

# A possibilistic approach to R & D portfolio selection \*

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## Abstract

A major advance in development of project selection tools came with the application of options reasoning to R&D. Our main concern is how to deal with non-statistical imprecision we encounter when judging or estimating future cash flows of R&D projects. In this paper we develop a model for valuing options on R&D projects, when future cash flows are estimated by trapezoidal fuzzy numbers and the expected investment costs are estimated by crisp numbers. We also present a simple fuzzy 0-1 mathematical programming model for R&D optimal portfolio selection problem.

## 1 Introduction

The real options models (or actually *real options valuation methods*) were first tried and implemented as tools for handling very large investments, so-called giga-investments, as there was some fear that capital invested in very large projects, with an expected life cycle of more than a decade is not very productive and that the overall activity around giga-investments is not very profitable (The Waeno project; Tekes 40470/00).

Giga-investments compete for major portions of the risk-taking capital, and as their life is long, compromises are made on their short-term productivity. The short-term productivity may not be high, as the life-long return of the investment may be calculated as very good. Another way of motivating a giga-investment is to point to strategic advantages, which would not be possible without the investment and thus will offer some indirect returns.

Giga-investments made in the paper- and pulp industry, in the heavy metal industry and in other base industries, today face scenarios of slow (or even negative) growth (2-3% p.a.) in their key markets and a growing over-capacity in Europe. The energy sector

faces growing competition with lower prices and cyclic variations of demand. There is also some statistics, which shows that productivity improvements in these industries have slowed down to 1-2% p.a., which opens the way for effective competitors to gain footholds in their main markets.

There are other issues. Global financial markets make sure that capital cannot be used non-productively, as its owners are offered other opportunities and the capital will move (often quite fast) to capture these opportunities. The capital market has learned the American way", i.e. there is a shareholder dominance among the actors, which has brought (often quite short-term) shareholder return to the forefront as a key indicator of success, profitability and productivity.

There are lessons learned from the Japanese industry, which point to the importance of immaterial investments. These lessons show that investments in buildings, production technology and supporting technology will be enhanced with immaterial investments, and that these are even more important for re-investments and for gradually growing maintenance investments.

The core products and services produced by giga-investments are enhanced with lifetime service, with gradually more advanced maintenance and financial add-on services. These make it difficult to actually assess the productivity and profitability of the original giga-investment, especially if the products and services are repositioned to serve other or emerging markets.

New technology and enhanced technological innovations will change the life cycle of a giga-investment. The challenge is to find the right time and the right innovation to modify the life cycle in an optimal way. Technology providers are involved throughout the life cycle of a giga-investment, which should change the way in which we assess the profitability and the productivity of an investment.

Now, rather surprisingly, the same type of arguments can be found when senior management ponders portfolios of R&D projects even if the funds to be invested are quite limited when compared to the giga-investments. R&D projects - and more specifically portfolios of R&D projects - may generate com-

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mitments, which are (i) showing long life-cycles, (ii) uncertain (sometimes vague, overly optimistic) future cash flow estimates, (iii) uncertain (sometimes questionable) profitability estimates, (iv) quite imprecise assessments of future effects on productivity, market positions, competitive advantages, shareholder value, etc. and (v) generating series of further investments.

Jensen and Warren [19] propose to use options theory to value R&D in the telecom service sector. The reasons are rather similar to those we identified above: research managers are under pressure to explain the value of R&D programmes to senior management and at the same time they need to evaluate individual projects to make management decisions on their own R&D portfolio, or simply put - to get and defend an R&D budget in negotiations with senior management and then to allocate this budget to individual projects so that the future value of the portfolio is optimised.

The research in real options theory has evolved from general presentations of flexibility in investment and industrial cases, to more theoretical contributions and the application of real options to the valuation of both industrial, and research and development projects.

The term real option was introduced in 1984 by Kester [20] and Myers [25]. The option to postpone an investment is discussed in McDonald and Siegel [27], and Pakes [28] looks at patents as options. Siegel, Smith, and Paddock [30] discuss the option valuation of offshore oil properties. Majd and Pindyck [26] look at the optimal time of building and the option value in investment decisions.

Trigeorgis' [31] book on managerial flexibility and strategy in resource allocation presents a theory of real options. Abel, Dixit, Eberly, and Pindyck [1] discuss a theory of option valuation of real capital and investments. Faulkner [18] discusses the application of real options to the valuation of research and development projects at Kodak. Kulatilaka, Balasubramanian and Storck [21] discuss a capability based real options approach to managing information technology investments.

The use of fuzzy sets to work on real options is a new approach, which has not been attempted too much. One of the first papers to use fuzzy mathematics in finance was published by Buckley [4], in which he works out how to use fuzzy sets to represent fuzzy future value, fuzzy present value, and the fuzzy internal rate of return. The instruments were used to work out ways for the ranking of fuzzy investment alternatives. Buckley returns to the discussion about comparing mutually exclusive investment alternatives with internal rate of return in Buckley [5], and proposes a new definition of fuzzy internal rate of return. Carlsson and Fullér [6] also dealt with the fuzzy internal rate of return in another context (the investment decisions to control several paper mills), and Carlsson and Fullér [7] developed a method for handling capital budgeting problems with fuzzy cash flows.

There are now a growing number of papers in the intersection of these two disciplines: real options and fuzzy sets theory. In one of the first papers on developing the fuzzy Black-Scholes model, Carlsson and

Fullér [8] present a fuzzy real option valuation method, and in Carlsson and Fullér [9] show how to carry out real option valuation in a fuzzy environment. Muzzioli and Torricelli [23] use fuzzy sets to frame the binomial option pricing model, and Carlsson and Fullér [10] discuss the optimal timing of investments with fuzzy real options. Muzzioli and Torricelli [24] present a model for fuzzy binomial option pricing. Carlsson, Fullér, and Majlender [13] develop and test a method for project selection with fuzzy real options, and Carlsson, Fullér [15] work out a fuzzy approach to real options valuation.

## 2 Real options for R&D portfolios

The options approach to R&D project valuation seeks to correct the deficiencies of traditional methods of valuation through the recognition that managerial flexibility can bring significant value to a project. Real options in option thinking are based on the same principals as financial options. In real options, the options involve "real" assets as opposed to financial ones [2]. To have a "real option" means to have the possibility for a certain period to either choose for or against something, without binding oneself up front. The value of a real option is computed by [22]

$$ROV = S_0 e^{-\delta T} N(d_1) - X e^{-rT} N(d_2)$$

where

$$d_1 = \frac{\ln(S_0/X) + (r - \delta + \sigma^2/2)T}{\sigma\sqrt{T}},$$

and where  $d_2 = d_1 - \sigma\sqrt{T}$ ,  $S_0$  is the present value of expected cash flows,  $N(d)$  denotes the probability that a random draw from a standard normal distribution will be less than  $d$ ,  $X$  is the (nominal) value of fixed costs,  $r$  is the annualized continuously compounded rate on a safe asset,  $T$  is the time to maturity of option (in years),  $\sigma$  is the uncertainty of expected cash flows, and finally  $\delta$  is the value lost over the duration of the option.

The main question that a firm must answer for a deferrable investment opportunity is: *How long do we postpone the investment up to  $T$  time periods?* To answer this question, Benaroch and Kauffman ([3], page 204) suggested the following decision rule for optimal investment strategy:

Where the maximum deferral time is  $T$ , make the investment (exercise the option) at time  $M$ ,  $0 \leq M \leq T$ , for which the option,  $C_M$ , is positive and attains its maximum value,

$$C_M = \max\{V_t e^{-\delta t} N(d_1) - X e^{-rt} N(d_2)\}, \quad (1)$$

where

$$\begin{aligned} V_t &= \text{PV}(\text{cf}_0, \dots, \text{cf}_T, r) - \text{PV}(\text{cf}_0, \dots, \text{cf}_t, r) \\ &= \text{PV}(\text{cf}_{t+1}, \dots, \text{cf}_T, r), \end{aligned}$$

that is,

$$\begin{aligned} V_t &= \text{cf}_0 + \sum_{j=1}^T \frac{\text{cf}_j}{(1+r)^j} - \text{cf}_0 - \sum_{j=1}^t \frac{\text{cf}_j}{(1+r)^j} \\ &= \sum_{j=t+1}^T \frac{\text{cf}_j}{(1+r)^j}, \end{aligned}$$

and  $cf_t$  denotes the expected cash flow at time  $t$ , and  $r$  is the risk-adjusted discount rate,  $t = 0, 1, \dots, T$ .

Of course, this decision rule has to be reapplied every time new information arrives during the deferral period to see how the optimal investment strategy might change in light of the new information. From a real option perspective, it might be worthwhile to undertake R&D investments with a negative NPV when early investment can provide information about future benefits or losses of a project.

### 3 A hybrid approach to real option valuation

A fuzzy set  $\tilde{A}$  in the real line  $\mathbb{R}$  is called a trapezoidal fuzzy number with core  $[a, b]$ , left width  $\alpha$  and right width  $\beta$  if its membership function has the following form

$$\tilde{A}(t) = \begin{cases} 1 - \frac{a-t}{\alpha} & \text{if } a - \alpha \leq t < a \\ 1 & \text{if } a \leq t \leq b \\ 1 - \frac{t-b}{\beta} & \text{if } b < t \leq b + \beta \\ 0 & \text{otherwise} \end{cases}$$

and we use the notation  $\tilde{A} = (a, b, \alpha, \beta)$ .

Usually, the present value of expected cash flows can not be characterized by a single number. We can, however, estimate the present value of expected cash flows by using a trapezoidal possibility distribution of the form

$$\tilde{S}_0 = (a, b, \alpha, \beta),$$

i.e. the most possible values of the present value of expected cash flows lie in the interval  $[a, b]$  (which is the core of the trapezoidal fuzzy number  $S_0$ ), and  $(b + \beta)$  is the upward potential and  $(a - \alpha)$  is the downward potential for the present value of expected cash flows. In a similar manner we can estimate the expected costs by using a trapezoidal possibility distribution of the form

$$\tilde{X} = (c, d, \gamma_1, \gamma_2),$$

i.e. the most possible values of expected cost lie in the interval  $[c, d]$  (which is the core of the trapezoidal fuzzy number  $X$ ), and  $(d + \gamma_2)$  is the upward potential and  $(c - \gamma_1)$  is the downward potential for expected costs.

In 2003 Carlsson and Fullér [15] suggested the use of the following fuzzy-probabilistic formula for computing fuzzy real option values

$$\tilde{C}_0 = \tilde{S}_0 e^{-\delta T} N(d_1) - \tilde{X} e^{-rT} N(d_2), \quad (2)$$

where,

$$d_1 = \frac{\ln(E(\tilde{S}_0)/E(\tilde{X})) + (r - \delta + \sigma^2/2)T}{\sigma\sqrt{T}},$$

and where  $d_2 = d_1 - \sigma\sqrt{T}$ ,  $E(\tilde{S}_0)$  denotes the possibilistic mean value of the present value of expected cash flows,  $E(\tilde{X})$  stands for the possibilistic mean value of expected costs and  $\sigma := \sigma(\tilde{S}_0)$  is the possibilistic variance of the present value of expected cash flows [11]. Carlsson and Fullér also generalized the probabilistic decision rule (1) for optimal investment strategy to fuzzy setting in [15].

## 4 A possibilistic approach to R&D portfolio selection

More often than not the expected investment cost of projects is known for sure, that is in the following we will suppose that  $X$  is crisp, but the cash flows will still be modelled by trapezoidal fuzzy numbers,  $\tilde{c}f_i = (A_i, B_i, \Omega_i, \Gamma_i)$ ,  $i = 0, 1, \dots, T$ . Furthermore, we will consider fuzzy rates of returns on investment (ROI) instead of revenues, that is, the fuzzy rate of return on investment  $X$  in year  $i$  of a project will be

$$R_i = \frac{\tilde{c}f_i}{X} = \left( \frac{A_i}{X}, \frac{B_i}{X}, \frac{\Omega_i}{X}, \frac{\Gamma_i}{X} \right) = (a_i, b_i, \alpha_i, \beta_i).$$

For example, let  $\tilde{c}f_i = (0.9, 8.4, 3.9, 5.6)$  and  $X = 6$ . Then

$$\tilde{R}_i = (15\%, 140\%, 65\%, 93\%)$$

with possibilistic mean value

$$\begin{aligned} E(\tilde{R}_i) &= \frac{a_i + b_i}{2} + \frac{\beta_i - \alpha_i}{6} \\ &= \frac{15 + 140}{2} + \frac{93 - 65}{6} \\ &= 82.17\%. \end{aligned}$$

and standard deviation

$$\begin{aligned} \sigma(\tilde{R}_i) &= \sqrt{\left( \frac{b_i - a_i}{2} + \frac{\alpha_i + \beta_i}{6} \right)^2 + \frac{(\alpha_i + \beta_i)^2}{72}} \\ &= \sqrt{\left( \frac{140 - 15}{2} + \frac{65 + 93}{6} \right)^2 + \frac{(65 + 93)^2}{72}} \\ &= 90.76\%. \end{aligned}$$

Then the fuzzy net present value of a project is computed by

$$\text{FNPV} = \left[ \sum_{i=0}^T \frac{\tilde{R}_i}{(1+r)^i} - 1 \right] \times X.$$

If a project with rates of return on investment  $(\tilde{R}_0, \tilde{R}_1, \dots, \tilde{R}_T)$  can be postponed by *maximum of  $K$  years* then we will define its possibilistic real option value by

$$\mathcal{F} = (1 + \sigma(\tilde{R}_0)) \times \dots \times (1 + \sigma(\tilde{R}_{K-1})) \times \text{FNPV},$$

where  $1 \leq K \leq T$ , and  $\mathcal{F}$  will be called as the project's possibilistic deferral flexibility value. If a project can not be postponed then its possibilistic flexibility value equals to its fuzzy net present value, that is,  $\mathcal{F} = \text{FNPV}$ .

The simplest optimal R&D portfolio selection problem then turns into the following fuzzy 0-1 mathematical programming problem

$$\begin{aligned} &\text{maximize} \quad \sum_{i=1}^N u_i \mathcal{F}_i & (3) \\ &\text{subject to} \quad \sum_{i=1}^N u_i X_i + \sum_{i=1}^N (1 - u_i) c_i \leq B \\ & \quad \quad \quad u_i \in \{0, 1\}, \quad i = 1, \dots, N, \end{aligned}$$

where  $N$  is the number of R&D projects,  $B$  is the whole investment budget,  $u_i$  is the decision variable that takes value one if the  $i$ -th project should start now (at time zero) or takes the value zero if it should be postponed and started at a later time,  $c_i$  denotes the cost of the postponement (i.e. keep the option alive),  $X_i$  is the investment cost, and  $\mathcal{F}_i$  denotes the possibilistic deferral flexibility of the  $i$ -th project for  $i = 1, \dots, N$ .

In our solution approach to fuzzy mathematical programming problem (3) we have used the defuzzifier operator for  $\mathcal{F}_i$

$$\nu(\mathcal{F}_i) = (E(\mathcal{F}_i) - \tau \times \sigma(\mathcal{F}_i)) \times X,$$

where  $0 \leq \tau \leq 1$  denotes the decision maker's risk aversion.

Since R&D projects are characterised by a long planning horizon and very high uncertainty, the value of managerial flexibility can be substantial. Therefore, the fuzzy real options model is quite practical and useful. Standard works in the field use probability theory to account for the uncertainties involved in future cash flow estimates. This may be defended for financial options, for which we can assume the existence of an efficient market with numerous players and numerous stocks for trading, which may justify the assumption of the validity of the laws of large numbers and thus the use of probability theory.

The situation for real options is quite different. The option to postpone an R&D investment will have consequences, differing from efficient markets, as the number of players producing the consequences is quite small.

The imprecision we encounter when judging or estimating future cash flows is not stochastic in nature, and the use of probability theory gives us a misleading level of precision and a notion that consequences somehow are repetitive. This is not the case, the uncertainty is genuine, i.e. we simply do not know the exact levels of future cash flows. Without introducing fuzzy real option models it would not be possible to formulate this genuine uncertainty.

The proposed model that incorporates subjective judgments and statistical uncertainties may give investors a better understanding of the problem when making R&D investment decisions.

## 5 Summary

Multinational enterprises with large R&D departments often face the difficulty of selecting an appropriate portfolio of research projects. The cost of developing a new product or technology is low in comparison to the cost of its introduction to the global market. The NPV rule and other discounted cash flow techniques for making R&D investment decisions seem to be inappropriate to build a portfolio of R&D projects as they favor short term projects in relatively certain markets over long term and relatively uncertain projects. Since many new products are identified as failures during the R&D stages, the possibility of refraining from market introduction may add a significant value to the NPV of the R&D project. Therefore

R&D investments can be interpreted as the price of an option on major follow-on investments.

In our *OptionsPort project* (Real Option valuation and Optimal Portfolio Strategies, Tekes 662/04) we have represented the optimal R&D portfolio selection problem by a fuzzy 0-1 mathematical programming problem, where a solution to this problem is an optimal portfolio of R&D projects having the biggest possibilistic flexibility value.

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