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A Primer on Real Options Pricing Methods

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Abstract

This paper reviews real options pricing methods and refers to relevant literature highlighting their main points. An overview on real options is presented initially and next the pricing methods that have been proposed so far is introduced. The main objective of the paper is to demonstrate the plurality of the approaches which along with the complexity of the methods leads to increasing sophistication and thus reduces intuition among practitioners. It also highlights some of the criticism found in relevant literature against real options and as conclusion discusses possible remedies to assist real options' adoption.

Keywords

Real Options, Pricing Models, Investment Appraisal, Capital Budgeting

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1. Overview

The concept of a real option refers to the flexibility of decision making under uncertainty in the light of new information, meaning that a predefined decision thread can be altered as new information arrive that reduce uncertainty. Financial options theory lead to the initiation of real option theory as similarities were found between the two and theorists built real option models mostly upon financial options models. In its roots, real options analysis is the application of financial options theory to the evaluation of real assets (Trigeorgis, 2005, Rigopoulos, 2014a, 2014b, 2014c, 2015).

A financial option is a security whose value changes along with the market value of some underlying assets, while a real option is a kind of derivative on a project or investment contingent upon time, uncertainty, costs and yield. A financial option provides the holder with the right, but not the obligation, to buy or sell a specified quantity of an asset at a fixed price (exercise price), at the expiration date of the option or before. In case the holder does not want to exercise the option, then it expires. The underlying asset can be stocks, indices, currencies, commodities, future contracts or debt instruments. On the other hand, a real option is the right, but not the obligation, to take an action on a project or an asset (expand, defer, contract, abandon etc.) at a predetermined cost (exercise price), for a predetermined period of time.

Myers was the one that introduced the term real options back in 1977 as an opportunity to buy real assets and pointed out the similarities between the financial options and real options. He introduced the concept that investment opportunities can be viewed as call options on real assets. Alternative definitions of real options are found in various authors since then, depending on the viewpoint of each author, however the common factor is that a real option models the future decision opportunities as flexibility. Following Myers, real options approach evolved and was further used for the study of investment under uncertainty by various authors. For the next decades the development of this new field resulted into a substantial body of literature which span across many domains in theory and practice. However, only after the influential contributions of Dixit and Pindyck, Tirgeorgis, and Amram and Kulatilaka, who actually established the initial theoretical framework for the application of real option theory and pricing of real options the field was accessible to the financial practitioners and the public (Dixit and Pindyck,

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1994; Tirgeorgis, 1996; Amram and Kulatilaka, 1998; Copeland and Antikarov, 2005).

Following this, large corporations included the real options methodological framework to their investment valuation techniques resulting thus to further development of the domain (He, 2007). Theorists were also at the same time promoting the theoretical superiority of real options theory against DCF methods for investment valuation and considered the approach as the tool to replace legacy DCF methods for capital planning and asset valuation. In the following years the adoption from theorists was quite extended resulting in a variety of approaches, while adoption in the field of practice was not so remarkable. From a more contemporary point of view it seems that the penetration of real options does not follow the theoretical hype.

This paper reviews the literature on real options pricing methods along with some basic overview on real options. Its main objective is to depict the plurality of the approaches which along with the complexity of the methods leads to increasing sophistication and thus reduces intuition among practitioners. It also highlights some of the criticism found in relevant literature against real options and discusses some remedies to assist their adoption.

2. Real Options Types and Applications

Real option theory can be applied to a broad range of business conditions and problems and there has been proposed numerous types of real options and variations of them. Several classifications and groupings have been presented in the previous years, reflecting each time the underlying business context. Trigeorgis' approach which is considered as a standard approach in real options literature is based on the concept that a real option reflects managerial flexibility to adapt future actions as new information becomes available (Trigeorgis, 1999). Thus, for instance, uncertainty about future cash flows realization at the beginning of a project is quite high and in many cases actual cash flows may be not sufficient according to management expectations finally and lead to losses. In this context of uncertain future cash flows, real option comes to provide managerial flexibility as every time new information arrives uncertainty is being reduced and management may alter its strategy and decision to operate in a way either to reduce losses or to capture future opportunities until the next milestone of novel information arrival. Investing to a project is not a one off decision but a multi-step process where management has the right and not the mere obligation to continue to the next step.

So, Trigeorgis initially distinguishes the following types of real options

1. Option to defer (Deferral or waiting option). It refers to the right or flexibility of management to wait and see before it proceeds to an irreversible investment decision until market conditions are clear as new information arrives and expected output is justifying the investment.
2. Time to build options (Staging or time-to-build option). It refers to the case of a decision that takes time or is taken in steps or phases, giving thus the managerial flexibility to revise at each stage if conditions are worsening.
3. Option to alter operating scale (Option to expand, contract, extend). It refers to the case of revising the scale or life of a project according to market conditions. So management can select either investing more to expand or extend the life or on the other hand contract in case of worsening.
4. Option to abandon (Contract or abandon option). It refers to the case of abandoning a project due to worsening market conditions. So management can select contract or abandon if there are no prospects.
5. Option to switch (Switching option). It refers to the flexibility of selection among optimal alternatives according to market conditions. Alternatives may include inputs, outputs locations, or any other variable that can be optimized.
6. Growth options (Compound option). It refers to the case of a multi-step investment that is seen as a series of interrelated projects, as a chain, where the decision to proceed to the next step is based on the previous project's prospect and output.

Later studies embrace the above concept and aforementioned real option types. However, there exists criticism on the fact that the above list is not well defined and is neither exhaustive nor the types are mutually exclusive and should be rather considered as a basis for introduction to the real options logic (Stellmaszek, 2010). Stellmaszek mentions another approach that can be a considered as a framework as well, given that it can bypass Trigeorgis's shortcomings. It is based on Copeland and Keenan's approach that proposes a grouping scheme with three major categories, which in turn contain seven basic real options (Copeland, 2001).

1. Growth options. This contains the option to scale up, to switch up and scope up a project.
2. Deferral/learning options. It contains the options to study/start and scale down a project.
3. Abandonment options. It contains the scale down, switch down and scope down options.

The application of real options requires the existence of uncertainty and flexibility in relative large investments. Such sectors include oil and gas industries, mining, pharmaceuticals and biotechnology. Tirgeorgis offers a quite extended review of application cases in several sectors (Trigeorgis, 1996). Real options applications can be found in a variety of sectors and settings. Research publications in real options applications are numerous and span across many diverse domains. To name a few, we can identify publications in the fields of strategic investment decisions, energy, competition and business strategy, real estate, environment, natural resources, production, research and development, advertising, corporate behavior, and mergers and acquisition.

3. Real Options Pricing

Table 1-1. Similarities between financial and real options.

Financial option Variable	Financial option on stock	Real option on a project	Real option Variable
S_0	Current stock price	Gross present value of expected cash flow	V_0
K	Exercise price	Investment cost	I
T	Time to maturity	Time until the opportunity expires	T
σ	Stock price volatility/ Standard deviation of stock returns	Project value uncertainty/ risk of project cash flows	σ
r	Risk-free interest rate	Risk-free interest rate/ Time value of maney	r
	Dividend	Cash flow or value leakage	

Table 1-2. Differences between financial and real options.

Characteristic	Financial options	Real options
Maturity	Short, months	Long, years
Underlying asset	Tradable	Non tradable
Competition and markets effect	Do Not affect pricing	Affect value
Managerial effect	Does not affect pricing	Affect value

Valuation of real options is based on the assumption, that real options are in close analogy to financial options, and as such, methods used for financial options are also suitable for real options pricing. However, the subject is still open and several approaches exist. An investment opportunity for example can be treated as a call option on the present value of expected future cash flows from the investment. The analogy is further depicted as a one to one relationship between their parameters, where the real options parameters are inferred by the more concrete definitions of financial options.

However there exist differences between the two which affect the one to one relationship and raise questions on the approach that is appropriate for real options valuation (Mun, 2002).

From a technical point of view the methods that are used for real options pricing can be divided in two major classes: Analytical and numerical methods. In the diagram below a further taxonomy is presented (Figure 1). This taxonomy is presented in more or less the same way by Schulmerich, Hommel and Lehmann and others (Schulmerich, 2010; Hommel and Lehmann, 2001; Hommel, Scholich and Baecker, 2003; Stellmaszek, 2010). Schulmerich presents the most thorough analysis of the approaches aggregating the relevant literature.

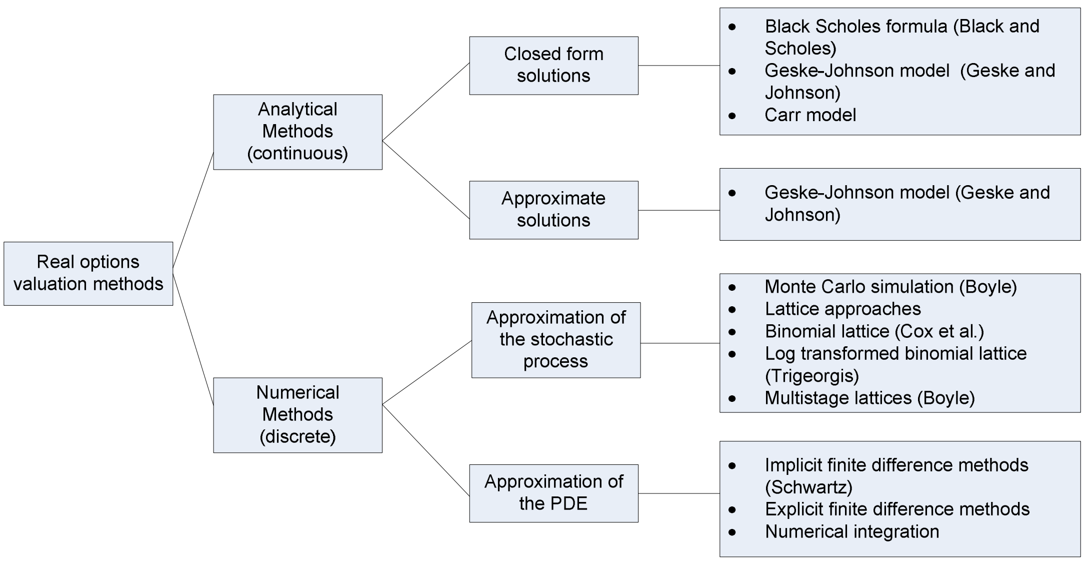

Figure 1. Real option valuation techniques.

4. Analytical Methods

The main characteristic of this class is that the solution can be provided in closed form. In general, analytical solutions can be further divided in closed form analytical solutions and approximate ones.

4.1. Analytical Solutions

Analytical methods include the famous Black & Scholes formula for European put and call options and approximate solutions are provided for American put and call options on normally or lognormally distributed underlying assets. For some types of options, such as for the European put option there can be derived analytical closed form solution under the Black & Sholes assumptions.

A review of closed form approaches up to 1995 is presented in details by Trigeorgis (1996), focusing on research publications which apply real options in various cases. The majority of them are applications to relatively simplified problems which according to Schulmerich are not appropriate, due to simplification, to model real world problems (Schulmerich, 2010). The solutions presented can be further grouped according to the option they evaluate, such as option to defer, option to shut down or abandon, option to switch (Geske, 1979) and compound options (Carr, 1995). The approach in general comprises of a diffusion process modeled by a similar stochastic differential equation with different coefficients or parameters. Almost all, in addition, use constant risk free rates. Brennan and Trigeorgis present another compilation of publications with works on analytical solutions, which use complex mathematical models (Brennan and Trigeorgis, 2000). Schulmerich mentions some flaws of analytical solutions, which he claims that are inherent to the approach itself. As such he notes that on the one hand the models can be solved only for very simplified cases, which is not realistic, while real world cases cannot be modeled by terms of partial differential equations. On the other hand, the majority of the approaches refer to simple rather than complex options which cannot be handled by the analytical approach.

4.2. Approximate Solutions

Approximate analytical solutions include American options and are derived by various approximations, e.g quadratic approximation (Geske and Johnson, 1984).

Although analytical solutions are in general mostly favorable for real options, the majority of real options cases do not fulfill the assumptions and requirements of the above approaches but they can be seen rather as limiting cases for real options that do occur in practice.

Two techniques that are used to derive analytical solutions for real options pricing are dynamic programming and contingent claims. In the following an overview of both methods is presented.

4.3. Dynamic Programming

This is a method of optimization and the overall idea is to approach a real option as an investment optimization problem under uncertainty, and as such to maximize the asset net present value under the problem’s constraints and considering the managerial flexibility. The dynamic programming approach is based on splitting the decisions in parts that comprise a sequence in time. Each time step then has a present decision and some future decisions. In order to find the optimal path of decisions we work backwards from the last decision point, as there is no decision pending. Working thus backwards, can derive the optimal path starting from the initial decision point. The time can be considered as either discrete or continuous.

For the discrete time case, a state variable is defined which describes the market conditions of the asset. And is assumed that follows a Markov process. At each time period the asset owner can decide on some asset operation, which is modeled by a control variable. Further, the profit and the asset value are defined as functions of the state and control variables. The optimization is thus defined as the maximization of a Bellman equation that is satisfied by the asset value, assuming a constant discount rate. The assumption behind this equation is that only the present decision is to be optimized as the remaining decisions are already optimal. So the objective of the problem is to find the optimal control variable value that maximizes the sum of the two components, namely the present and the remaining decisions.

In the continuous time case, the assumption is that the state variable follows a continuous Geometric Brownian Motion and the firm can decide at any time, e.g., to invest or no. the Bellman equation is modified accordingly and after applying the Ito’s Lemma and simplifying it turns into a well-known partial differential equation which in order to be solved two boundary conditions must be used. The first implies that if the investment is optimal at a value of state variable, then the project value should be equal to the termination value. The second implies that the values of project value and termination value should meet tangentially at the boundary value of the state variable for reason of continuity. Under these boundary conditions the value function and the state variable critical value can be solved (He, 2007).

4.4. Contingent Claims

This approach is based on the no arbitrage theory, where the assumption is that if we can replicate the cash flows of a project investment by a portfolio of traded assets then the project value is equal to the portfolio value. Or else there exists arbitrage opportunity. Recalling the dynamic programming method, the capital gain can be calculated by using Ito's Lemma on firm's value. By replicating the risk, the two assets with the same risk must have the same expected return and thus the drift term of the two equations must be the same. This leads to a PDE which is very similar to the dynamic programming one. A difference between the two is that in the contingent claims approach only the risk free rate is considered as exogenous, while in the dynamic programming the discount rate is considered as exogenous as well.

Both contingent claims and dynamic programming are assumed to provide exactly the same result, and it is confirmed by Dixit and Pindyck cases. Comparing, it seems that the dynamic programming method is easier in incorporating operational constraints, but the usage of a subjective discount rate may lead to valuation result which deviates from the market price of the asset. While the contingent claims method always gives the market price of the asset, but requires the existence of a sufficiently rich set of traded assets.

Black and Scholes formula results from the contingent claims method under some strict assumptions. Under the assumption of similarities of real options to financial options we can directly calculate the real option's value with the Black-Scholes formula as if the real option is a financial option with appropriate values of the parameters. This is the reason why the usage of Black-Scholes formula has gained popularity among practitioners. However, a problem lies in the imprecise nature of the analogy between financial and real options. Given the non-standard and non-financial aspect of real options, coupled with market incompleteness, the pricing of real options is more complicated. Even if exact analogy between financial and real option is assumed ignoring the limitations, the estimation of some of the parameters is not always easy (Yizhi He, 2007).

5. Numerical Methods

Dynamic programming and contingent claims are methods of solving a PDE with boundary conditions for the calculation of real options value. However, for advanced options analytical solutions may not be possible to be derived, and closed form solutions are not easy to be found so numerical methods are required. In reality, in most of the cases numerical approaches are used instead. These can be further divided into numerical approximations of the partial differential equations (PDEs) and approximations of the underlying stochastic process.

Before we proceed further to the presentation of the numerical methods, we provide some background information. In overall, the traditional approach for the valuation of an asset or investment is based on the calculation of future cash flows inferred by the investment or asset. Future cash flows can be either certain or uncertain.

In the case that there is no uncertainty about the cash flows and they can be determined, then they are converted to their present value equivalents by applying a discount factor in order to consider the time value of money. This way the asset or investment value is determined.

In the case of uncertain future cash flows, the asset valuation becomes more complex. One issue is that in the time value of money discount factor another factor must be also added in order to include the uncertainty or risk of cash flows. The way to do it is either to add a risk factor to the discount or calculate some certainty equivalent cash flows. Another issue which is more difficult to handle is the case when cash flows depend on stochastic variables in non linear way. In such case, it is not easy to derive the risk factor and certainty equivalents. The contingent claims is an approach that can offer practical certainty equivalents in such a case.

Simulation is another way to provide asset valuation under uncertainty. However a distinction has to be made in the way future cash flows are determined in terms of information. So, in case of future cash flow that depends on past information only and not on future events the approach followed is known as forward induction and it is the characteristic of European call options. In this case the option value is the maximum between two assets and is past dependent. On the other hand when the future cash flows depend on future information as well, that is the characteristic of American options as they can be exercised at any date, the approach followed is known as backward induction. This is a process which begins from the end value and rolls back to the initial value.

So, for the European type options forward induction is used, while for American type ones the backward induction is used instead. Since Real options are very similar to American options backward induction techniques are preferred. Backward induction techniques include dynamic programming, binomial trees, finite difference methods for partial differential equations. Simulation was not used for backward induction until recently, where some novel approaches were proposed in literature advancing the field (He, 2007; Schulmerich, 2010).

5.1. Numerical Approximations of the Partial Differential Equations

This type of solutions can be distinguished into implicit finite difference, explicit finite difference and numerical integration (Slumerich, 2010).

In general, finite difference methods are used to numerically approximate the solutions of certain ordinary and partial differential equations. Finite difference methods approximate solutions of PDEs by creating a relationship between every point on the solution domain. FD methods create a mathematical relationship which links together every point on the solution domain, like a chain. The first links in the chain are the boundary conditions and from these, we 'discover' what every other point in the domain has to be. The most popular FD methods used in computational finance are: Explicit Euler, Implicit Euler, and the Crank-Nicolson method. Each one has its advantages and disadvantages. The easiest to implement is the Explicit Euler method. Implicit Euler and Crank-Nicolson are implicit methods, which generally require a system of linear equations to be solved at each time step, which can be computationally intensive on a fine mesh. The main disadvantage to using Explicit Euler is that it is unstable for certain choices of domain discretisation. Though Implicit Euler and Crank-Nicolson involve solving linear systems of equations, they are each unconditionally stable with respect to the domain discretisation. Crank-Nicolson exhibits the greatest accuracy of the three for a given domain discretisation.

Finite Difference methods are popular approach for pricing options as all options satisfy the Black-Scholes PDE, or appropriate variants of it. The difference between each option is in the boundary conditions that it satisfies. Finite Difference methods can be applied to American (early exercise) Options and they can also be used for many exotic contracts (Slumerich, 2010).

5.2. Approximations of the Underlying Stochastic Process

The approximations of the underlying stochastic process comprise from lattice or tree models and simulation models.

Lattice or tree models

Lattice tree method is a relative simple method to approximate the value of the underlying process that has also the benefit of being easy to understand. The concept is based on the construction of a tree that starts with the start value of the underlying. It includes the Binomial tree method and the more complex trinomial. The idea was initiated by Cox and Ross who introduced the replicating portfolio for the construction of a synthetic option from the option and a bond. This approach is risk neutral, Similar to contingent claims analysis, and uses risk adjusted probabilities and risk free rates.

The approach is based on the construction of a binomial tree which can be assumed as a case of dynamic programming where decisions are binary. The tree uses discrete time framework and the real option's underlying variable evolves in time for a number of time steps between valuation date and expiration. In the tree the state variable can move either up or down in every node by a factor which is a function of volatility of the underlying stock price and the time. Cox, Ross and Rubinstein have developed a classic solution. For a given state variable the probabilities for up and down motion are calculated using the risk free rate, assuming Brownian motions in risk neutral world. At the final nodes the option value is equal to its intrinsic value and in earlier nodes the option is calculated recursively. An important fact is that when the time interval is close to zero the binomial method result converges to the Black and Scholes value. Except the binomial approach, variations also exist for lattice methods such as trinomial tree or adaptive mesh models. However, although for simple options the approach is easily implemented and understandable, when there exist many sources of uncertainty or for complex options it turns into difficulty to handle the complexity as the tree expands exponentially as the stochastic factors increase. Another limitation of lattice method is that the value is given for one initial asset value. So it is required to run it repeatedly in case an option value distribution is requested. In addition, lattice methods cannot handle complex options, such as compound options or packages, but they treat all in the same single option (Cox, Ross and Rubinstein 1979; He, 2007).

5.3. Simulation Models

For complex options or many sources of uncertainty simulation techniques are applied. Simulation approach is also used often and can handle many risk drivers. Monte Carlo simulation is a numerical technique that is used extensively, as it has features that are advantageous. Pojezny groups the applications of Monte Carlo in Combination procedures, Parametrisation of early excercise boundary, Estimation of bounds and Approximation of value function. Monte Carlo is a numerical integration method and by sampling the range of integration it can be used to estimate a risk neutral option value (Pojezny, 2002).

Monte Carlo is a forward looking method, unlike the dynamic programming so it cannot provide solutions for American options. So, initial it was used for European options but lately it is also extended to American options as well, as there exist approaches which combine simulation and dynamic programming, like Least Squares Monte Carlo (Longstaff and Schwartz, 2001).

The basic idea of the Monte Carlo approach is the following. From the no arbitrage pricing theorem we infer that the value of a derivative is equal to the discounted expected value of the derivative payoff under the risk-neutral measure. So an expectation is an integral with respect to the measure. So, we suppose a risk neutral probability measure and a derivative with payoff that depends on a set of underlying instruments. Next the value of the derivative is calculated over a sample from the probability space. The current value of the derivative is next calculated by taking the expectation over all possible samples and discounting at the risk free rate. Next the integral is approximated by generation of sample paths and taking the average.

If the underlying asset follows a GBM then the equation is the stochastic differential equation that describes the underlying as used in analytical methods. The stochastic differential equation describes the paths of the underlying and ihe parameters in this can be estimated from financial data.. By using discrete time the equation allows the simulation of such a path with a simulation. The goal is to simulate a path value for each of the time points. Having simulated a path, the further steps depend on the type of option that needs to be priced.

One of the most well known issues of the method is the computational complexity which requires exponential execution time for accurate results, as accuracy grows by the number of simulations and number of dimensions (He, 2007).

6. Issues and Criticism

Empirical evidence proves that the adoption rate of real options for investment decisions is relative low in comparison to the time being to the market. Although some argue that it is not meant to be a one for all tool, but a niche method with specific target users and cases, it cannot be avoided to think it as a lost promise as nobody can claim in behalf of its non-maturity. Financial options on the other hand have flourished and do not face such issues despite the increasing complexity of their pricing methods and the development of new exotic options, which is not always easily comprehensible. In this section we review the most important objections towards the application of real options relevant to this study with references to relevant literature.

As mentioned earlier the real options theory is in close relationship with financial options theory and as such it is based on the same assumptions. This is however, a subject of criticism, as there is doubt that the no-arbitrage pricing approach is valid for real assets too due to the non-tradable nature of real assets (Trigeorgis, 1996; Dixit and Pindyck, 1994). Another assumption that is mentioned is that the stochastic process is considered as continuous in the Black Scholes model while for real assets this may not be the case, as jumps may occur. Another criticism comes from the fact that while a financial option can be exercised in a very short time, almost immediately, a real option may require a long time and preparation in order to be exercised. So the lifetime may be less than the stated life in some cases (He, 2007). Finally, the complex mathematical modeling is considered as too sophisticated and not transparent to non-academics despite the computing advances (He, 2007; Teach, 2003).

The valuation is also affected by a series of points of critique that have been raised during the previous years as the domain was evolving in both theory and practice.

One major difference is the way the private risk is handled. For financial options the market risk is the major source of risk and private risk is treated as error. While real options do not have market risk, as they are not traded, and their private risk cannot be hedged. In addition, financial options are considered to be market efficient, as single transactions or managerial decisions do not affect the price. While, real options are unique and managerial decisions can affect the option value considerably. Another difference is that the real option underlying assets are not tradable. So the return that a real option may earn as non tradable can be below the rate of return expected in the financial market and a dividend-like adjustment is necessary. Risk neutral valuation is usually used in option pricing by using either certainty-equivalent or risk-adjusted growth rate (actual growth rate minus an appropriate risk premium) (Yizhi He, 2007). In addition, according to Brealey and Myers the covariance between real assets and financial assets has not been investigated in the way that has been done for financial assets and overall market so it is almost impossible to find a portfolio to diversify the risk of a project (Brealey and Myers 2000). Another fact is that many real options include more than one risk factor, unlike the Black and Scholes model, and many uncertainties do not follow Brownian motion with normal distribution or cannot be modeled in a simplified way. In addition, aeal investments can be considered as nested American option which is harder to valuate by classic approach (Cortazar et al., 2001). Another issue is that the efficient market hypothesis is not valid for many investment projects since many factors are considered, such as socioeconomic, political etc., which are not aligned with the hypothesis that all investors aim to maximize their economic utility.

One of the issues that is often a subject of real options criticism, and is an argument against real options application, is the volatility estimation. The application of the real options model requires the definition of the volatility value. Results show that the volatility level affects the payoffs and the real option value. As such it is an important parameter and needs to be estimated accurately. Or else it may result to over investments. By definition, volatility in financial options reflects the underlying financial asset future price uncertainty, while in real options volatility reflects the uncertainty of the project value future cash flows. When we deal with financial options the underlying assets are tradable and option volatility can be estimated by historical market prices of the financial assets or by using the Black-Scholes formula (implied volatility). However, in real options setting, assets are not tradable and there exist no historical data. So, it is not always feasible to derive the real option volatility.

7. Conclusion

It has been almost four decades since Myers introduced the real options term and during that period a tremendous development of the finance field has occurred due to the active academic research and application of models like Black and Scholes. Research publications in finance were numerous and their proposals were adopted by the international markets resulting in the exponential development of the field of derivatives. However, real options have not evolved into a widespread tool for investment decisions, while it rather seems that still remain a more or less academic subject. Empirical findings suggest that small to medium enterprises do not adopt sophisticated models and use relative simple methods for investment decisions.

As a conclusion we can say that probably the most important issue for the real options application is the establishment of standard methods in terms of framework with correspondence to reference cases. Work towards the establishment of some common frameworks which would provide certain roadmaps for every practitioner on some typical cases will reduce the pluralism and the ad hoc approach.

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