Real Options "in" Projects

by

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Abstract

Real options "in" projects are the latest extension of real options theory into physical systems design. Real options "in" projects are different from real options "on" projects. Real options "on" projects refer to the standard real options treating the physical systems as a "black box", while real options "in" systems concern design features built into the project or system. This paper defines real options" in" projects, addresses their special issues, and presents possible valuation methods. Although the crux of financial options theory – especially the "no arbitrage" assumption – is hardly valid for real options "in" projects, this paper argues that the definition of options - right not obligation - defines basic unit of flexibility. Options thinking offers important insights into flexibility in physical systems.

Keywords

Real Options, Physical Systems, Engineering Systems

Real Options "in" Projects

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Introduction

Real options can be categorized as those that are either "on" or "in" projects (de Neufville, 2002). Real options "on" projects are financial options taken on technical things, treating technology itself as a 'black box'". Real options "in" projects are options created by changing the actual design of the technical system. For example, de Weck et al (2004) evaluated real options "in" satellite communication systems and determined that their use could increase the value of satellite communications systems by 25% or more. In that case, the real options "in" the satellite constellation involved additional positioning rockets and fuel in order to achieve a flexible design that could adjust capacity according to need.

In general, real options "in" systems require a deep understanding of technology. Because such knowledge is not readily available among options analysts, there have so far been few analyses of real options "in" projects, despite the important opportunities available in this field. Moreover, because of the data available for real options "in" project analysis are of much poorer quality than that of financial options or real options "on" projects, real options "in" projects are different and need an appropriate analysis framework - existing options analysis has to adapt to the special features of real options "in" projects.

There are much less literature on real options "in" projects than that on real options "on" projects. Zhao and Tseng (2003) discussed the value of flexibility in multistory parking garages. Enhancing the foundation requires extra up-front cost, but has a return for future expansion when demand growth is large. The extra construction cost can be viewed as an option in which a premium has to be paid first and the option can be exercised later. Trinomial lattice and stochastic dynamic programming were used to model the demand and optimal expansion process. A model with

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flexibility compares with that without flexibility, and the difference of the optimal value from the two models is the value of flexibility. This value of flexibility is significant in the case. Zhao, Sundararajan, and Tseng (2004) presented a multistage stochastic model for decision making in highway development that incorporating real options in both development and operation phase. A simulation algorithm based on the Monte Carlo simulation and least-squares regression is developed. Ho and Liu (2003) presented a quantitative valuation method based on options pricing theory for evaluating major investments in emerging architecture/engineering/construction (A/E/C) technology investments. The framework took into account technology investment risks and managerial options. Leviakangas and Lahesmaa (2002) discussed the application of real options in evaluation of intelligent transportation system and pointed out the shortcoming of traditional cost-benefit analysis that may discard the value of real options. Kumar (1995) presented the real options approach to value expansion flexibility and illustrated its use through an example on flexible manufacturing systems. Ford, Lander, and Voyer (2002) proposed a real options approach for proactively using strategic flexibility to recognize and capture project values hidden in dynamic uncertainties. An example for a toll road project was employed. Wang and de Neufville (2004) proposed a two stage real options "in" projects framework to design flexibility into physical systems and a mixed-integer stochastic programming model to evaluate real options "in" projects. An example on hydropower stations development was drawn to show the general framework and mixed-integer programming algorithm. de Neufville, Scholtes, and Wang (2005) developed a spreadsheet Monte Carlo simulation model to value real options in the design of a multistory park garage and gained insights into real options "in" projects, especially the key trait of real options taking advantage of upside potential while cutting downside risk.

The existing literature on real options "in" projects does not provide a big picture on real options "in" projects, but on single specific project or issue. It does not attack the general special issues facing real options "in" projects, for example, path-dependency or identification of real options. The existing work on real options "in" project is limited. This area needs a lot of creative work.

Real options “in” projects

Again we describe the two basic flavors of real options: those that are “on” systems and treat the technology as a black box, and those that are “in” systems, and provide the flexibility and the option through the details of the design (de Neufville et al, 2004). A simple example of a real option “in” a system is a spare tire on a car: it gives the driver the “right, but not the obligation” to change a tire at any time, but this right will only rationally be used when the car has a flat.

Real options “in” projects are of special interest to the study of engineering systems. Large-scale engineering projects share three major features. As Roos et al (2004) have indicated, “they

- Last a long time, which means they need to be designed with the demands of a distant future in mind;
- Often exhibit economies of scale, which motivates particularly large construction;
- Yet have highly uncertain future requirements, since forecasts of the distant future are typically wrong.”

This context defines the desirability of creating designs that can be easily adjusted over time to meet the actual needs as they develop. System leaders need to build “real options” into their designs. Engineers increasingly recognize the great value of real options in addressing intrinsic uncertainties facing large-scale engineering systems and, more importantly, are learning to manage the uncertainties proactively (de Neufville et al, 2004).

Note the difference between real options “in” projects and the engineering concept of “redundancy”. Both real options “in” projects and redundancy refer to the idea that some components should not have been designed if the design were optimized given the assumption that things are not going to change. Redundancy refers to more than enough design elements to serve the same function, while real options “in” projects may not serve the same functions as some currently existing components (though such real options may not prove necessary given the current situation).

Real options “in” projects are those that are most interesting to systems designers, and are the focus of this paper. Following are several examples of real options “in” projects for engineering systems.

Example 1: "Bridge in bridge"

The design of the original bridge over the Tagus River at Lisbon provides a good example of a real option "in" a major infrastructure system. In that case, the original designers built the bridge stronger than originally needed, strong enough so that it could carry a second level, in case that was ever desired. The Portuguese government exercised the option in the mid 1990s, building on a second deck for a suburban railroad line (Gesner and Jardim, 1998).

Example 2: Satellite systems

In the late 1980s, Motorola and Qualcomm planned the Iridium and Globalstar systems to serve their best estimates of the future demand for space-based telephone services. Their forecasts were wrong by over an order of magnitude (in particular because land-based cell phones became the dominant technology). The companies were unable to adjust their systems to the actual situation as it developed and lost almost all their investments -- 5 and 3.5 billion dollars respectively. However, if the companies had designed evolutionary configurations that had the capability to expand capacity, it would have been possible both to increase the expected value of the system by around 25%, as well as to cut the maximum losses by about 60% (de Weck et al, 2004). Such evolutionary configurations can be realized by designing real options for the room of future capacity expansion. For example, a smaller system with smaller capacity can be established first. For a smaller system, there are fewer satellites with a higher orbit. One possible real option is designing a small rocket into each satellite. When demand proves big, the rockets can be launched and propel the satellites to a lower orbit. With additional satellites launched to the lower orbit, a bigger system is accomplished to serve the big demand. The small rockets designed into the satellites are real options. They can be exercised when the circumstances turn favorable. There is a cost to acquire such real options – the cost of designing and installing such rockets and the extra weight sent into space. Decision makers have the right to exercise the options, but not the obligation – they can leave the rockets there never launching them.

Example 3: Parking garage design

This example is extrapolated from the Bluewater development in England of a multi-level parking garage. A car parking garage for a commercial center is planned in a region that is growing as population expands. Economic analysis recognizes that actual demand is uncertain, given the long time horizon. If the owners design a big parking garage, there is a possibility that the demand will be smaller and the cost of a big garage cannot be recovered; however, if the owners design a small parking garage, they may miss the opportunity if the demand grows rapidly. To deal with this dilemma, the owners can design a real option into the design by strengthening the footings and columns of the original building so that they can add additional levels of parking easily. This premium is the price to get the real option for future expansion, a right but not an obligation to do so. (de Neufville, Scholtes, and Wang, 2005)

Comparison of real options “on” and “in” projects

Real options “on” projects are mostly concerned with the valuation of investment opportunities, while real options “in” projects are mostly concerned with design of flexibility. Some classic cases of real options “on” projects are on valuation of oil fields, mines, and pharmaceutical research projects, where the key question is to value such projects and decide if it is worthwhile to invest in the projects. The examples of real options “in” projects are extra small rockets on satellites, strengthened footings and columns of a multi-level parking garage, or “bridge in bridge”.

Real options “on” projects are mostly concerned with an accurate value to assist sound investment decisions, while real options “in” projects are mostly concerned with “go” or “no go” decisions and an accurate value is less important. For real options “on” projects, analysts need to get the value of options, but for real options “in” projects, analysts do not have to provide the exact value of the options but simply provide what real options (flexibility) to design into the physical systems.

Real options “on” projects are relatively easy to define (a categorization of real options can be found in Trigeorgis, 1993), while real options “in” projects are difficult to define in physical systems. For an engineering system, there are a great number of design variables, and each design variable can lead to real options “in” projects. It is hard to find out where the flexibility can be and where is the most worthy place to design real options “in” project. Identification of options is an important issue for real options “in” projects.

Real options “on” projects do not require knowledge on technological issues, and interdependency/path-dependency is not frequently an issue. However, real options “in” projects need careful consideration of technological issues. Complex technological constraints often lead to complex interdependency/path-dependency among projects. Table 1 summarizes the comparison between real options "on" and "in" projects.

Real options "on" projects	**Real options "in" projects**
Value opportunities	Design flexibility
Valuation important	Decision important (go or no go)
Relatively easy to define	Difficult to define
Interdependency/Path-dependency less an issue	Interdependency/Path-dependency an important issue

Table 1 Comparison between real options "on" and "in" projects

Difficulties facing the analysis of real options "in" projects

There are many difficulties facing the analysis of real options "in" projects:

1. In order to define a real option "in" a system, it is necessary to understand the technology – competence in financial analysis is not sufficient. Analysts must possess the special technical knowledge in the projects studied.
2. Financial options are well-defined traded contracts that need to be valued individually. But real options "in" projects are fuzzy, complex, and interdependent: To what extent is there a predetermined exercise price? What is the time to expire? Moreover, it is not obvious the usefulness to value every element that provides flexibility.
3. Real options "in" projects are likely to be path-dependent. For example, the capacity of a thermal power system at some future date may depend on the evolutionary path of electricity use. If the demands on the system have been high in preceding periods, the electric utility may have been forced to expand to meet that need, as it might not have done if the demand had been low. Real options "in" projects may thus differ fundamentally from stock options, whose current value only depends on the prices at that time. The evolutionary path of a stock price does not matter. Its option value is path-independent. This is not true for many real options.
4. Real options "in" projects are likely to be highly interdependent, compound options. Moreover, such interdependency are often exotic and never met in financial options circumstances, for example, a series of power stations on a

river, a power station built downstream will affect the power generation capacity of upstream stations since it changes water flow. Their interactions need to be studied carefully as they may have major consequences for important decisions about the design of the engineering system. The associated interdependency rapidly increases the complexity and size of the computational burden.

Possible valuation techniques for real options "in" projects

This section examines the applicability of the three most important options valuation techniques to real options: the Black-Scholes formula, simulation, and binomial lattice.

Black-Scholes Formula

The Black-Scholes formula for the prices at time zero of a European call option on a non-dividend-paying stock[3]:

$$c = S_0 N(d_1) - Xe^{-rT} N(d_2)$$

where

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

$$d_2 = \frac{\ln(S_0 / X) + (r - \sigma^2 / 2)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$$

and N(x) is the cumulative probability distribution function for a variable that that is normally distributed with a mean of zero and a standard deviation of 1.0.

The formula is the result of solving a Partial Differential Equation (PDE), seemingly opaque and incomprehensible to those not familiar with financial mathematics or physics. Moreover, if lack of understanding of the underlying assumptions for Black-Scholes formula, it is very easy to apply the formula blindly and obtain a useless and misleadingly precise "value of real options". The major assumptions underlying Black-Scholes approach are that

1. There is a market that prices the asset;

[3] Similar formulas can be derived for European puts options, and European call or put options with dividend paying.

2. This market is efficient that provides no riskless arbitrage opportunities, and having some special conditions:
    - the short selling of securities has no limitation,
    - no transaction costs or taxes,
    - all securities are perfectly divisible,
    - security trading is continuous,
    - the risk free rate of interest is constant and the same for all securities;
3. The asset price follows Geometric Brownian Motion with μ and σ constant.

For the big picture of this study on real options and for simplicity, it is possible to assume that the special conditions for the market in point 2 are approximately satisfied or are secondary in comparison to the three major points and have a much less impact on the valuation.

Now let us examine the three most important assumptions:

1. The price assumption for Black-Scholes approach is not discussed in finance literature, since prices are intrinsic to financial markets, stocks, derivatives, and theories. But for real options, it is sometimes not the case that the analyst has a market price for the subject studied. There may be market prices for the final products whose price dynamics are well understood, for example, oil or copper. For other cases, however, it may not be easy to decide the dynamics of market price for the products of a system, for example, computers. For still some other cases, it may not even be possible to decide market price for the product of a system, for example, national defense.
2. The no arbitrage condition is often hard to satisfy for real options. If people can construct a replicating portfolio to match PERFECTLY the payoff of the real options under all possible situations, then arbitrageur can take advantage of any mismatch of the price between the portfolio and the real options, and earn profit RISKLESSLY. If the price for the real options is too high, arbitrageurs could sell the real options and buy the replicating portfolio to earn riskless profit; else if the price for the real options is too low, arbitrageurs could sell the replicating portfolio and buy the real options to earn riskless profit. Since such activities of arbitrageurs will change the demand and supply of the real options on the market, and finally drive the price of the real options to equal that of the replicating portfolio. Such “no arbitrage” is usually hard to prove valid for a real option. The payoff of a stock option can be perfectly matched by a portfolio of stocks and loan, but how can we match a

real option? Sometimes, it may be possible to assume a reasonable approximation for the replicating portfolio; for example, a portfolio of long position in oil futures and borrowed money can replicate purchase of an oil field with the option to postpone development. Often, however, it is not possible to find replicating portfolio for real options. For example, how might one replicate the real options of strengthened footings and columns for a parking garage?

3. The Geometric Brownian motion assumption has the property that the price grows forever. For some underlying assets, for example the stock price because of continuous inflation and investment, this is an acceptable assumption. For other underlying assets, however, the Geometric Brownian motion is not a best assumption. For example, Wang (2003) studied real options in river basin development with the purpose of power generation, using the underlying of electricity price. Empirical evidence shows that Geometric Brownian motion is not the best model to describe the stochastic movement of electricity price, and mean-reverting proportional volatility model is a better model (Bodily and Buono, 2002). Constant μ and σ is needed for Black-Scholes approach even if Geometric Brownian motion assumption is validated. Fortunately, if μ or σ vary with respect to time, we have means to deal with such relaxation of assumption in finance theory.

With the above discussion of assumptions for Black-Scholes, we can conclude that the Black-Scholes approach may be valid for real options “on” projects, but it hardly works for real options “in” projects where replicating portfolios are almost impossible to define.

<u>Simulation</u>

Monte Carlo simulation does not have as many assumptions as the Black-Scholes formula. If it is possible to specify the stochastic processes for the underlying uncertainties, and to describe the function between the input uncertain variables and the output payoff, computers can do the “brute force” work. Plausibly, simulation can obtain any valuation that Black-Scholes can get at any specified level of accuracy, and it can tackle problems with complex and non-standard payoffs that Black-Scholes cannot deal with. However, several issues need to be understood before using the Monte Carlo simulation:

1. We have to have sound stochastic models for the underlying uncertain variables, especially the parameters in the stochastic models. If we use the wrong model or wrong parameters, the simulation model can only serve the

role of “garbage in and garbage out”. If the analyst uses the common Geometric Brownian motion blindly in the simulation without checking its validity in the special context, the results may be both useless and misleading.

2. The computational cost could be expensive for simulation methods. To get the required accuracy, the convergence could be slow and time consuming. In this context, variance reduction procedures are important. These include antithetic variable technique, and control variate techniques, importance and stratified sampling, moment matching, quasi-random sequences, and representative sampling through a tree, etc.
3. Simulation is not a panacea; there are cases where simulation is ineffective. The "Curse of Dimensionality" refers to the number of samples per variable increase exponentially with the number of variables to maintain a given level of accuracy. If there are multiple sources of uncertainty, then it could be computationally prohibitive to calculate the value at required accuracy. Also, simulation needs an analytic form of exercise condition for the options. If there are no closed-form analytical exercise conditions, for example American options, the simulation technique may not work without special treatment. If the backward looking optimality criterion for American options is used, it excludes the possibility of straightforward use of implicitly forward looking simulation technique.
4. Simulation can only provide a value, but does not shed light on the intrinsic relationship between variables and does not provide insights into the key drivers for the valuation. Whereas the Black-Scholes formula provides a closed-form analytic solution, which allows people to understand the important role of volatility in options pricing, and to calculate sensitivity measures. Simulation provides fewer critical insights.

With the understanding of the issues and limitation of simulation technique, we can unleash the power of the simulation in valuation of real options “in” projects because of its versatility and low requirement of assumptions.

Binomial Tree

Binomial tree provides the basis for a dynamic programming algorithm. The approach is not necessary binomial, but could be trinomial or more. Whatever multinomial it is, the essence is the same: the approach allows the recombination of states to decrease the computational burden. When the number of nodes grows at only one for each additional stage considered, we can improve the precision of binomial tree method to a very high level by dividing the life span of an option into more stages.

Binomial trees work with both risk-neutral valuation and actual valuation. Risk-neutral valuation uses risk-neutral probabilities and discounts at risk-free interest rate; actual valuation uses actual probabilities and discounts at risk-adjusted rates. For real options "in" projects, the "no arbitrage" condition often does not hold and risk-neutral valuation is thus problematic, so we should not naively use Black-Scholes formula, though we can still use binomial tree for actual valuation.

The tree structure can deal with more than Geometric Brownian Motion implied by the standard binomial tree. We can establish different trees for different stochastic processes. The recombination structure of a binomial tree implies path-independence. If a new process has path-dependent features, we can break the recombination structure of the tree. Although with the recombination structure broken, the number of nodes increases exponentially rather than arithmetically when the number of periods increases, it is still maneuverable for a small number of stages.

Depending on the circumstances, some techniques may be more effective or accurate than others. To summarize,

- Black-Scholes approach should be used with great care when applied to real options "in" projects, we have to justify its assumptions;
- Simulation is very useful but we need to understand its limitations and apply variance reduction techniques; and
- Binomial tree is versatile and powerful, but keep in mind that if path-dependency exists (as common for real options "in" projects), we have to break the recombination structure of the tree and limit the number of periods considered.

Attack and defense of real options method

Some people doubt the theory of real options. They believe the essence and beauty of financial options theory lies in arbitrage enforced pricing or contingent claims analysis. However, it is hard to see that arbitrage enforced pricing is relevant in many cases of real options. In many cases, real options method is hard to avoid the problem of deciding risk adjusted discount rate and decision maker's subjective valuation of risk. This implies that real options analysis cannot obtain an objective valuation based on market observable prices, and people can maneuver the real options analysis. Everybody can reach a different result from his/her own real options analysis and there is no possibility to prove who is correct and who is wrong, because the subjective valuation of risk enters the analysis.

Although all the doubts, real options theory is popular and developing fast… "Whatever is reasonable is true, and whatever is true is reasonable." (Hegel, G) The author has an explanation on why real options theory is popular and highly useful.

Arbitrage-enforced pricing and real options

For arbitrage enforced pricing to work, we must understand how arbitrage opportunities are removed. The crux most relevant to real options lies in two points:

- There is some traded asset has the stochastic components that obey the same probability law and perfectly correlated with the real options, and
- Arbitrageurs are able to short sell the real options[4].

If these two conditions and some other conditions are true, an arbitrageur can construct a portfolio to replicate the options perfectly and remove all risk. The arbitrageur then earns the risk-free rate since there is no risk involved. If the arbitrageur earns more than risk-free rate, there is arbitrage opportunity, and arbitrageurs' activities will eliminate such opportunities quickly. If arbitrage-enforced pricing works, we can prove that there is a market price of risk, which is the same for all derivatives that are dependent on the same risk at the same time. With the market price of risk, we can link the risk-free rate and risk-adjusted discount rate and helps us move from a world with risk preference to a risk neutral world. The valuation obtained from the risk neutral world is valid in the worlds with risk preference. With the validity of risk neutral valuation, we can obtain an objective value of options independent of individual risk preference – a very difficult part of analysis.

[4] If short selling of the real options is not possible, then arbitrageurs cannot earn profit by short the real options and long the replicating portfolio, though they can earn profit by long real options and short the replicating portfolio. This will make the price of the real options greater than or equal to the price for the replicating portfolio, rather than equal to the price of the replicating portfolio, and thus the arbitrage-enforced price does not hold.

For real options, it is hard to find a traded asset that has the stochastic components perfectly correlated with the real options. If it is possible for some real options "on" projects, it is almost never the case for real options "in" projects. Moreover, many real options are large-scale projects, so that short selling of the real options is not realistic. If arbitrage-enforced pricing does not work for a real options project, there is no sense to talk about Black-Scholes formula or risk-neutral valuation.

What is the definition of real options?

People have different definitions of real options. To some extent, we do not even have a consensus on what are real options. Following is a partial list of different definitions:

- "In a narrow sense, the real options approach is the extension of financial option theory to options on real (nonfinancial) assets." (Amram and Kulatilaka, 1999)
- "Similar to options on financial securities, real options involve discretionary decisions or rights, with no obligations, to acquire or exchange an asset for a specified alternative price." (Trigeorgis, 1996)
- "Opportunities are options – right but not obligation to take some action in the future." (Dixit and Pindyck, 1995)
- "A real option is the right, but not the obligation, to take an action (e.g. deferring, expanding, contracting, or abandoning) at a predetermined cost called the exercise price, for a predetermined period of time – the life of the option." (Copeland and Antikarov, 2001)
- "In fact, it is possible to view almost any process that allows control as a process with a series of operational options. These operational options are often termed real options to emphasize that they involve real activities or real commodities, as opposed to purely financial commodities, as in the case, for instance, of stock options." (Luenberger, 1998)

Above definitions agree that options are rights not obligations. The key difference of the definitions lies in the scope of real options, from assets in a narrow sense to actions in a broad sense. If we insist that real options are application of financial options theory to nonfinanical assets, real options theory cannot be applied beyond the boundary where the "no arbitrage" assumption is valid. As designers of engineering systems, we think of real options in a broad sense that is close to Luenberger's definition – focusing on the trait of right not obligation and extending the real options concept in a more abstract way. And thus physical flexible design in an engineering systems can be thought of as real options, not only the engineering project as an investment opportunity as a whole.

Following the narrow and broad senses of definition of real options, there are two ways to understand the key contributions of real options concept:

- The nice theory of “no arbitrage” and risk-neutral valuation of assets that avoids the trouble to find out the correct risk-adjusted discount rate; or
- Defining the basic unit of flexibility analysis for any action or asset, that is, options (right not obligation)

We have proven the first contribution hardly stands for many real options “in” projects cases, if not most. Now let us examine closely the second argument of the contribution.

<u>Options define flexibility</u>

What is flexibility? How should it be measured? How should it be valued? Without a clearly defined basic unit of flexibility, it is hard to study it in an organized fashion.

Options concept neatly defines the basic unit of flexibility. The concept of real options is a right, but not obligation, to do something for a certain cost within or at a specific period of time. This concept models flexibility as an asymmetric right and obligation structure for a cost within a time frame. This is the basic structure of human decision making – take advantage of upside potential or opportunities and avoid downside risks. We can construct complex flexibility using the basic unit of real options.

Does Decision Analysis provides a means to structure flexibility? See the decision tree in Figure 1. The tree structure represents the flexibility to choose among Project A, Project B, Project C and Do Nothing. To a certain extent, decision tree defines flexibility[5], but it has some inadequacy:

- It aims at an expected value of the projects. This is over simplified with respect to the study of flexibility and human initiatives in risk management. It does not analyze each separate option and lose sight of the intricacy of flexibility.

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[5] Trigeorgis (1996) points out that decision tree analysis is “practically useful in dealing with uncertainty and with the modeling of interdependent variables and decisions, but they stumble on the problem of the appropriate discount rate.”

- It could easily grow messy, and make analysts lose sight of the most important issues and choices.
- Decision tree discretize possibilities, but options analysis works with a continuous distribution and obtain more accurate and convincing results.

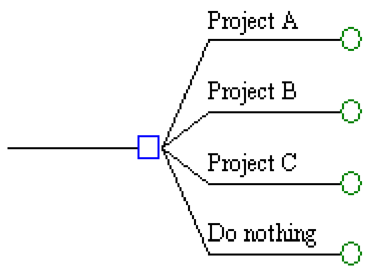

Figure 1 Decision Tree Analysis

Instead, a real option can serve as a basic unit to model flexibility. Real options can be stacked together to describe complex flexibility. For example, the decision tree in Figure 1 can be defined as a portfolio of three mutually exclusive call options on Project A, B, C. Flexibility is a portfolio of real options.

Moreover, in comparison with decision tree analysis, real options analysis compares the value with and without options to get the value of options, helps people keep focus on the most important options, and values projects based on a continuous probability distribution of events.

Is real options "in" projects analysis is merely a fancy name for decision analysis? Doesn't it catch the essence of financial options theory that circumvents the problem of deciding appropriate discount rates? This argument got something, but real options and decision analysis are different. Real options are building blocks to describe flexibility, and can be thought of as a formal way to define flexibly. Decision analysis is a way to organize different decision alternatives and possible outcomes to assist decision. Decision analysis is merely a tool and real options analysis is a way of thinking to understand, organize, summarize, and quantify flexibility.

In practice, real options theory has been extended into many areas where arbitrage-enforced pricing does not hold. The issue is not whether it is a **correct** real options valuation; there are some merits in such extension. Options definition has nothing to do with arbitrage-enforced pricing. It is broader. If they are financial options, we can use arbitrage-enforced pricing; if they cannot be valued by arbitrage-enforced pricing, they are still options, and they are still an interesting and useful way to define flexibility. This is the reason why real options grow more and more popular, while ingenious part of financial options theory is sometimes not valid in real options.

Conclusion

Real options "in" projects are the latest extension of real options work into physical systems. The concept is new. Methodology needs to be further developed. Standard valuation tools need to adapt to real options "in" projects. One dimension of the general development of options is depicted in Figure 2. With the development of options theory, the scope of application is expanding, from financial options to real options "on" projects to real options "in" projects. Real options "in" projects further expand the options thinking into physical systems, adding flexibility systematically with awareness. With the success of the real options theory and its key insights into uncertainty and flexibility, it has bright prospects to improve engineering systems design in meeting customer demands, economical feasibility or profitability, and regulatory requirements.

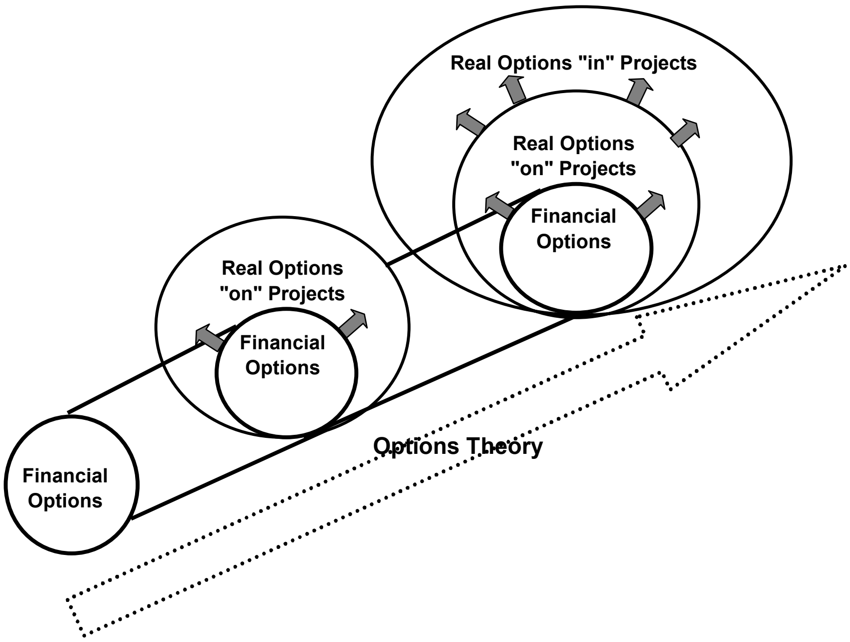

Figure 2 Development of Options Theory

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