash flows exceeding discounted costs should be chosen, helps decision makers choose between two alternatives: accept (if NPV > 0) or reject (if NPV < 0) an opportunity.

Among alternative valuation approaches proposed as remedies for the static NPV approach, the most prominent one is the decision tree analysis (DTA). DTA can help management to structure investment decision-making by mapping out feasible investment actions contingent on all states in a hierarchical manner. Project investment is modelled as a sequence of decisions for choosing among alternative courses of action, where the consequence of each alternative action depends on uncertain events that can be described probabilistically on the basis of past information. The value of the investment project is then estimated by discounting outcomes along optimal decision path by the risk-adjusted rate, i.e.

$$V = \sum_{t=0}^{T} \frac{E[\tilde{C}_t - COST_t | Y_t]}{(1 + r_{adj})^t}$$ \hspace{1cm} (2)

where $E[\cdot | Y_t]$ is expectation operator conditioned on time $t$. Whereas the conventional NPV rule assumes initial investment strategy is unchanged through the investment duration, DTA recognizes that the implicit operational flexibilities are embedded in the project and allows the initial strategy to be altered during the investment duration. However, this approach suffers the same difficulty as static NPV when it comes to determine the risk-adjusted discount rate. Subjective probability distribution has to be adopted to achieve the adjustment needed to compensate risk bearing, then probably resulting in inconsistent investment valuation (Copeland and Antikarov, 2001).

Problems with the static NPV rule and the dynamic decision tree analysis can be easily solved with contingent claims analyses (CCA). Theoretically, the option pricing approach for financial instrument is based on CCA. This approach requires that the project’s risk is replicated completely by the portfolio of some other traded assets as mentioned in the first section. This method technically also adopts the decision tree analysis, in which investment involves a sequence of decisions of choosing among alternative courses of action, and each decision is treated as an option. However, it differs from DTA, in which the no-arbitrage argument adopted contingent claims analyses ensure investment valuation is independent of evaluator’s risk preference. The risk-neutral assumption required in DTA can be relaxed. In particular, the contingent claims approach uses the market prices of existing assets to infer state prices, and hence get risk-neutral probabilities associated with every future node implicit
in the decision tree. These risk-neutral probabilities are then used to value cash flows from alternative decisions and the optimal decision can be chosen. Thus, the value of the investment project can be calculated by discounting expected cash flows that derive from the optimal decision strategy by the risk-free interest rate, i.e.

\[
V = \sum_{t=0}^{T} \frac{\hat{E}[\tilde{C}_t - \text{COST}_t | Y_t]}{(1 + r)^t}
\]  

(3)

Where \( \hat{E}[\cdot | Y_t] \) is expectation operator with respect to the risk-neutral probabilities conditioned on time \( t \) and \( r \) is the risk-free interest rate. We will evaluate an R&D project’s value using CCA. Given the stochastic process of an R&D project described in the previous subsection, we could derive the risk-neutral probabilities of the stochastic process of an R&D project applying the no-arbitrage condition. The detailed computation procedure for the risk-neutral probability is described below.

Suppose that the stock price follows Binomial process. Its volatility is denoted by \( \sigma_s \) (the standard deviation of the stock price), accompanied by upward-moving factor, \( u \), and downward-moving factor, \( d \), \( d = 1/u \). For the underlying process established, there are consequently three basis assets a firm could choose to form its portfolio, namely, the industrial stock portfolio, the compensatory reward derived from the diversification effect, and the risk-free asset. Under the no-arbitrage condition, the risk-neutral probabilities of the whole evolution process of an R&D project could be derived. According to the estimated cash flows occurring at each state, the fair value of an R&D project could be achieved by backward procedure with respect to the risk-neutral probabilities. Consider the \( i \)-th period in Figure 1 for \( i = 1\sim2 \). It is assumed that a firm could obtain return rate of compensatory reward, \( r_i \), for the \( i \)-th period while unfavourable situations occurring. The magnitude of \( r_i \) depends on the diversification effect, for \( i = 1\sim2 \). According to no-arbitrage theory, the risk-neutral probabilities for \( i \)-th period, \( Q_i = (q_{i1}, q_{i2}, q_{i3}, q_{i4}) \), must satisfy the following equation system:

\[
\begin{align*}
(q_{i1} + q_{i2} + q_{i3} + q_{i4}) / (1 + r_f) &= 1, \\
(uq_{i1} + uq_{i2} + dq_{i3} + dq_{i4}) / (1 + r_f) &= 1, \\
[(1 + r_i) q_{i2} + (1 + r_i) q_{i4}] / (1 + r_f) &= 1,
\end{align*}
\]

with \( r_f \) as the risk-free interest rate. The general solution of this equation system could be derived as

\[
Q_i^* = ((1 + r - d) / (u - d))^{-1} / (1 + r_i) + \alpha_i, \ 1 / (1 + r_i - \alpha_i), 1 - (1 + r_f - d) / (u - d) - \alpha_i, \ \alpha_i
\]

with \( \max[0, 1 / (1 + r_i) - (r - d) / (u - d)] < \alpha_i < \min[1 - (1 + r_f - d) / (u - d), 1 / (1 + r_i)] \) for \( i = 1\sim2 \). Obviously, the derived risk-neutral probability measure is not unique for each period. Making up \( Q_i \) for \( i = 1\sim2 \), the risk-neutral probability set of the whole process of an R&D project could be obtained. Incorporating the estimated revenue streams and cost inputs, the fair value of an R&D project could be calculated by (3) applying the backward procedure with respective to the risk-neutral probability set. However, since the risk-neutral probability set for this process setting is not unique, an R&D project’s value obtained would be bounded by a range. We will choose the maximum of the interval as the measurement of project’s value.
4. Numerical analyses

4.1 Illustrative example

In order to illustrate and to provide a better understanding of the risk model, the scenario that a firm will carry out an R&D project is assumed. The evolution process of this R&D project is simplified into a two-phase model, as shown in Figure 1. Since the goal of the numerical analyses is to yield comparative properties among the proposed method and the traditional ones, this setting might not totally fulfill the real world cases. The treatment employed here will not affect the results for generalized cases. For simplicity, each phase will last for a year. Before calculating the project’s value, it is necessary to choose relevant parameters appropriately. In order to use appropriate numbers of parameters, we refer to numerical example employed by Boer (2003) and Faulkner (1996). Suppose that initial investment of $5 million is required, the project will be completed one year later, and the total commercialization cost is about $20 million in the next phase. The revenue associated with the project is assumed to be 30 million. Furthermore, the volatility of average stock price within the same industry ($\sigma_s$) is 25%.

With a typical treatment, we also assume a specific relationship between the volatility of R&D revenue streams and that of the average industrial stock price. The average stock price in industrial section usually reflects the overall performance of the industry. It is expected that an individual R&D project has higher total risks than the whole industrial section. The risk for an R&D project aiming especially at emerging technologies would be much higher. We will set the volatility of an individual R&D project $\sigma$ to be 50%. It follows that $\delta = e^{0.5}$. In addition, the probabilities for all possible states should be estimated in advance. Since the estimated probabilities of different state will be influenced by subjective expectations of the firm, various attitudes regarding to the future prospect of the R&D project including normal, optimistic and pessimistic will be assumed. For the “normal” case, the probabilities that the market condition turns to be better and to be worse are set to 0.5 and 0.5 respectively. Besides, the probabilities of the R&D’s success and failure are assumed to be 0.5 and 0.5 respectively. Assuming that market risk and technological risk are independent, it then follows that the probabilities of four states at the end of the first period are 0.25, 0.25, 0.25 and 0.25 respectively. In the second phase, the probabilities of technology domination and technology replacement are supposed to be 0.7 and 0.3 respectively. It follows that the probabilities for the eight states in the second period are 0.0875, 0.0375, 0.0875, 0.0375, 0.0875, 0.0375, 0.0875 and 0.0375 respectively. If the commercialized technology is replaced by other technologies in the second period, assume the market share of products will shrink to one-fifth of the original scale with the revenue reduced proportionally, i.e. $\theta = 0.2$. With these relevant parameters setting, the probabilities and estimated cash flows for each state as shown in Figure 1 could be calculated.

For simplicity, let the risk-free rate to be zero and the required return of the R&D project based on its risk level be fixed to 15%. And assume that solvency value ($V_s$) of the project is also zero if failed R&D. We will evaluate the project using traditional NPV rule and real option method (i.e. decision tree method) without diversification effects. With the required return as the discount rate, NPV of the project is -11.44 million. When abandonment is the only option embedded in the R&D project and the market condition is not good (or R&D is failed), the firm will terminate this project. The estimated net value of the projects (the value of project minus all costs) is -1.33 million. Consider the next case with both the abandonment and defer options incorporated, the firm will not make commercialization till the market condition turns into be better as well as the new technology can dominate in the market. In this case, the net value of this project increases to 0.56 million.
We will then consider other types of firm’s attitudes toward the future outlook, namely optimistic and pessimistic. For the “optimistic” case, assume that the probabilities of the R&D’s success and failure are 0.7 and 0.3 respectively based on the firm’s view of the technological outlook. On the other hand, the associated probabilities for technology outlook in the “pessimistic” case are set to 0.3 and 0.7 respectively. The probabilities of the market condition turning to better and to worse are set to 0.7 and 0.3 respectively for the “optimistic” case while they are set to 0.3 and 0.7 respectively for the “pessimistic” case. In accordance with aforementioned valuation procedure, we can also obtain the net values of the R&D project embedding various option types for the two cases. The valuation results of the project are summarized in Figure 2.

![Figure 2: The valuation results of the R&D project by the traditional real option method for various firms’ expectation on R&D prospect.](image)

The traditional real option methods implicitly assume that an R&D firm is risk-neutral with respect to the estimated probabilities. Evaluation of an R&D project with diversification effect will be explored utilizing contingent claims analysis. The risk-neutral assumption would be relaxed. The distinguishing characteristic of the proposed valuation method is to consider the fact that a firm could still obtain compensatory rewards through diversifying investments while unfavourable situations occur. The diversification effect is likened to possessing another asset, which is similar to getting insurances. The magnitude of the compensated reward would represent the diversification effect. Accordingly, we suppose that if an R&D failed, the firm could obtain the compensatory reward with the return rate of 50% in the first period. This return rate for the compensatory reward depends on the diversification effect. The greater the diversification effect is, the higher the return rate will be. We consider the diversification effect varies from 20% to 100%. The setting of about 50% for the middle degree is appropriate because it implies that the firm can obtain average return of 25% from the diversification effect in the “normal” case. According to the database of return history in American stock market (1926–2003), the average return of small company stock is about 18%. Since the risk level of a project portfolio usually is much greater than small company, the expected return of a project portfolio should be higher than that of small company. Therefore the setting for the range of diversification effect may be rather reasonable and appropriate. With the similar argument, it is supposed that the firm could obtain the rate of return of 50% in second period in case the new technology is replaced by others.

While incorporating the diversification effect into the valuation of an R&D projects, the three real option types, no option, abandonment option only, as well as both the abandonment
and defer options, would be considered. It is obvious that the risk-neutral probability of the whole projects evolution would not be influenced by the firm's subjective expectation, i.e., the estimated probabilities. Therefore, no matter what the firm’s attitude toward the future market prospect (normal, optimistic or pessimistic) is, the valuation results for various cases would be the same. According to the calculation procedure in the previous section, the fair project’s value could be calculated and the results are summarized in Figure 3.

![Figure 3: The valuation results of the R&D project by the proposed method with the diversification effect for various firms’ expectation on R&D prospect.](image)

The compensatory reward received by the firm in unfavourable situations depends on the diversification effect. Greater management effectiveness for diversifying will create higher compensatory reward. The impact of various degree of diversification effect on the project value should also be studied. For simplicity, we still assume that the compensatory reward is the same for the first period and the second period. The values of each real option type are calculated when the degree of diversification effect varies from 20% to 100% with a step of 20%. In other words, we let the corresponding compensatory rewards be 20%, 40%, 60%, 80% and 100% respectively. The evaluation results for various degree of diversification effect are summarized in Figure 4.

![Figure 4: The valuation results of the R&D project by the proposed method for various degrees of diversification effect.](image)
4.2 Discussion

Referring to Figures 2 and 3, it is found that the outcomes derived by the proposed approach are obviously different from those by the traditional real option methods (DTA). It is obvious that the estimated probabilities have quite heavy influence on the valuation outcomes by the traditional real option methods, as could be seen from Figure 2. The outcomes obtained by the proposed method, which is based on no-arbitrage condition or CCA, actually are independent from the estimated probabilities. In other words, the assumption that the R&D firm is risk-neutral with respect to the estimated probabilities is not required for the proposed model. The traditional real option methods usually assume that evaluator has risk-neutrality with respect to the estimated probabilities. Thus its valuation outcomes are correlated significantly with estimated probabilities. Take as an example, if the estimated probability that market condition turns better is higher, the project’s value calculated will be higher. If the attitude toward an R&D prospect is more optimism, its estimated value will be larger. Although the traditional real option method is recognized as a superior valuation tool than DCF model due to its capability to capture the value of managerial flexibility, the attitude toward an R&D project is not appropriately considered. When a firm’s attitude toward R&D project is over-optimistic, the estimated value of projects would be over-evaluated. On the other hand, while being over-pessimistic toward the future outlook, the firm may underestimate the project’s value.

In addition, the value-creation effect from project diversification has been examined through the numerical analysis. According to Figure 4, it should be noticed that a project’s value obtained by the proposed method is influenced by the magnitude of compensatory reward. A greater diversifying effect would generate higher value of an R&D project. Moreover, management inefficiency for diversifying investment will decrease a project’s value. They are the two sides of the same coin. In other words, the diversifying actions of R&D firms can not only eliminate the risks of project, but also can enhance the project value. As demonstrated by Boer (2002) “In the technological world, the risks are scarier. Who is to predict whether Internet content will enter the home in 2010 predominantly via the ubiquitous twisted pair of phone wires (which have proved with DSL [digital subscriber line] to be far more versatile than first estimate), by cable, by satellite, by microwave, by fiber optics, or over electrical power lines? An accurate forecast would be invaluable to the companies competing in this marketplace and to private investors evaluating telecommunications stocks. But the outcome of the battle of broadband technologies has not been determined and will yet be influenced by thousands of R&D programs, investment decisions, regulatory decisions, and other factors that have yet to play out. False confidence is a risk, too, and to counter this risk, company such as 3M has asked each of their businesses to proactively identify a pacing project – one that has the capability of changing the basis of competition – and to fund it”. The results imply that R&D firms should attach great importance to the diversifying investment for R&D projects in order to increase its market value, which is consistent with the viewpoint of Boer (2002).

Even though the results indicate that the valuation outcomes generated by the proposed method is independent to the estimated probabilities, we need to make additional estimation for the compensatory rewards that can occur in unfavourable situations while utilizing this method. But the diversification effect that firms can technically derive should be taken into account for the valuation of an R&D project. Finally, it is also found that no matter which kind of method is adopted, project’s value will increase with the volatility coefficient (σ). This result coincides with the option pricing theory. In other words, it implies that a higher uncertainty for the future revenue streams associated with an R&D project will induce a higher management-flexibility value (Dixit and Pindyck, 1994 ).
5. Conclusive remarks

An alternative valuation method incorporating the diversification effect for R&D projects has been developed in this paper. Since diversification could reduce the unique risk of an R&D project, it may be necessary as well as important to take the diversification effect into account while a firm assesses an R&D project. This factor actually can affect the true value of projects. This research provides a modified valuation method with the consideration of no-arbitrage condition required in option pricing theory. Through the numerical analyses, it could be seen that the proposed method could yield more reasonable and reliable outcomes. The numerical outcomes are also compared with those by the traditional real option methods.

The traditional real-options evaluation assessment is apt to be affected by a firm’s subjective expectation on future market and technology condition. It might cause over- or under-estimation of a project’s value for some cases. Considering the diversification effect, the value of an R&D project derived by our method will overcome the deficit caused by firm’s subjective view. Besides, it is also found that the diversification effect could actually affect the value of R&D projects. It is shown that more effective management for diversified investments could increase the value of a project. This management implication is consistent with the prescription “although the diversifying actions would come at a cost, the combination of successively increasing cost and sharply reduced relatively risks will power value creation” by Boer (2003).

References


