Real Options Valuation Methods in Energetics

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Abstract

Energy industry is highly capital-intensive with a demand for complex plants, equipment and machinery. Traditional deterministic DCF method used for their valuation has long been challenged for undervaluation and gradually complemented by real options analysis enabling to embrace other determinants of value such as flexibility and uncertainty and incorporate them into the project value calculation process. Multiple valuation methods have emerged and continue emerging as reaction to complexness and distinction of the real asset class compared to its financial counterpart. These can be divided into contingent claims, dynamic programming and simulation methods. Each of the methods uses different approach and it is based on different assumptions. This paper brings comparison of the methods in context of energy industry and it should provide a practitioner with a guide for the selection process of an optimal valuation method.

Keywords: real options, energetics, contingent claims, dynamic programming, Monte-Carlo simulation

1. Capital investment appraisal in Energetics

Energetics as one of the most capital-intensive industries demands significant capital investments. Distillation columns, turbines, storages or pipelines can be mentioned as typical pieces of equipment utilized in the industry.
Especially due to the deregulation of the energy market and transition towards renewable sources of energy, there has been an increase in the level of uncertainty capital investments must face. Main sources of risk include market risk stemming from volatility of commodity and carbon prices, technology evolution and changes in policy. These changes have to be reflected in the methods used for valuation of capital investment projects on assets conversing commodities utilized in energetics. Based on the type of conversion they can be categorized as follows [1]:

1. Production of commodity: this group includes assets such as oil drilling platforms or facilities necessary for opening a mine.
2. Physical transformation of a commodity: assets transforming one commodity into another such as oil refinery or gas-fired power plant.
3. Change in availability of a commodity: depending on whether we talk about a change in time or a change in location we can include assets such as a storage or a pipeline, respectively.

1.1. Comparison of ROA and DCF

Large capital investment projects have been traditionally appraised with use of deterministic DCF method but ROA gains an increasing popularity regardless of the fact that in many cases only as a conceptual framework [2].

ROA outweighs DCF especially in situations where projects possess high flexibility and uncertainty. The latter attribute has recently been driven mainly by deregulation of energy sector and more rapid spread of renewable energy sources, both resulting in an increase of market risks [3].

Traditional DCF models struggle to cope with this increase in uncertainty and thus ROA comes into the picture as a useful alternative for capital investment appraisal. ROA also proves to be a favourable method when flexibility is present.

Kozlova concludes in her review focusing on ROA that the option to defer is the most often used real option, thus determination of optimal timing plays a key role in ROA in energetics. If a decision-maker possess such flexibility and different scenarios can be modelled, then in contrast to DCF method ROA can increase project value [4].

Schachter and Mancarella provide main drawbacks of DCF methods as follows [5]:

1. They assume investments are reversable but in fact most investments in the field of energetics are irreversible, especially due to their capital intensivity.
2. Decisions are fixed at the outset of the investment process. In other words, they assume a project cannot be modified during implementation process.
3. Inappropriate valuation of risk in a discount rate.

1.2. ROA in energetics

Due to the specifics of energy commodity prices including properties such as mean-reversion and jumps, the practitioners need to pay an increased attention to assumptions of the models they will use for capital investment appraisal in order to provide realistic valuation.

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For example, the jumps can cause that the probability distribution of returns has fat tails. This causes challenge to those models where normal distribution is assumed.

Selection of a valuation model is of major importance as this choice defines what underlying process is used for modelling of the underlying asset which reversely will define the way in which the derivative (real option) will be valued. For this reason, when selecting a particular valuation model, it is necessary to evaluate whether the model of the underlying asset matches empirical dynamics of the uncertainty variable

2. Analytical and numerical methods

The methods deployed for real options valuation have evolved from the methods of their financial counterpart where the models were typically derived with use of assets such as stocks. This evolution has caused that the assumptions bound to the pricing models do not always match the actual properties of real assets. In order to be able to select a valuation method best suiting the valuation case, it is necessary to understand these assumptions and be able to attach them to the valuation result in a way understandable by the decision-maker (management).
The real-options valuation models can be divided into two groups: analytical methods and numerical methods.

2.1. Analytical methods

Also referred to as closed-form solutions use mathematical apparat including calculus and trigonometry [6].

The stochastic process of the underlying asset is continuous [7].

Computational time is usually low as closed-form solution/formula exists. The use of the closed-form solution is bound to acceptance of assumptions which may not always match the real-world assumptions. The best-known model of this group is the Black-Scholes model which is typically used for pricing the European options.
It is important to mention that an analytic solution for American options does not exist [8].

2.2. Numerical methods

In situations where the mismatch between assumptions of analytical methods and the real-world assumptions is significant enough to undermine credibility of the results of analytical solution, numerical methods can be a better option.
These methods can modify analytical solution or use simulations in order to approximate the solution [8].

Compared to analytical methods, the stochastic process is discrete [7].

3. Real options valuation methods

Another well used way of categorization of real-options valuation methods divides the methods into three groups: contingent claims, dynamic programming and simulation methods.

3.1. Contingent claims (CC)

The approach developed by Black and Scholes in 1973 uses the risk neutral valuation as its main premise [9].

This states that if the market trading the underlying asset is effective and no arbitrage is possible then we can create a riskless portfolio earning a risk-free interest rate. The fact that the asset comparable to the underlying asset is traded, we can derive the key parameters (volatility, spot price, exercise price, time to expiration, risk-free interest rate) from them and use them as inputs for the model. However, this is usually not the case in the field of real options. For example, a real asset such as a copper mine is not typically traded [7].

Risk preferences of investors are irrelevant here. The risk-free interest rate is used for discounting future cash flows in order to get the present option value. This approach can be also applied in the real world where investors can require an interest rate higher than the risk-free interest rate because of their risk preferences. This is caused by the fact that the discount rate increases together with the increased risk preferences, thus bringing the present value back to the level expected in the risk neutral world [8].

This approach has many opponents in the real options field arguing the market is often incomplete, thus the risk-neutral measure cannot be applied. They recommend a use of alternative methods such as the dynamic programming instead.

The best-known method of the CC group is the Black-Scholes method.

3.1.1. Black-Scholes model (BSM)

The Black-Scholes model (BSM), sometimes also called the Black-Scholes-Merton model, is an analytical method with a closed-form solution. This was derived with use of Itô's lemma which states that if there is a variable following a stochastic process, we can construct a function of this variable in such a way that the function also follows the same stochastic process. The derived differential of the function of the stochastic process represents a key element of financial derivatives valuation. Full derivation of the Black-Scholes-Merton differential equation from Itô's lemma can be found in Hull [8]. The differential equation can be rewritten into a closed-form solution which simplifies adoption of option theory calculus by practitioners.

$$c = S_t N(d_1) - K e^{-r(T-t)} N(d_2) \tag{1}$$

$$d_1 = \frac{ln\left(\frac{S_t}{K}\right) + (r + \sigma^2/2)(T-t)}{\sigma\sqrt{T-t}} \tag{2}$$

$$d_2 = d_1 - \sigma\sqrt{T-t} \tag{3}$$

BSM assumes the percentage change of underlying stock price has a normal distribution which implies that natural logarithm of future stock price is normally distributed, in other words the stock price is log-normally distributed [8].

While this might be the case for stocks, commodity spot prices have usually fat tails meaning outliers are present more frequent than in situation of Gaussian probability density function. Cartea and Figueroa perform a normality test for electricity spot prices in the UK market with the result confirming significant diversion from normality [10].

Use of GBM for projects where outliers are strong determinants of project value can then cause undervaluation. An example of such a situation can be a project on price arbitrage where a magnitude of a spread between prices during peak and off-peak periods is the source of cash inflows.

Another important assumption of BSM is that the stock (underlying asset) follows the Geometric Brownian Motion (GBM) which is a Brownian motion with a drift:

$$dS_t = \mu S_t dt + \sigma S_t dw_t \tag{4}$$

This means that when using BSM for ROA we must be aware of the fact that we expect the underlying asset follows GBM. This can be perceived as a significantly strong assumption for commodity spot prices, especially when it comes to certain commodities such as power which cannot be even perceived as an asset because it cannot be stored. The assumption of GBM contradicts with some typical properties of commodities such as seasonality which causes spikes in the price followed by a return to the mean.

Besides mean reversion, Ronn brings other empirical properties of commodities [11]:

1. Seasonality in both prices and volatilities in accordance to the season of the year.
2. Backwardation and contango in futures prices.
3. Limited correlation among futures prices.
4. Short-dated price volatility is greater than long-dated price volatility.

Seasonality is typical especially for spot commodity markets. We can observe several different seasonality attributable to daily, weekly and yearly cycles in the electricity spot market. This seasonality can be translated into autocorrelation of returns which is in contradiction to one of the assumptions of BSM expecting independently distributed returns [10].

Despite its limitation, GBM is widely used for modelling forward prices in energetics [11]

Thus, when selecting BSM we suppose the underlying asset has no seasonality, there is no mean-reversion process present and the mean is constant over time. We also assume that volatility evolves with the square root of time and it is homoscedastic [11].

One solution of how to overcome the above-mentioned limitations of GBM is to use the Generalised Black-Scholes model with generalised risk-neutral process which is more realistic as the strict requirement for homoscedasticity is relaxed. Heteroscedasticity together with introduction dividends enables richer and more realistic properties of the price. Original BSM expects stocks bring no dividends. By including dividends in the generalised BSM, we can add convenience yield $y(S_t, t)$, where S_t is spot price at time t, and thus extend the model with mean-reverting process. Dividends y higher than risk-neutral interest rate r_f result in a negative trend in a spot price, thus S_t converges back to its central tendency. On the other hand if S_t is below its mean, dividends y have to be lower than the risk-neutral interest rate r_f, in order S_t is pushed back up to its mean [5].

Some other modifications of BSM introducing mean-reversion and jumps have been developed. Merton (1997) introduced BSM with GBM extended with lognormal jumps and Clewlow and Strickland (2000) brough extension with mean-reversion. However these modifications does not provide typically closed-form solutions [10].

Another limitation is the fact that BSM can work with only one uncertainty factor but in real lime projects usually face more sources of uncertainty.

Further, BSM expects the underlying asset to be tradable in order arbitrage can take place. This allows for risk-neutral state with a risk-free interest rate. This is usually not the case with real options as the real assets are hardly tradable. Another problem can be seen in the fact that not all energy commodities are assets. Typical example is power which is not an asset but a tradable goods because it cannot be stored. To overcome this property, Ronn introduces the concept of the price of risk which facilitates transition of the non-asset price dynamics of power into the risk-neutral price dynamics typical for assets [8].

It must be also underlined that Black-Scholes formula can be used only for European type of options which is a significant limitation for real options where decisions typically need to be taken during the life of the real option. Black-Scholes formula can be used for pricing of American call option in a limited way but due to the limitation this will not be consider any further in the paper [8].

3.2. Dynamic programming (DP)

DP was developed as a management tool by Bellman and others in 1950's. DP perceives the investment process as a chain of interconnected decision points. It uses the Hamiltion-Jacobi-Bellman equation that is solved by backward induction. The interest rate used is exogenous and constant reflecting individual risk preferences [9].

DP can deliver similar results as CC. Insley and Wirjanto present conditions that must hold in order CC and DP generate the same results [9].

Dynamic programming typically uses partial differential equation (PDE) which adds complexity to the problem being solved [6]. Complexity is a well-known barrier for adoption of the ROA by practitioners. Some authors such as Ampofo find complexity as the main barrier for adoption of ROA by practitioners. For that reason, Ampofo recommends to develop easier adoptable but still realistic models in order to transmit the value of ROA from academic environment to practitioners [12].

Main difference between CC and DP can be seen in the choice of the discount factor. Whereas CC use a risk-free interest rate, DP perceives a risk rate reflecting opportunity costs as an ideal discount factor. However, the adjusted interest rate is fixed for the whole length of a project which is a drawback compared to CC [6]. Still, Wang highlights DP as a preferable method for incomplete financial markets where risk-neutral valuation cannot be effectively deployed [13]. On the other hand, Insley and Wirjanto contradict this view by comparing a constant risk adjusted discount rate of DP with the variable risk-free discount rate of CC and comes to the conclusion that fixing the discount rate implies a constant volatility which is restrictive in such a way that CC should be a preferable method for real options [9]. Schachter and Mancarella do not share this view, simply because they consider unrealistic to hold the assumptions necessary for using a risk-free interest rate, specifically the one that the underlying asset must be tradable, in the field of real assets. Nonetheless, they oppose the idea of a constant discount factor at the same time [5].

At this point, we can conclude that it does not seem possible to deduce, based on the sources used, which of the two approaches is the more convenient one for real options.

3.2.1. Lattice model - binomial model

Model developed by Cox, Ross and Rubinestein.
It is used mostly for valuing American options but it can be used for European options as well [8].

The underlying asset follows a binomial distribution. At each time node the asset price can either move up with a probability p and have value f_u or move down with a probability $1-p$ and have value f_d. The present value f of a two-step binomial tree can be then calculated as discounted sum of future option values in the upper and lower state [8]:

$$f_t = e^{-rT}[pf_u + (1-p)f_d] \tag{5}$$

The model is discrete as opposed to continuous BSM. This can be perceived for the purpose of ROA in energetics, where stage approach is typical for capital investments, positive.
The value is calculated at the predefined nods which can correspond to project milestones and thus well track the project life.

As the distance between two time points gets smaller, the resulting option price converges to a price calculated by the Black-Scholes-Merton model [8].

Lattice models better reflect the idea of real options. The option can be exercised at any nod and not as late as at the expiration date as is the case of Black-Scholes model. They are also easier to understand due to their graphical representation.

Lattices do not necessarily have to be binomial. Trinomial or multinomial lattices can be applied. Nonetheless the number of dimensions will rapidly increase complexity of the lattice.

Even a binomial lattice can become difficult to solve as its complexity is an exponential function of the number of uncertainties and time steps [5].
The binomial model, the same as BSM, is based on risk-neutral valuation which can be described as a possibility to hedge the position by creating a portfolio including the underlying asset. This assumes, besides other, that the underlying asset is tradable [8].

In regards to other assumptions of the binomial model, the underlying asset is assumed to have a constant volatility. As already mentioned above, commodity spot prices typically evince heteroscedasticity, which again contradicts such an assumption.

For example, Schachter and Mancarella explain that due to the assumption of homoscedasticity, the binomial model provides correct results only at the nodes closest to the beginning and the end of the lattice [5].

Despite the shortcomings, the binomial model is a valuation method widely used in ROA in energetics [13].

3.3. Simulation models

3.3.1. Monte-Carlo simulation (MSC)

MCS is a numerical method based on simulating n possible paths of the underlying asset. As a next step, option value c_i for each of the paths is calculated. Final option price $\hat{c}$ is a simple average of these values discounted to present value [14]:

$$\hat{c} = [\textstyle\sum_{i=1}^{n} c_i^*/n]e^{-r(T-t)} \tag{6}$$

In contrast to BSM and lattices, more uncertainties can be modelled at the same time.

Lattices can also model more than one uncertainty but this rapidly increase complexity and for that reason will this model not be considered the best choice for projects with multiple sources of uncertainty. Hull presents this characteristic as one of the two main reasons for the use of MCS. The other reason is modelling of the whole underlying asset trajectory which can be used for path-dependent options [8].

Another advantage, compared to the previous models, is the possibility of modelling stochastic processes without the limitation on probability distribution. This means that the probability distribution of the underlying asset does not have to be limited only to the normal or log-normal distribution [5]. Relaxing this condition, stochastic processes followed by commodity prices can be modelled more precisely due the capturing properties such as mean-reversion and jumps. This enables a broad use in the field of energetics [13]. For example, Kroniger and Madlener use MCS for valuation of hydrogen storage. With use of MCS, uncertainty variables such as wind speed, electricity spot price and call of minute reserve capacity are simulated at the same time [15]. Similarly,Tian et al. simulate investment costs and spot electricity price and carbon price in order to value a photovoltaic power plant [16].

Huimin uses MCS to calculate volatility of NPV of a project on oil drilling project. This volatility is then an input for BSM to calculate an option value [17]. Similarly Wu and Lin use MCS to determine volatility and resulting value of coal capacity NPV in China [18].

MCS as a simulation method can be combined with other methods such as dynamic programming [13]. This is well justifiable because MCS is forward-working method but in order to determine an optimal timing of investment one needs to proceed backwards. This is also a reason why a standalone MCS method cannot value

American options and the combination of MCS as a forward-working method with a backward-working method must be considered [5].

Special case is the Least Squares Monte Carlo (LSMC) model which can work both forward and backward and thus in order to determine optimal timing does not need to be combined with another model [8]. This means it can be used for valuing for American options and timing real options [19].

Zhu, Zhang and Fan use LSMC to simulate paths of the value of a oversees oil project. The process starts backwards in order to define exercise decision at each time point of the discrete model and then proceeds forwards up to the exercise time point in order to determine the abandon value [20].

Nadarajah, Margot and Secomandi use LSMC for valuation of crude oil swing and natural gas storage options [21].

4. Conclusion

The paper focused on the most popular real options valuation methods in the context of energy sector. For an easier comparison, these are listed in the table 1.

Table 1. *Comparison of real options valuation methods*

Method	Time	Options	Prob. distr.
BSM	Continuous	Eur	Log-normal
Binomial	Discrete	Eur/Ame/Exo	Binomial
PDE	Continuous	Eur/Ame/Exo	Not restricted
MCS/LSMC	Discrete	Eur/Ame/Exo	Not restricted

It is not possible to conclude with certainty which of the methods can be recommended as the most suitable method for the purpose of real options analysis in the field of energetics. Instead, one needs to understand the assumptions the method is based on and subsequently select a method which best matches the assumptions with the specific valuation case.

While BSM provides a closed-form solution which significantly decrease the calculation time, the fact that the underlying asset has log-normal distribution is a way too strong assumption in energetics. Also, the closed-form solution (formula) has to be fully accepted by the decision-makers as this can be perceived as a black-box by many. It should also be mentioned that the most popular real option is the timing option. This option can be hardly valued as European option.

The binomial model can provide a better-suited alternative. The graphical representation of nods corresponding to milestones in a project can be easier accepted by decision-makers. Positive is also the fact that it can value American options. The same as BSM, the binomial model is based on risk-neutral valuation. This is often negatively addressed due to the fact the real assets can be in general traded only in a limited way. Also, the risk-free interest rate and normal distribution are often negatively perceived properties of this valuation model.

The latter mentioned property is overcome in MCS which allows for modelling other probability distributions. Positive is also the ability of modelling several sources of uncertainties at once, thus better matching the model with real world where the real asset value is rarely determined by only one source of uncertainty. Yet this results in an increase in computing time. MCS can be combined with other valuation methods and due to the fact, that the basic MCS is a forward-looking method, it can be even necessary. The most significant limitation of the method is large computation time which must be considered when making decision about the most suitable valuation method. The robustness of MCS can cause that this method can be considered rather as the last resort when lighter methods cannot be used.

List of used symbols

c_i option value of i-th path
$\hat{c}$ final option price
d_2 variable
f_d option value in the down state
f_u option value in the up state
K strike price
N cumulative normal distribution
p risk-neutral probability
r interest free rate
S_t spot price at time t
t time
T time to expiration

μ mean
σ annualized volatility
ω_t Wiener process

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