Real Option Valuation Methods and their Application for Emission Abatement Investments

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Nearly complete paper! Language and content may be revised and updated!

Abstract

Real option analyses are broadly discussed in economics and finance and multiple application examples have been published over the last centuries. Different calculation methods for option values have been presented and successfully implemented in theoretical case studies and practical applications. Especially in application-oriented publications, however, there is often no detailed explanation, why a specific calculation method has been chosen and which effects this may cause regarding the results as well as the transparency and practicability of the method.

Therefore we will present a brief overview of the type of applications we consider - investments in emission abatement investments for large industrial plants, typically of the energy, steel or chemical sector. These investments have some specific characteristics, most importantly they are usually not economically reasonable as they do not generate noteworthy revenues, but are enforced by political regulations. We will discuss how the specific features and assumptions can be “translated” in the financial language of option valuation. Afterwards, an overview of the most relevant option valuation methods will be provided, considering analytic, numeric and stochastic approaches. Finally, the applicability of the considered approaches to the above mentioned type of investment decisions is assessed and possible influences on results and implementation are derived thereof from a methodology oriented perspective.

For the considered application, the stochastic simulation method “Least Squares Monte-Carlo-Simulation” extended by the “Exercise Boundary Parameterization Approach” seems a very promising approach due to its flexibility and the distinct deduction of a stopping rule for American options.

1 Introduction and Background

Environmental investments are typically of use for the society and economy as a whole, but tend to be costly and effort causing for plant operators and/or investors. Especially emission abatement investments in the energy sector or energy intensive industries such as iron and steel, metals, glass, cement, etc. are usually long term oriented and cause high investments and operating costs. Therefore, political authorities set rules for emissions that are, however, very diverse if considered in a global context. For the example of nitrogen oxides (NO_X) emissions of the energy sector, Mayer et al. (2016b) provide a broad overview of the different regulation mechanisms worldwide. In the discussion about COP21 and COP22 it becomes obvious, however, that not only industrialized countries enforce their emission regulation but more and more emerging countries start to implement regulation mechanisms as well. This leads to a strong need for investments that investors may try to avoid or delay due to the negative economic impact on their business. In order to analyze investment behavior it is thus inevitable to not only consider current investments but to integrate the option of waiting to invest or splitting an investment, as far as legally possible.

This issue has also been discussed in literature. Sarkis and Tamarkin (2005) state that "every project that may be delayed competes with itself at future dates." Classical investment appraisal methods, however, only consider now-or-never decisions. Especially regarding irreversible investments this is a major simplification that does not account for the actual situation of an investor (Zhou et al., 2010). The only investment appraisal method that takes this waiting-to-invest option and especially the value of the waiting option in uncertain conditions explicitly into account is the Real Options Analysis (ROA). ROA goes back to Black and Scholes (1973) and was pioneered by Myers (1977) before being broadly discussed and applied to investment projects over the last decades. Lee (2011) summarizes the basic idea of ROA, stating that "*a firm that decides to make an irreversible investment exercises an option. The lost option value is an opportunity cost that must be incorporated in the assessment of the investment cost, i.e. an essential feature in explaining the lack of consistency between neoclassical investment theory and investment behavior.*" ROA can incorporate managerial flexibility in several types of options (an overview is provided by Brach (2003) and Lee (2011)). The most relevant option in the given case is the option to defer, i.e. the option to postpone an investment until information uncertainties were resolved or market prices reached a certain threshold. According to e.g. Hommel and Pritsch (1999) ROA is particularly recommended in applications with high managerial flexibility and high overall risk. In the energy sector with its various sources of uncertainty and risk ROA has been used frequently in recent years. Exemplary case studies are provided by Sekar (2005), Reedman et al. (2006), Szolgayova et al. (2008), Fernandes et al. (2011), Lee (2011), Zhu and Fan (2011), Boomsma et al. (2012) and Park (2012). These publications deal primarily with the implementation of new energy generation capacities or with CO_2 abatement technologies. (Mayer et al., 2016a)

In general, ROA is characterized by a Real Option Value (ROV) added to the net present value (NPV) of an investment, which refers to the value of keeping managerial flexibility. This value is a calculatory cost item added to the total cost of the investment in case of exercising the option to invest. The option value can be determined in various ways, a more detailed discussion thereof will be provided in the following, as this is the main scope of this paper and a major influencing factor regarding the final results and conclusions of investment decision making.

In the following we will investigate the influence and the context specific meaning of different analytic, numeric and stochastic ROV calculation methods. As mentioned already we do not intend to define a right or wrong approach but we focus on analyzing the specific characteristics and try to make their impacts more transparent and predictable.

2 Methodology

In order to analyze the impact of different ROV calculation methods we will define the characteristics of the investment under investigation first. This is considered essential, as the set of acceptable assumptions and simplifications can only be assessed correctly if the characteristics of the investment decision have been understood in detail.

In the following, in order to analyze the actual impact of the option valuation methods we cannot compare realistic quantitative results as they would require a huge amount of sensitive data and precise predictions of future developments. Not only information about technical parameters and system configurations would be necessary but also about risk perception and investment decision making behavior of particular deciders.

Hence, we will analyze existing approaches and applications thereof in related sectors in order to assess the resulting effects. Afterwards, we will select the most relevant real option valuation methods and evaluate them from a general and application specific perspective. Their inputs, characteristics, assumptions, advantages and disadvantages will be analyzed as well as possible influencing mechanisms on the final results. Finally, overall conclusions that can be drawn thereof will be presented and discussed.

3 Characteristics of the considered investment option

In order to analyze real option valuation methods, several characteristics of the regarded type of investment decisions need to be considered. While for CO_2 emission reduction investments the whole plant is usually taken into account with all relevant cash flows including production output and its revenues, this seems hardly reasonable for pollutants that are less in scope of political regulation, such as NO_X, PM or SO_2. This appears reasonable, because with the implementation of certificate trading schemes, the market price of CO_2 becomes more flexible and the selling of allowances may gain new revenues or the operating scheme of a plant might be modified depending on the CO_2 emission prices. For other pollutants, the influence is a lot lower and we expect it to be rather unlikely that a market-based or imputed price for any of these pollutants will ever be a key influence parameter for a plant operator to adjust his production output. Furthermore, we do not consider the option of shutting down a plant due to the cost for emission abatement. This would of course be theoretically possible, but in order to keep it simple, the focus will be on the question when to invest. Therefore, the production output and the thereof resulting revenues are considered fixed and can thus be neglected.

From a company internal and purely economic point of view, an investment in emission reduction measures is hardly ever reasonable. Therefore, the main question is not, if or when the overall Project Value (PV)[1] will be above zero, but which investment strategy causes the lowest negative outcome and has thus the highest PV (even though it might be below zero). Depending on the project, there might be alternative technologies that compete with each other, even though in the field of emission abatement for large plants the variety of techniques is rather limited and the

[1] We define the Project Value as the total value of the investment at a certain time. It can thus be calculated as the NPV of the continuation scenario in case of postponing the investment and thus keeping the option to invest, or the NPV minus the (positive) ROV if executing the investment.

selection is usually based on their technical performance. This implies that the main competitor of the investment is often the same investment at a later date. Depending on the political circumstances, not investing at all might not be an option, as political regulation might force plant operators to invest until a certain deadline. Otherwise they would lose their production permit, which, in our case, would be equal to the option of shutting down the plant which we cannot consider as we do not consider all relevant cash flows of the plant.

The complexity of the investment decision can be enlarged in any order, as basically all considered cost components (whether they are pagatoric or calculative cost elements) can be considered uncertain. For more background information about the given context, Mayer et al. (2016a) summarize the main risk categories and a typical investment decision making process for the considered type of investments. It will thus be necessary to focus on a certain number and extent of uncertainties in order to allow full understanding and assessing of the results.

Hence, we can call our application a dividend-free American call option, as the investment decision could be made anytime between the start and the end of the period under consideration, although in reality, it is sufficient to consider only discrete time steps because investment decisions are typically made at certain times and not throughout the year (i.e. end of the month, end of the year, etc.).[2] (Brach, 2003) Furthermore the question of defining an appropriate "stopping rule" will be of great importance in our case. This means we need to investigate in detail, at which point in time based on which decision rule the investment should be exercised even though it is probably not economically viable but expected to cause the least negative impact.

Moreover we focus on industrial decision making from a microeconomic perspective, i.e. on individual decision makers that may have differing risk perceptions and decision making criteria. Therefore, in contrast to macroeconomic considerations with average or common practice evaluation, there is no "right or wrong" approach in our case. In practice, the assessment of a rather similar investment might differ a lot not only depending on external influencing factors such as prices, policies and other types of risks, but also depending on the (company) culture, previous experiences and specific knowledge of the decision maker or the decision making board.

4 Real option valuation methods

Different methods to valuation real options have been published over the last decades. Brach (2003) and Baecker et al. (2003) list various approaches and discuss further details about the different calculation alternatives. The first approach to valuate real options was published by Black and Scholes and their so called Black-Scholes equation. However, not only Brach (2003) criticizes this approach by stating that *„the Black Scholes formula, which is used to price financial options, may indeed not be the right formula to price many real options. Several of the basic assumptions and constraints that come along with the Black Scholes equation simply do not hold in the real word (…). This, however, does not imply that the use of real options analysis is impractical or incorrect. There are other methods to price real options that can be applied."*

Nevertheless it is important to understand the basics of option prizing and its background in order to discuss and evaluate the already mentioned assumptions, constraints and results. Baecker et al. (2003) provide an overview of methods to valuate options (Fig. 1). In the following, we are going to present the most relevant approaches from our point of view and for the considered type of

[2] Even though the decision itself may be made at any time, it is considered accurate enough to allocate investment decisions at certain time steps.

applications. For further understanding and implementation of the most common approaches Kodukula and Papudesu (2006) provide very descriptive explanations and examples.

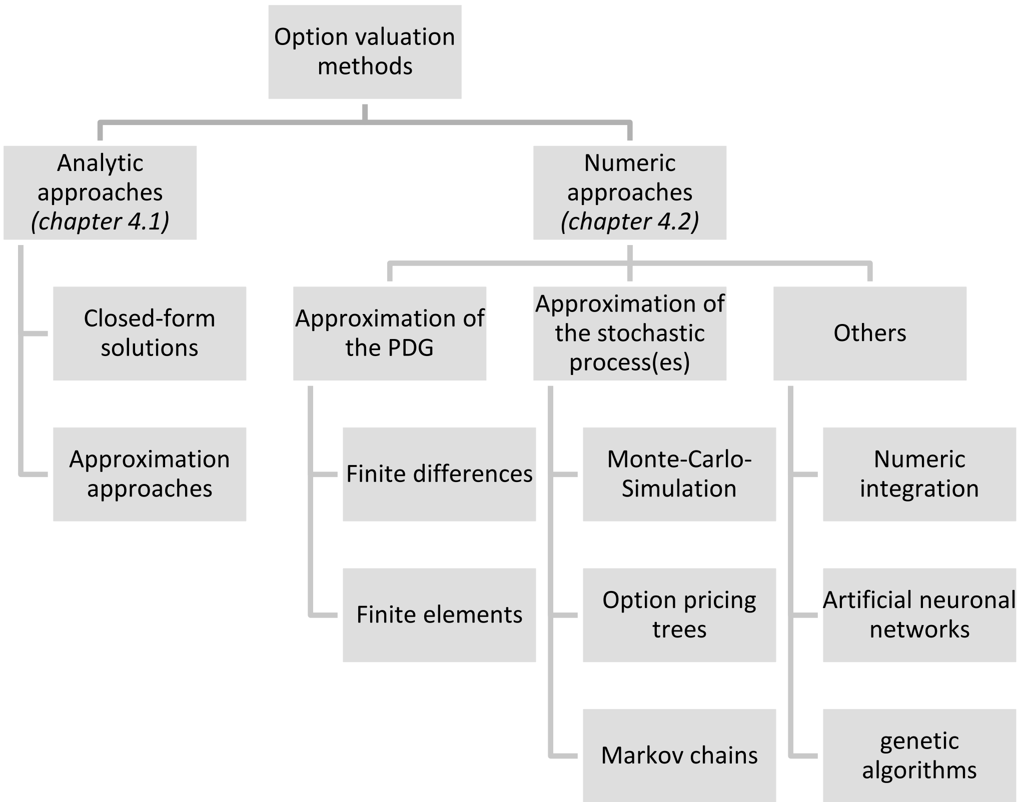


Fig. 1: Common option valuation methods (cf. Baecker et al., 2003)

4.1 Analytic approaches

In the history of option valuation, a variety of analytic approaches have been published. A brief overview is provided by (Brach, 2003). In recent years, however, the only analytic approach with relevance for real option applications seems to be the Black-Scholes equation and modifications thereof. Therefore we will focus on this method in the following as it would go beyond the scope of this paper to discuss the whole range of available option valuation methods.

Black-Scholes equation:

One of the first and most recognized approaches to valuate real options was the closed-form analytic equation developed by Black and Scholes (1973). Their partial differential equation (PDE) offers an analytic solution for a continuous time stochastic process (e.g. Brownian motion) under specific circumstances. The idea of the Black-Scholes equation is to valuate options based on only five parameters. The PDE can be noted as

$$\frac{\partial f}{\partial t} + rS\frac{\partial f}{\partial S} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 f}{\partial S^2} = rf \qquad (1)$$

with

f = price of a call option or other derivative contingent on S
S = stock price
t = time between 0 and T (maturity date)

$r =$ risk free interest rate
$\sigma =$ price volatility. (Hull, 2012)

For European call options, an analytic solution can be achieved. Other types of options can be considered as well but might require a numeric solution of the PDE. More details about the PDE, possible solutions and necessary assumptions are provided in Hull (2012).

The possible closed-form solution makes it a comparably easy to use approach, lacking, however, transparency of the influence of individual parameters, assumptions and boundary conditions. (Uszczapowski, 2008) Furthermore, it is especially suitable for low-dimensional problems, which means in contrary, that solutions for multi-dimensional problems (such as many industrial investment decisions) are difficult to achieve. (Longstaff and Schwartz, 2001; Stentoft, 2004)

Approximation procedures:

For applications that cannot be solved in an analytic way it may be possible to derive closed-form solutions for approximations of the original problem. To give an example, two or more correlated variables could be integrated in one variable in order to reduce the dimensions of the problem. Depending on the type of problem and the required accuracy of the results, such approximations might still deliver acceptable results. The advantage of this approach is the simplified use of the method, while the rising amount and impact of simplifications might falsify the results and disguise the influence of individual parameters. (Baecker et al., 2003)

4.2 Numeric approaches

The scheme in Fig. 1 divides the numeric approaches for option valuation in three subcategories. We will shortly introduce all of them, with an emphasis on the approximation of the stochastic process(es), which we consider the most relevant for our type of applications.

Approximation of the PDG

In order to avoid the difficulties of solving a PDG, the price of an option can be assessed by using the discrete equivalent of the PDG. Typical methods are for example the finite differences and finite elements methods. Such approaches are frequently used in the fields of engineering and natural sciences. In economics and finance, however, there are some theoretical discussions (cf. Trigeorgis, 1996), but applications in the field of real options are scarce. Especially for multidimensional problems the complexity is very difficult to handle. (Baecker et al., 2003)

Approximation of the stochastic process(es)

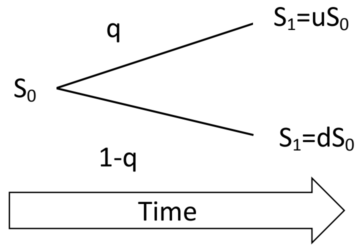
Approximations of the stochastic processes exist in manifold forms. There are methodological differences between the approximation methods themselves and their application and implementation. We do not aim at providing a complete picture of all existing methods and combinations thereof but at outlining the general concepts, their applicability, advantages and disadvantages.

Option pricing trees (binomial pricing model)

A frequently used option valuation method is the option pricing tree (also called lattice[3]), often built on the binomial pricing model of Cox et al. (1979). Its idea is not to use a PDG or estimates of

[3] cf. Kodukula and Papudesu (2006)

volatility but probability distributions for certain state variables. In the easiest – the binomial – case, there are only two possible states of the asset value, it can either go up or down. In the following, the general structure of a binomial tree is indicated according to Brach (2003) and Hull (2012)



Value of the asset in t_1:

$$S_0 = \frac{[q\cdot uS_0+(1-q)\cdot dS_0]}{(1+r)^t} \tag{2}$$

with

$q =$ path probability
$u =$ factor for path "up"
$d =$ factor for path "down".

Pricing trees are based on a discrete time scheme which suites the needs of industrial investment decisions very well. Multidimensional problems, however, are difficult to implement as the calculation effort rises quickly with the number of nodes and branches to be considered. Furthermore, the dependency of the probability distributions, which are, in our context, hardly ever known in advance, is another disadvantage of this method. For other types of applications, however, there is a comparably large number of studies based on this approach, (e.g. Hundt, 2015; Lee and Shih, 2010) so that its practical significance shall not be denied. A detailed discussion of the method and its applications is provided by Brach (2003) and Kodukula and Papudesu (2006).

Monte-Carlo-Simulation

The idea of Monte-Carlo-Simulation is to calculate a large number of exemplary price paths following the rules of the underlying stochastic price process (often a Geometric Brownian Motion or a related stochastic process). The present value of the expected value of future payoffs can thus be calculated and considered as the risk neutral option value in a standard application. (Baecker et al., 2003)

According to Hull (2012) "*the key advantage of Monte Carlo simulation is that it can be used when the payoff depends on the path followed by the underlying variable S as well as when it depends only on the final value of S. (For example, it can be used when payoffs depend on the average value of S between time 0 and time T.) Payoffs can occur at several times during the life of the derivative rather than all at the end. Any stochastic process for S can be accommodated. (…) the procedure can also be extended to accommodate situations where the payoff from the derivative depends on several underlying market variables. The drawbacks of Monte Carlo simulation are that it is computationally very time consuming and cannot easily handle situations where there are early exercise opportunities.*"

Generally speaking, the Monte-Carlo-Simulation is a very flexible tool that can easily be adopted to the specific needs of the application, examples are provided by Laurikka and Koljonen (2006) and Muche (2007). Especially in case of real option applications, where the circumstances to be considered do not fully comply with standard financial option characteristics, it is possible to adopt the simulation to the specific needs. In case of American options, however, the use of a standard

Monte-Carlo-Simulation is more difficult. One approach, however, has been suggested for this specific situation and will be presented in the following.

Least Squares Monte-Carlo-Simulation (LSM)

The LSM approach, published by Longstaff and Schwartz (2001) and discussed by Stentoft (2004) is an approach specifically suitable for multidimensional problems based on American options. Its aim is to approximate the value of American options by simulation, keeping the computational effort low in relation to the complexity of the problem while still achieving high quality results. The basic idea is to "*regress the ex post realized payoffs from continuation on functions of the values of the state variables.*" (Longstaff and Schwartz, 2001)

In general, various types of stochastic processes, such as geometric Brownian motions, but also jump diffusions or other more exotic processes can be handled. In case of multidimensional problems, however, the considered factors need to correlate to a certain extent. Otherwise a least-squares regression will not deliver reasonable results. Exemplary applications in the energy sector were published by Boomsma et al. (2012) and Zhu and Fan (2011).

The Exercise Boundary Parameterization Approach (EBP)

As a further extension of the LSM approach, the EBP aims at providing a defined stopping rule for each of the considered time steps. It is thus based on a discrete time consideration (as well as the LSM approach) and tries to maximize the expected value of the option at every time step, by calculating the values of the option according to the LSM approach for different simulated stopping or boundary values. This approach was developed by Gamba (2002) and a very descriptive explanation is provided in Hull (2012).

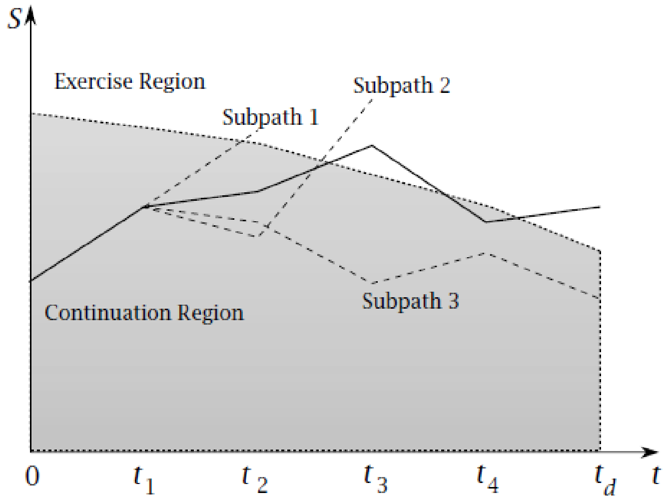


Fig. 2: Visualization of EBP calculations (Andersen and Broadie, 2004)

Fig. 2 visualizes the calculations performed by the EBP method. The subpaths are exemplary random paths generated by the Monte-Carlo-Simulation. If at time t, the value S_t of the subpath is in the exercise region, the option will be exercised for this path. If, however, the path is in the continuation region (such as all paths in this example are in t_1), the path will be followed without exercising the option. Once the option is exercised, there is no way back (irreversible option), so the value of this path is determined and it thus stops or, in a real option context, it continues with the cost/revenue parameters of the exercising option until the end of the considered lifetime T. The EBP identifies by simulation the threshold between the exercise and the continuation region at every time t_i that delivers the highest expected value $E(S_T)$.

A big advantage of this approach is that it is not necessary to predefine a certain, more or less arbitrary, stopping value[4] but that the optimal stopping value is explicitly derived by the method itself. Furthermore the advantages and disadvantages of the LSM apply accordingly, as according to Hull (2012) the LSM can be considered as a part of the EBP.

An important disadvantage of both, LSM and EBP is the fact that they tend to underprice American options because of the assumption of suboptimal early exercise boundaries. (Hull, 2012) In order to solve this issue, Andersen and Broadie (2004) proposed another extension of the EBP, introducing not only lower but also upper bounds to the price. We aim at giving a brief overview of methods, therefore we do not go deeper into the specifics of this extension as we consider it more important for a detailed quantitative analysis of a certain application than for the general understanding of the influence and applicability of real option valuation methods.

Others

Regarding the “other” methods, there is one method which we consider interesting in our context, the ***artificial neuronal network***. As we do not aim at providing a full list of possible methods, we do not go deeper into other more specific approaches. Even though there might be successful applications for less popular methods we do not consider them appropriate in our context as we try to find an approach that does not only deliver good results but causes only reasonable implementation efforts and is as transparent and comprehensible as possible for people who might not be experts in finance and option valuation.

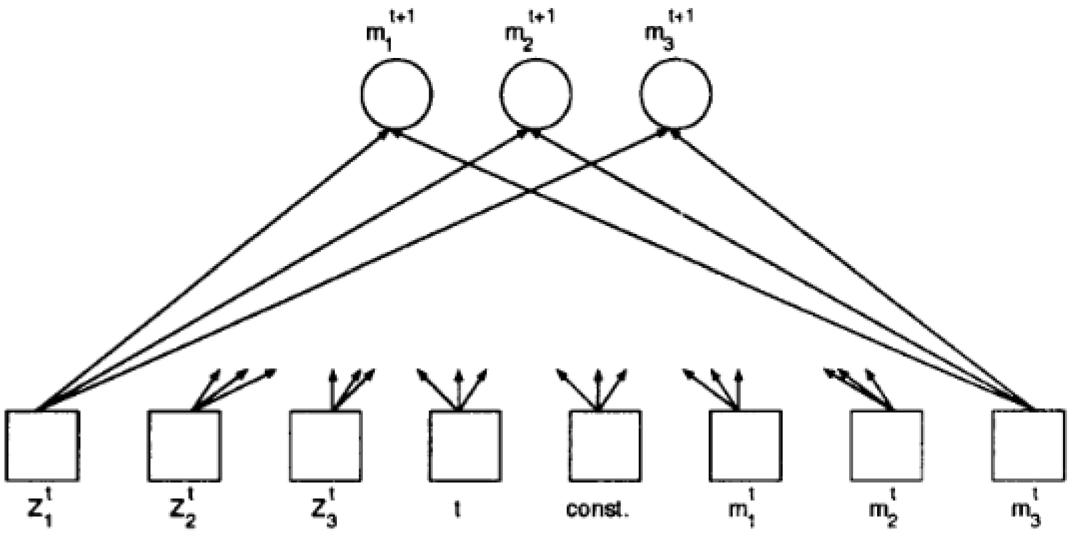


Fig. 3: Exemplary structure of an artificial neuronal network ((Taudes et al., 1998)

The neuronal network approach is based on the general idea of a broad set of input data and a significantly lower amount of output data or state variables. Fig. 3 provides an example where a company wants to deciding which product to produce in order to maximize the output. Based on various input parameters, the self-learning network teaches itself, which variables are most important and which thresholds they need to reach in order to switch the decision for the next

[4] A predefined stopping rule would be for example the standard net present value calculation that stops with an option value above zero.

period. Hahn (2013) and Taudes et al. (1998) provide more specific information about the mathematical implementation of such a network.

In general, the most important disadvantage of this approach is the large amount of data that is necessary to set up and calibrate the network. In an industrial context – if data is available – it is usually historic data so that the approach assumes a forward projection not only of stochastic data (as other stochastic approaches do as well), but also of the influence and relevance of specific parameters. Depending on the context of the application, this is not necessarily the case. Furthermore, the determination of the major influencing factors and thus the methodology of decision making happens usually in a black box environment. Without detailed knowledge of the methodology itself and the underlying data, it will be hardly possible to understand the drivers and mechanisms of the evaluation process.

A brief literature survey showed that there are some theoretical studies and exemplary applications of the methodology, yet there are very few practical examples in real option valuation. This leads to the assumption that the disadvantages mentioned above (including the complexity of the method) are too severe compared to the specific advantages of the methodology that it is of large practical use.

4.3 Overview

Fig. 4 provides an overview of the above mentioned option valuation methods.[5] It shows that the evaluation based on the Black-Scholes equation differs considerably from the numeric /stochastic approaches. The other approaches have several similarities and differences that will be investigated in further detail in the subsequent chapter.

<table>
<tr><th></th><th>Black-Scholes Equation</th><th>Option Pricing Trees</th><th>Monte-Carlo Simulation</th><th>LSM</th><th>EBP</th></tr>
<tr><td>Focus type of Options</td><td>European</td><td colspan="2">primarily European</td><td colspan="2">American</td></tr>
<tr><td>Time scheme</td><td>continuous</td><td colspan="4">discrete/discretized</td></tr>
<tr><td>Multi-dimensionality</td><td>hardly possible</td><td>computation-ally limited</td><td>possible, but dependencies may blur</td><td colspan="2">possible, if variables correlate</td></tr>
<tr><td>Stopping rule for American options</td><td>irrelevant</td><td colspan="3">irrelevant or application specific definition necessary</td><td>distinct determination</td></tr>
<tr><td>Quality of results</td><td>Analytic solution</td><td colspan="2">Depending on the quality of input/forecasting data and applicability of the method (according to the predefined assumptions)</td><td colspan="2">Depending on the quality of input/forecasting data. Tendency to underestimate the option value. Degree of correlation of input parameters determines the quality of the regression.</td></tr>
</table>

Fig. 4: Characteristics of the most relevant option valuation methods

[5] artificial neuronal networks are excluded, as we consider them inappropriate for our approach and due to their variability they are difficult to fit in the provided scheme.

5 Application oriented assessment of option values

Based on the results of chapters 3 and 4 we will analyze a typical investment decision of the considered application in the following. In general, the value of an option can be calculated as the intrinsic value of the option plus opportunity costs or revenues plus a risk premium. (Uszczapowski, 2008) In our case, the intrinsic value of the option can be a deviation of the total investment sum, due to e.g. technological improvements, market price fluctuations or the like. Opportunity costs could be emission taxes or fees and the risk premium can be considered as the "original" option value, as this incorporates the risk of no return in case of an investment. The investment can be considered irreversible in our applications, due to the technical complexity, the low degree of standardization and the thereof resulting large share of engineering and installation expenses. It would of course be possible to liquidate some components of the total investment, yet this seems hardly ever techno-economically reasonable and is thus not considered as an option.

Starting again with the analytic solution of Black and Scholes and its approximation procedures, we do not consider this an appropriate solution for our application, as too many simplifications and manipulations would be necessary to get the original problem in a form that is solvable by the equation. The major difficulties in this case are the focus on European options and the difficulty to solve multidimensional problems. Brach (2003) lists more detailed explanations why the Black-Scholes equation is usually not suitable for real option applications, therefore we will not go in further details regarding this method but focus on the generally more suitable and far more frequently applied numeric simulation approaches.

Regarding simulating approaches is it is important to discuss the type of option again. In chapter 3 we named our application an American option. Taking Fig. 4 in account, there are only two methods for American options, while one of them is primarily an extension of the other one. We could thus draw the conclusion that there is basically one method to be considered. By introducing another simplification, however, it would be possible to consider the other two numeric methods as well. For that purpose, we do not consider the investment decision as an American option that can be executed at any time between t=0 and T, but as a series of European options. In a discretized consideration of time (which we regard reasonable for this type of investment decisions), there will be a new European option at the next time step t_{i+1} if the investment has not been executed at t_i. By dynamic programming (recursive consideration), this approach is also able to find an optimal exercise time based on the comparison between the execution and the continuation scenario at every time t_i. It is thus able to answer the question, whether it is better to invest now or to continue while keeping the option to invest (and wait for better data/resolved uncertainties in the future) rather than answering the question which is the best time to invest between now and T. As the first question is the most relevant question in an industrial context, this approach can be considered a tolerable simplification in our context.

However, this approach is only suitable for applications with a certain predefined threshold that needs to be met. A typical example is an investment decision for production facilities, where certain revenues need to be gained in order to reach the economic break-even-point. Yet in our case, it will be very difficult to define an appropriate stopping or execution rule for such an approach, as emission abatement investments are hardly ever profitable. However, in an extraordinary example, where significant revenues can be generated by selling emission certificates for example, it would be possible to use such an approach. In this case, we consider the standard Monte-Carlo simulation more suitable due to the easier integration of multiple dimensions and the difficulty to predict realistic probability distributions especially for political risks in the case of a pricing tree approaches.

Altogether, the LSM approach combined with the EBP seems the most appropriate method for considered applications with variables that are sufficiently correlated. The necessary degree of correlation can be derived of related discussions in statistics. More specific research on this issue would certainly be an interesting field for the future.

In any case the investor needs to define the direction of uncertainty he wants to focus on. There are two general possibilities. The investor can either hope for future price drops and thus focus on the value of the option as a possible reduction in costs or fear future increases in operating expenses and thus consider the option value as a risk premium against these risks. Both scenarios are possible and depending on the characteristics of the investment the focus may shift.[6] It is in any case necessary to analyze the investment decision in detail, understand internal and external influence mechanisms and derive realistic scenarios in order to focus the analysis on the most relevant factors. In very complex cases, it may be reasonable to execute several incremental analyses and compare the results thereof in order to understand the main drivers of the influencing variables.

6 Conclusions and Outlook

In the past (or even nowadays when explicit risk valuation methods are not applied) the risk premium was a very subjective sum in a decision makers experience and imagination; depending on his, her or the team's risk perception, the surrounding environment and other influencing factors such as the company culture etc. The goal of the real option valuation approach is to standardize and objectify the calculation of the risk premium by valuating the worth of keeping the option to invest. Due to the different calculation methods for option values and their necessary assumptions and simplifications the results are expected to be significantly influenced by the option valuation method.

Depending on the parameter under investigation, different methodological recommendations can be derived regarding the valuation of real options in the considered context. The LSM approach seems a very flexible tool that is comparably easy to implement and operate especially for multidimensional problems. With the EBP expansion, this is the only method that is capable to solve the difficulty of the undefined stopping rule in case of investments with an overall negative economic impact. If, however, the correlation between the investigated variables is not sufficient, the results may be questionable. On the other hand, a binomial tree may be an alternative if the investigation shall be focused on a very specific scenario such as the question of a new technology coming into the market or a new emission threshold being implemented or not. Standard Monte-Carlo-Simulation seems to be the most frequently used approach in content related applications. Yet this does not necessarily mean that it is the most appropriate solution for the task.

For future research, it would be interesting to implement one or more of the above mentioned valuation methods for identical case studies and compare their results. Even though the lack of data and the problems regarding the comparability of specific influencing parameters makes this analysis very difficult, it would be interesting to get some quantitative results of the deviations between the methodological approaches.

[6] Important characteristics are the distribution of total costs in initial investment and operating expenses, technological alternatives (for the considered type of investments there are often very few), current state of research and development in the sector, dissemination of the technology and size and growth of its market, providers and their existing and upcoming competitors and so on.

7 References

Andersen, L., Broadie, M., 2004. Primal-Dual Simulation Algorithm for Pricing Multidimensional American Options. Management Science 50, 1222–1234.

Baecker, P., Hommel, U., Lehmann, H., 2003. Marktorientierte Investitionsrechnung bei Unsicherheit, Flexibilität und Irreversibilität. Eine Systematik der Bewertungsverfahren, in: Hommel, U., Scholich, M., Baecker, P. (Eds.), Reale Optionen. Konzepte, Praxis und Perspektiven strategischer Unternehmensfinanzierung. Springer [u.a.], Berlin [u.a.], pp. 15–35.

Black, F., Scholes, M., 1973. The Pricing of Options and Corporate Liabilities. Journal of Political Economy, 637–654.

Boomsma, T.K., Meade, N., Fleten, S.-E., 2012. Renewable energy investments under different support schemes: A real options approach. European Journal of Operational Research 220, 225–237.

Brach, M.A., 2003. Real options in practice. John Wiley & Sons, Hoboken, N.J.

Cox, J., Ross, S., Rubinstein, M., 1979. Option Pricing: A Simplified Approach. Journal of Financial Economics 7, 229–263.

Fernandes, B., Cunha, J., Ferreira, P., 2011. The use of real options approach in energy sector investments. Renewable and Sustainable Energy Reviews 15, 4491–4497.

Gamba, A., 2002. Real Options Valuation: A Monte Carlo Simulation Approach. Working Paper, Verona.

Hahn, J.T., 2013. Option Pricing Using Artificial Neural Networks: An Australian Perspective. Dissertation, Robina, Australia.

Hommel, U., Pritsch, G., 1999. Investitionsbewertung und Unternehmensführung mit dem Realoptionsansatz, in: Achleitner, A.-K., Thoma, G.F. (Eds.), Handbuch Corporate Finance. Deutscher Wirtschaftsdienst, Köln, pp. 1–67.

Hull, J., 2012. Options, futures, and other derivatives, 8th ed. Prentice Hall, Boston.

Hundt, M., 2015. Investitionsplanung unter unsicheren Einflussgrößen. Thermische Kraftwerke als Realoptionen. Springer Gabler, Wiesbaden.

Kodukula, P., Papudesu, C., 2006. Project valuation using real options. A practitioner's guide. J. Ross Pub, Ft. Lauderdale, Fla.

Laurikka, H., Koljonen, T., 2006. Emissions trading and investment decisions in the power sector—a case study in Finland. Energy Policy 34, 1063–1074.

Lee, S.-C., 2011. Using real option analysis for highly uncertain technology investments: The case of wind energy technology. Renewable and Sustainable Energy Reviews 15, 4443–4450.

Lee, S.-C., Shih, L.-H., 2010. Renewable energy policy evaluation using real option model — The case of Taiwan. Energy Economics 32, S67–S78.

Longstaff, F.A., Schwartz, E.S., 2001. Valuing American Options by Simulation. A Simple Least-Squares Approach. Rev. Financ. Stud. 14, 113–147.

Mayer, C., Breun, P., Schultmann, F., 2016a. Considering risks in early stage investment planning for emission abatement technologies in large combustion plants. Journal of Cleaner Production.

Mayer, C., Lanzrath, N., Breun, P., Schultmann, F., 2016b. A Comparison of International Nitrogen Oxide Emission Regulation for the Energy Sector, in: Joanaz de Melo, J., Disterheft, A., Caeiro, S., Santos, R.F., Ramos, T.B. (Eds.), Proceedings of the 22nd Annual International Sustainable Development Research Society Conference. Rethinking Sustainability Models and Practices: Challenges for the New and Old World Contexts, Lisbon, pp. 394–406.

Muche, T., 2007. Investitionsbewertung in der Elektrizitätswirtschaft mit dem Realoptionsansatz. Zeitschrift für Energiewirtschaft 31, 137–153.

Myers, S.C., 1977. Determinants of corporate borrowing. Journal of Financial Economics 5, 147–175.

Park, H., 2012. Real option analysis for effects of emission permit banking on investment under abatement cost uncertainty. Economic Modelling 29, 1314–1321.

Reedman, L., Graham, P., Coombes, P., 2006. Using a Real-Options Approach to Model Technology Adoption Under Carbon Price Uncertainty: An Application to the Australian Electricity Generation Sector. Economic Record 82, S64-S73.

Sarkis, J., Tamarkin, M., 2005. Real Options Analysis for “Green Trading”: The Case of Greenhouse Gases. The Engineering Economist 50, 273–294.

Sekar, R.C., 2005. Carbon Dioxide Capture from Coal-Fired Power Plants: A Real Options Analysis. LFEE 2005-002 RP. http://sequestration.mit.edu/pdf/LFEE_2005-002_RP.pdf. Accessed August 14, 2015.

Stentoft, L., 2004. Assessing the Least Squares Monte-Carlo Approach to American Option Valuation. Review of Derivatives Research 7, 129–168.

Szolgayova, J., Fuss, S., Obersteiner, M., 2008. Assessing the effects of CO2 price caps on electricity investments—A real options analysis. Energy Policy 36, 3974–3981.

Taudes, A., Natter, M., Trcka, M., 1998. Real Option Valuation with Neuronal Networks. International Journal of Intelligent Systems in Accounting, Finance & Management 7, 43–52.

Trigeorgis, L., 1996. Real options. Managerial flexibility and strategy in resource allocation. MIT Press, Cambridge.

Uszczapowski, I., 2008. Optionen und Futures verstehen. Grundlagen und neue Entwicklungen, Orig.-ausg., 6., aktualisierte und erw. Aufl. Dt. Taschenbuch-Verl; Beck, München, [München].

Zhou, W., Zhu, B., Fuss, S., Szolgayová, J., Obersteiner, M., Fei, W., 2010. Uncertainty modeling of CCS investment strategy in China’s power sector. Applied Energy 87, 2392–2400.

Zhu, L., Fan, Y., 2011. A real options–based CCS investment evaluation model: Case study of China’s power generation sector. Applied Energy 88, 4320–4333.