

A fuzzy approach to R&D project selection

Christer Carlsson

IAMSR, Åbo Akademi University,
Åbo, Finland
christer.carlsson@abo.fi

Robert Fullér

Department of OR,
Eötvös Loránd University,
rfuller@mail.abo.fi

Péter Majlender

IAMSR, Åbo Akademi University,
Åbo, Finland
peter.majlender@abo.fi

Abstract

The complexity of R&D investment projects makes this task especially challenging. R&D investments are characterized by multiple sources of uncertainty, and produce cash flows only after many potentially unpredictable stages of research. The net present value (NPV) rule and other discounted cash flow techniques (DCF) 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 this paper we describe some basic properties of the fuzzy real options approach for research and development project evaluation, when the present values of future net cash flows and expected costs are estimated by fuzzy numbers of trapezoidal form.

Keywords: real option, R&D investment project, possibilistic mean value, possibilistic variance

1 Introduction

The real options models 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).

It is clear that 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 commitments, 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.

The term real option was introduced in 1984 by Kester [13] and Myers [18]. Faulkner [12] discusses the application of real options to the valuation of research and development projects at Kodak. Kulatilaka, Balasubramanian and Storck [14] discuss a capability based real options approach to managing information technology in-

vestments.

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 [2], 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 [3], and proposes a new definition of fuzzy internal rate of return.

Carlsson and Fullér [4] also dealt with the fuzzy internal rate of return in another context (the investment decisions to control several paper mills), and Carlsson and Fullér [5] 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 [6] present a fuzzy real option valuation method, and in Carlsson and Fullér [7] show how to carry out real option valuation in a fuzzy environment.

Muzzioli and Torricelli [16] use fuzzy sets to frame the binomial option pricing model, and Carlsson and Fullér [8] discuss the optimal timing of investments with fuzzy real options. Muzzioli and Torricelli [17] present a model for fuzzy binomial option pricing.

Carlsson, Fullér, and Majlender [10] develop and test a method for project selection with fuzzy real options, and Carlsson, Fullér [11] work out a fuzzy approach to real options valuation.

2 Real options for R&D portfolios

The value of a real option is computed by [15]

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

where

$$d_1 = \frac{\ln(S_0/X) + (r - \delta + \sigma^2/2)T}{\sigma\sqrt{T}}, \quad (1)$$

$$d_2 = d_1 - \sigma\sqrt{T},$$

and where 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), σ is the uncertainty of expected cash flows, and finally δ 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 ([1], page 204) suggested the following decision rule for an 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 attends its maximum value,

$$C_M = \max\{C_t \mid t = 0, 1, \dots, T\}$$

$$= V_t e^{-\delta t} N(d_1) - X e^{-rt} N(d_2), \quad (2)$$

where

$$V_t = PV(cf_0, \dots, cf_T, \beta_P) - PV(cf_0, \dots, cf_t, \beta_P)$$

$$= PV(cf_{t+1}, \dots, cf_T, \beta_P),$$

that is,

$$V_t = \sum_{j=t+1}^T \frac{cf_j}{(1 + \beta_P)^j},$$

and cf_t denotes the expected cash flow at time t , and β_P is the risk-adjusted discount rate (or required rate of return on the project).

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 fuzzy approach to real option valuation

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 $\tilde{S}_0 = (s_1, s_2, \alpha, \gamma)$, i.e. the most possible values of the present value of expected cash flows lie in the interval $[s_1, s_2]$ (which is the core of the trapezoidal fuzzy number \tilde{S}_0), and $(s_2 + \gamma)$ is the upward potential and $(s_1 - \alpha)$ 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 $\tilde{X} = (x_1, x_2, \alpha', \gamma')$, i.e. the most possible values of expected cost lie in the interval $[x_1, x_2]$ (which is the core of the trapezoidal fuzzy number \tilde{X}), and $(x_2 + \gamma')$ is the upward potential and $(x_1 - \alpha')$ is the downward potential for expected costs.

In these circumstances Carlsson and Fullér [11] suggested the use of the following heuristic formula for computing fuzzy real option values

$$\tilde{C}_0 = \tilde{S}_0 e^{-\delta T} N(d_1) - \tilde{X} e^{-rT} N(d_2), \quad (3)$$

where,

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

$$d_2 = d_1 - \sigma\sqrt{T},$$

$E(\tilde{S}_0)$ 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 [9].

Carlsson and Fullér [11] generalized the probabilistic decision rule (2) for optimal investment strategy to fuzzy setting: 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, \tilde{C}_M , is positive and attains its maximum value,

$$\tilde{C}_M = \max\{\tilde{C}_t \mid t = 0, 1, \dots, T\}$$

$$= \tilde{V}_t e^{-\delta t} N(d_1) - \tilde{X} e^{-rt} N(d_2), \quad (4)$$

where

$$\tilde{V}_t = \text{PV}(\tilde{c}f_0, \dots, \tilde{c}f_T, \beta_P) - \text{PV}(\tilde{c}f_0, \dots, \tilde{c}f_t, \beta_P)$$

$$= \text{PV}(\tilde{c}f_{t+1}, \dots, \tilde{c}f_T, \beta_P),$$

that is,

$$\tilde{V}_t = \sum_{j=t+1}^T \frac{\tilde{c}f_j}{(1 + \beta_P)^j},$$

where $\tilde{c}f_t$ denotes the expected (fuzzy) cash flow at time t , β_P is the risk-adjusted discount rate (or required rate of return on the project). And the maximizing element from the set

$$\{\tilde{C}_0, \tilde{C}_1, \dots, \tilde{C}_T\},$$

is computed by the help of the following value function

$$v(\tilde{C}_t) = \frac{c_t^L + c_t^R}{2} + r_A \cdot \frac{\gamma_t - \alpha_t}{6},$$

where $\tilde{C}_t = (c_t^L, c_t^R, \alpha_t, \gamma_t)$ and $r_A \geq 0$ denotes the degree of the manager's risk aversion. If $r_A = 1$ then the (risk neutral) manager compares trapezoidal fuzzy numbers by comparing their possibilistic expected values, i.e. he does not care about their downward and upward potentials. If $r_A > 1$ then the manager is a risk-taker, and if $r_A < 1$ then he is risk-averse.

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.

4 Implementation

In our *OptionsPort* project (Real Option valuation and Optimal Portfolio Strategies, Tekes 662/04) we have represented R&D portfolios by dynamic decision trees, in which the nodes are R&D projects that can be deferred or postponed for a certain period of time. Using the theory of real options we have been able to identify the optimal path of the tree, i.e. the optimal R&D portfolio with the biggest real option value in the end of the planning period.

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