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SCHOOL OF BUSINESS, ECONOMICS AND LAW

Evaluation of a Joint Investment in an Industrial Cluster using Real Options

A study on an integrated utility system investment in the chemical cluster in Stenungsund

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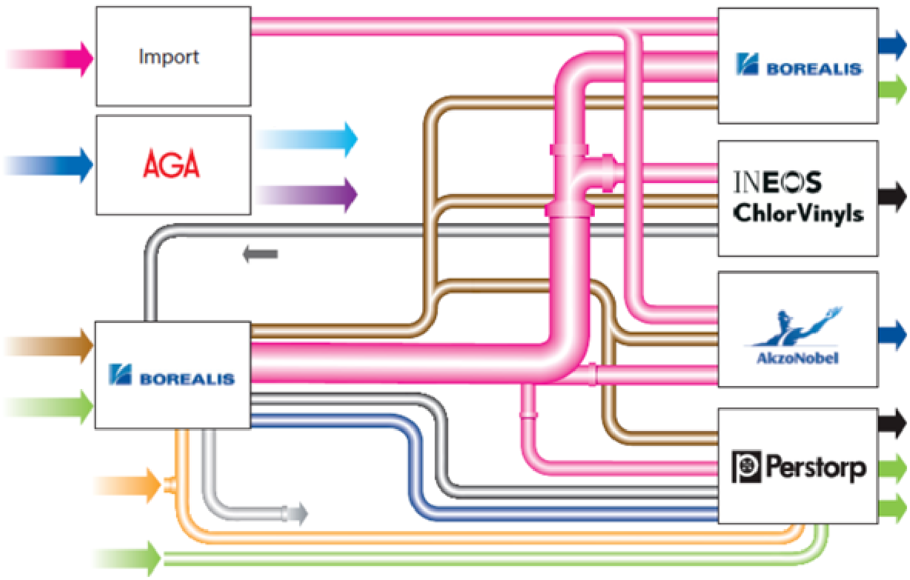

Bachelor's Thesis

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Evaluation of a Joint Investment in an Industrial Cluster using Real Options

A study on an integrated utility system investment in the chemical cluster in Stenungsund

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Bachelor's Thesis

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Cover:
An illustration of the internal dependencies in the chemical cluster. Courtesy: Kemiföretagen i Stenungsund.

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Abstract

A Real Option Analysis is performed on the investment of an integrated utility system within a chemical cluster in Stenungsund, Sweden. The utility system investment is an energy saving investment where the revenues arise due to decreased import of natural gas used as fuel in boilers. Even though the system reduces the combustion of natural gas and hence the CO_2 emissions, no investment decision has yet been taken. The hold up for the investment is cooperation and risk handling issues between the companies in the cluster. To overcome these challenges, the thesis analyses investment data and identifies a project structure with the involvement of as few companies as possible in the beginning of the project. Thus the project complexity is decreased. The structure results in a base investment with two independent expansions. Available options are identified from the project structure.

The real options are valued using the binomial lattice model. Two distinct investment scenarios are identified, expansion and delay. The value- and decision trees for the two scenarios and a combined scenario are presented and analysed. The expansion scenario is found to be 36 % more profitable than the delay scenario. The delay scenario on the other hand delays one third of the base investment. Hence the companies are given the possibility to only invest partly and evaluate the cooperation before making decisions of the final investments.

A sensitivity analysis is performed by investigating the impact of uncertainties on the real option value. The real option value is most sensitive to the natural gas price and the hurdle rate. External uncertainties motivates the further investigation of the sensitivity to the natural gas price. Random walk simulations on the two scenarios are performed to estimate the distribution of the project value. The project value is larger than the investment cost with 87 % probability for the expansion scenario and 82 % probability for the delay scenario.

Keywords: Joint Investment, Industrial Cluster, Real Option Analysis, Window Opportunities, Energy Savings Investment.

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The authors

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Abbreviations

Symbol	Full text
B&S	Black and Scholes
CF	Cash Flow
d	Down movement factor in binomial lattice
DCF	Discounted Cash Flow
div	Dividends
IRR	Internal Rate of Return
I_t	Outlay at time t
N	Sampling size or large integer
NPV	Net Present Value
sNPV	Static Net Present Value
eNPV	Expanded Net Present Value
O&M	Operation and Maintenance
p_d	Possibility for down movement in binomial lattice
p_j	Monte Carlo simulation variable j
P_j	Distribution for variable j in Monte Carlo simulation
p_u	Possibility for up movement in binomial lattice
PDE	Partial Differential Equation
PV	Present Value
q	Dividend rate
r	Rate of return
r_f	Risk free rate of return
r_h	Hurdle rate
r_t	Corporate tax rate
ROA	Real Option Analysis
ROV	Real Option Value
S	Asset value or stock price
S_i	Value of underlying asset at state i in asset tree
σ	Volatility
V_i	Value of underlying asset at state i in value tree
T	Option life span
T_D	Depreciation time
T_P	Project life span
TSA	Total Site Analysis
t	Time
$\hat{t}$	Time to maturity ($\hat{t} = T - t$)
Δt	Discretised time step
u	Up movement factor in binomial lattice
X	Exercise price or strike price

1 Introduction

Real Options Analysis (ROA) is a flexible tool for valuation of complex investments spanning over long time periods. Several authors have proposed ROA as a complementary valuation tool to DCF models. This section gives a brief background of previous studies on ROA in different industries. However, the application of ROA has been limited to single companies. In this thesis a study on an industrial cluster is conducted. Hence a definition of an industrial cluster is given and the studied cluster is presented. Finally the purpose and research questions are presented as well as the limitations required for the realisation of the thesis.

1.1 Background

Companies facing large project investments need tools to value these investments. The common methods used today are discounted cash flow (DCF) analyses such as net present value (NPV), internal rate of return (IRR) or payback time. According to an investigation by Sandahl and Sjögren from 2003 [39] on the Swedish industry, ROA is not used at all while payback time and NPV are the dominating tools. The payback method is used by almost four out of five companies.

The result of the NPV is the value of the project in today's monetary value, the IRR gives the discount rate that drives the NPV to zero and the payback time gives the time the project has to be ran to pay back the initial outlay. A major drawback with all of these methods are that they are static. That is, neither of the methods take into account the possibility of taking new decisions during the course of the project. In addition, all expected future cash flows are typically based on a one point estimation of a "normal year", introducing further possible errors due to model simplifications [32].

Capital-intensive investments are likely to be rejected if it is not possible to show economical profits, regardless of other positive effects, such as environmental or social gains. Companies commonly have several possible investment opportunities but a limited investment budget and only the most profitable investments will be undertaken. It is therefore difficult to have companies invest in environmentally sustainable projects since the short term economical profit is typically smaller than for conventional projects. A suggestion by Trigeorgis [43] among others, is that companies should use more flexible valuation tools in order to capture also managerial flexibility, which can increase the project value significantly. Besides, a more flexible valuation tool will more accurately capture the value of complex projects where many uncertainties are present. This thesis investigates a complementary valuation technique, allowing for more managerial flexibility. The technique of choice is the Real Options Analysis (ROA).

Previously, ROA has been adopted on large and complex investments, spanning over a long time. Several studies show that ROA can be used as tool for valuation of such investments with good results. To mention a few, Svavarsson [41] investigates how ROA can be used to value investments in the IT sector and concludes that ROA is a more suitable valuation tool than traditional DCF-methods. Also Kulatilaka et al. [26] have studied the usefulness of ROA in the IT sector. Fernandes et al. [13]

have studied the use of ROA in the energy sector. The conclusion is that ROA is a valuable tool but is not extensively used. Other studies have been made in sectors such as oil by Armstrong et al. [3] and natural resources by Colwell et al. [9].

However, all of these studies are made on a single company. Paul Krugman [25] has noted that companies joining business clusters is becoming more and more common as more companies either realises the benefits or are forced to do so to survive. According to Michael Porter [36] a cluster can be defined as a

> (...) geographic concentrations of interconnected companies and institutions in a particular field. (...) [It] promote both competition and cooperation.

The sense of 'geographic' can vary from the same city district to the same country depending on the companies' or the cluster's type. Also, a cluster can consist of companies in the same business area or it can be in the vertical direction with suppliers and customers cooperating. Porter mentions for example Hollywood and Silicon Valley as two examples of very large clusters. Although business clusters offer advantages to the participating companies there are drawbacks, adding complexity, as well. Porter mention internal forces such as groupthink, overconsolidation and cartels and external forces such as technological discontinuities. However, by being aware of the drawbacks, they can be minimised, leaving the advantages overcome the disadvantages. When clusters mature, the involved companies might extend the cooperation to joint investments. This creates a need for good tools to value these investments.

In this thesis, ROA is used to investigate the possibilities, opportunities and limitations with a long term environmentally sustainable joint investment within a chemical industry cluster. To be able to perform a ROA, project specific data is crucial; data that is normally not available for external stakeholders.

Since January 2012 there is a collaboration between the University of Gothenburg, SP Technical Research Institute of Sweden[1], Chalmers University of Technology[2] and a cluster with five companies in Stenungsund, to be presented in 1.2, *The Chemical Cluster in Stenungsund*. The purpose of this collaboration is to find ways to meet the cluster's ambitious sustainable vision for 2030. Thanks to this collaboration access to internal and unpublished data required for the analysis in this thesis was granted.

1.2 The Chemical Cluster in Stenungsund

The five companies Borealis AB, AkzoNobel Sweden AB, INEOS Sweden AB, Perstorp OXO AB and AGA Gas AB in Stenungsund constitute Sweden's largest petrochemical cluster, hereinafter the Cluster. The Cluster is currently one of Sweden's major emitters of CO_2 and are responsible for around 5 % of Sweden's yearly fossil fuel consumption. The fossil fuel consumption is mainly used for feedstock purposes [22].

[1] http://www.sp.se/en/Sidor/default.aspx

[2] http://www.chalmers.se/en/Pages/default.aspx

In the Cluster there is no internal competition between the companies since the plants are profiled against different business segments. But the holding companies compete on a global level. Borealis is the largest actor with two separate plants, one polyethylene plant (Borealis PE) and one cracker plant (Borealis Cr). The cracker plant is the heart of the Cluster and provides the other plants with ethylene, fuel gas, propylene and hydrogen.

The Cluster has adopted a common vision

Sustainable Chemistry 2030

which states that the Cluster should mainly be based on biogenic feedstock and renewable energy by 2030 [14]. One important step which can be taken in the near future is an increased heat integration for hot water, steam and internal excess fuels. The realisation of such a system is investigated in a Total Site Analysis (TSA) developed by Chalmers University of Technology [17]. It is concluded that an integrated utility system would lead to large savings in emissions, energy and cost for the Cluster. An integrated utility system is beneficial for the Cluster as a whole but the impacts on each single company are more difficult to establish. In the Cluster, as in all process industries, there are processes that either generate or consume heat. By optimisation of the heat exchange between different processes and plants a more efficient overall process can be obtained leading to lower emissions, energy consumptions and costs.

In a previous Bachelor's Thesis the authors investigate how the cost and savings would be distributed within the Cluster when implementing the integrated utility system proposed in the TSA report [24]. A clear unbalance between costs and savings is identified between the companies. Perstorp will be able to make large savings while Borealis will hardly make any savings at all but still have to carry a heavy investment burden. Also the possibility for a third part to make the investment is discussed.

Notable is the uncertainty whether or not INEOS will receive a renewed chlorine production permit. If a permit is not received, the chlorine production facility will be closed and the overall production at the INEOS site will be heavily reduced. The realisation of an integrated utility system is still possible. However, the costs and energy savings have to be recalculated.

1.3 Sustainability Opportunity

Since sustainability is a very frequently used word in market communication a clear definition of the word for this thesis is desirable. Therefore, in this thesis sustainability will be defined as the ability to

> meet the needs of the present without compromising the ability of future generations to meet their needs [19].

With this definition an integrated utility system within the Cluster would lead to a more sustainable society, since the energy used will be lowered while the output level will remain the same.

There are several benefits from an economic point of view for the companies as well. A more efficient process leads to initial cost savings since less input fuels are required. Porter and van der Linde have found that companies subject to harder environmental restrictions find innovations to satisfy these regulations. These innovations do not only allow the company to comply the regulations but will in many cases also lead to development of new technology which gives the company a competitive advantage [37]. Further benefits for the Cluster is an improved environmental image as well as increased stakeholder values.

1.4 Problem Framing and Research Questions

Since ROA is exceedingly problem specific, this thesis studies a sub-problem of energy efficiency within the Cluster. The TSA report from Chalmers University of Technology [17] shows that large energy savings are possible with a integrated utility system. The estimated effect reduction presented in the TSA report is of magnitude 89 MW for fuel usage in boilers, corresponding to almost 0.8 TWh yearly savings in energy consumption. This is equivalent to approximately 142'000 kg CO_2 per year[3]. Sweden's yearly energy consumption is approximately 600 TWh whereof 150 TWh is within the industry [12]. Assuming a fuel price of 270 SEK/MWh, the saving expressed in economical terms is about 200 MSEK/year [17]. The total cost of the investment is estimated to 660 MSEK.

Although these are very good numbers, taking the step to actually do the investment is not obvious. As the study by Komi and Mofakheri [24] points out, the uncertainties of distributions of risks, savings and costs within the Cluster is a major concern. The flexibility in the ROA framework is one possible way to handle these challenges. Miller and Park [31] claims that ROA can be a tool to pro-actively manage risks. Therefore this thesis will investigate if the ROA framework can manage the previously identified risks and if possible benefits with a joint investments, not captured by the NPV, can be displayed. The problem framing can be reduced to two questions, one specific for the Cluster and one more general.

- How can ROA contribute to future discussions about an integrated utility system within the Cluster towards an investment decision?
- What are the possibilities and limitations with ROA as a tool for complex investments within a cluster?

1.5 Purpose

The purpose of this thesis is to

> Investigate how ROA can be used to value a long term, environmentally sustainable, joint investment within an industrial cluster and what contributions and limitations ROA may have on the ensuing decision making.

[3]Using a conversion factor 0.178 $^{kg\ CO_2}/_{kWh}$ [4]

1.6 Limitations

The thesis is not supposed to give an exact solution for the considered investment but rather show what possibilities ROA can offer.

Although the number of options are kept low, a variety of option types are chosen in order to indicate how different options has to be treated in the analysis. Even if some of the options chosen are intuitively redundant they are included to broaden the analysis.

All possible investments identified in the TSA report are not considered in this thesis. Those neglected are of a small magnitude compared to those included and requires a more extensive chemical understanding. Since this thesis aims at investigating the usage of ROA for this investment as well as for joint investments in an industrial cluster the maximisation of energy savings is not a main objective.

All costs and revenues are treated as common for the Cluster. No regard has been taken to who gains and who pays for each investment. This is considered as part of a future business model and is outside the scope of this thesis.

1.7 Thesis Outline

The thesis is outlined as

1, *Introduction.* An introduction to the Cluster in Stenungsund and a specification of the problem. Research questions are defined as well as the purpose and limitations.

2, *Theory.* The theoretical framework required to perform a ROA is presented as well as the analogy with financial options. The ROA process is described.

3, *Method.* A motivation of ROA as valuation technique is given. Required data for NPV and ROA is presented as well as the available project data.

4, *Restructuring and Option Identification.* The project data is restructured and quantified to reduce project complexity and identify available options. A Monte Carlo simulation on the underlying asset is presented. The section is finalised with the modelling of the value and asset trees.

5, *Simulation Results.* The resulting value trees and decision trees are presented as well as the most profitable combination of these. The section is finalised with a presentation of the real option value.

6, *Sensitivity Analysis.* The impact of the parameters on the real option value is investigated. Simulations of random walks showing the distributions of project value for different scenarios are presented.

7, *Discussion.* A discussion on how the results from the ROA and the sensitivity analysis can aid the decision making in the Cluster for the utility system investment is given.

8, *Concluding Remarks.* The concluding remarks of the thesis and suggestions for future work are given.

2 Theory

Real options are derived from the theory of financial options and is based on a solid and advanced mathematical foundation. By combining real options with the theory of discounted cash flow the theory of Real Options Analysis is obtained. Options theory is used to model future decisions while the modelling of the market development is based on the DCF theory. This section shortly introduces the concept of financial options and the differences and similarities to real options. It is followed by a vast presentation of the theoretical foundation required to perform a Real Option Analysis, refereed to as ROA.

2.1 Option Pricing Theory

Options are defined as a special contract that gives the owner the *right* but not the *obligation* to buy (call) or sell (put) an asset at a predetermined price, either at the expiration day (European option) or at any time before the expiration date (American option). The cost for this contract is denoted option premium.

American and European options (commonly referred to as *plain vanilla options*) are the most commonly used, both as financial options and as real options. Therefore no other families of options will be presented or treated in this thesis. However it is worth mentioning that there exist other more *exotic options*. Rainbow options, spread options, basket options and mountain range options are based on several assets or uncertainties. Lookback options depend on the maximum or minimum value of the asset and barrier options depend on whether or not this value reaches a certain limit. The value of an Asian option is governed by the average value of the asset over a specified time [20].

Option pricing theory, which builds on the idea of pricing assets by arbitrage methods, were first introduced during the 70s by pioneers such as Black & Scholes [5], Merton [29] and Cox & Ross [11]. By combining the underlying asset and the option, a risk-free portfolio can be constructed where the payoff of the portfolio matches the payoff of the option and therefore has the same value, assuming no arbitrage opportunities. This risk neutral condition permits the option value to be discounted at the risk-free rate [42]. The condition is also a general assumption for real options which will be discussed in 2.2, *Real Options* [20].

By the definition of an option, the owner is assumed only to exercise its right when it is favourable. The seller on the other hand, is obligated to fulfil the contract. Consequently, the option value, V, is assumed to always be non-negative since the premium cost to buy the option is not part of the value. The option value can thus be given by

$$V_{\text{Call option}} = \max[S_t - X, 0] \tag{2.1}$$

$$V_{\text{Put option}} = \max[X - S_t, 0] \tag{2.2}$$

where X is the predetermined strike price and S_t is the value of the asset at the day the option is exercised. The seller's profit equals the option premium minus the option value.

Table 2.1: The fundamental option pricing variables and their impact (if increased) on the value of a call or put option.

	Symbol	**Name**	**Call**	**Put**
Variables	X	Exercise price	$-$	$+$
	S	Asset price	$+$	$-$
	r_f	Risk free interest rate	$+$	$-$
	$\hat{t}$	Time to maturity	$+$	$+$
	div	Dividends	$-$	$+$
Parameter	σ	Volatility	$+$	$+$

The most common valuation tool for valuing financial options are the Black & Scholes model (B&S) [5]. The value of the option is in this model dependent on the five variables, X, S, r_f, $\hat{t}$, div and the parameter σ. X is the exercised price (or strike price), that is the price at which the underlying asset can be bought at the strike day. Therefore the value of a call (buy) option is lowered if the exercise price goes up while the value of a put (sell) option goes up. With the same reasoning the value of call option increases in value if the asset price, S, goes up and the put option value is decreased. If the risk free rate, r_f, is increased the value of future incomes are increased. Hence the value of a call option is increased and the value of a put option is decreased. If the time to maturity, $\hat{t}$, is increased the uncertainty of the value of the underlying asset increases. Therefore the possibility for a higher difference between exercise price and asset price exists. Hence the value increases both for call and put options. The same reasoning is valid for the volatility, σ. Dividends, div, will lower the value of the underlying asset and the value of a call option will thus be lowered while the value is increased for a put option. Table 2.1 summarises this discussion.

The B&S model is the analytical solution to a set of PDEs that reflects the payoff for an option. The model is based on the assumption that it is possible to construct a risk free portfolio by combining the option and its underlying asset. Also, if the market is assumed to be efficient, which will disable the arbitrage opportunity, the gain of the portfolio will be the risk free rate. The B&S valuation formula relies on this “ideal condition” which implies that the value of the asset follows a random walk described by a geometric Brownian motion of the form

$$\mathrm{d}S = \mu S \mathrm{d}t + \sigma S \mathrm{d}W \tag{2.3}$$

where $\mathrm{d}t < T$ is the time step, $\mathrm{d}W$ is the increment of a Wiener process[4] $W(t)$, σ is the volatility of the stock price which is constant over the time period T and μ is the expected rate of return over T. Even though a B&S model will not be used for the analysis in this thesis the formulation for a European call option will be presented here [20]. This is to illustrate the complexity of the model. The option value, V, for a European call option is given by

[4] A Wiener process is a type of Markov stochastic process, which is a particular type of stochastic process where only the current value of a variable is relevant for predicting the future. The future values are therefore independent of values in the past [16].

$$V(S,t) = N(d_1)Se^{-q(T-t)} - N(d_2)Xe^{r(T-t)} \tag{2.4}$$

where $T - t = \hat{t}$ is the time to maturity and

$$d_1 = \frac{\log(S/X) + (r - q + \sigma^2/2)(T-t)}{\sigma\sqrt{T-t}} \tag{2.5}$$

$$d_2 = \frac{\log(S/X) + (r - q - \sigma^2/2)(T-t)}{\sigma\sqrt{T-t}} = d_1 - \sigma\sqrt{T-t} \tag{2.6}$$

$N(x)$ is known as the cumulative normal distribution given by

$$N(x) = \frac{1}{2}\left[1 + \text{erf}\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right] \tag{2.7}$$

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{t^2}\mathrm{d}t \tag{2.8}$$

and q is the pre-known dividend rate.

2.2 Real Options

The term "real options" was presented by Stewart Myers 1977 [33] who observed that financial option pricing methods could be used to evaluate investments in projects of high risk and complexity. The basic idea behind real options is that crucial decisions in a complex project are comparable to financial options. Consider a common example.

> A firm wants the possibility to explore an oil field, but without being obligated due to market uncertainties. Therefore the company buys the rights required to use the land in the future, but defer the heavy industrial investments. The financial analogue is a call option; a premium is paid today to have the opportunity to exercise a purchase to a given maximum price in the future.

2.2.1 Similarities with Financial Options

There are several similarities between real options and financial options but there are also some important differences. The main similarity is the rate of return, r, which in both option theories is assumed to be the risk free interest rate, r_f, due to the utilisation of the risk free framework. The volatility, σ, is in both theories based upon the underlying asset, S, which for financial options usually is a stock. For a real option the underlying asset can be the present value of future cash flows, a real asset or some other suitable measure. The time frame, $\hat{t}$, used in ROA considers the investment decision while in financial option theory it is the time until the fictive purchase or sell of the underlying asset. The strike price, X, is the predetermined price to purchase or sell for a financial option while it is the estimated investment

Table 2.2: Similarities between financial options and real options.

Symbol	Financial Options	Real Options
X	Exercise price	Investment cost
S	Asset price	Present value of future cash flows
r_f	Risk free interest rate	Risk free interest rate
$\hat{t}$	Time to maturity	Time frame for or until investment decision
div	Dividends	Cash out flows
σ	Volatility of S	Volatility of S

cost for a real option. Finally there is the dividend, div. For a financial option the dividends are the stock dividends while the dividends for a real option are the cash out flows caused by for example replacements of old equipment, royalties and licenses [23]. Table 2.2 summarises this discussion.

Furthermore, there is a significant difference in risk perception. According to Wihlborg [44] the sources for real option values can be both company- and industry specific. Additional risks for real options are internal factors such as technical success [32] and non-rational decision making [18]. Hamberg [18] further discusses the asymmetric perception of risk between business leaders and shareholders. He argues that shareholder prefer a larger risk to increase the return while there are business leaders who prefer to eliminate risks. Also external factors such as political changes, development of new technology and longer time horizons increases the amount of non quantifiable risks [44].

2.2.2 Option Types and Valuation Techniques

When valuing a project with ROA the risk-neutral framework is always applied and assumed valid [8]. The risk-neutral framework of ROA has three major advantages [42].

- It provides a practical way to represent and account for the flexibilities in a project.
- It uses all the information contained in the market prices with known or measurable statistical distributions (when such exist).
- It leads to formulas or processes that can be computed using powerful analytical and numerical techniques developed in contingent analysis to determine both the value of the investment project and its optimal operating policy.

In an investment opportunity there are five real options that are commonly used and which cover most of the possible managerial decisions. These are listed and shortly summarised below [20].

- *Abandonment Option* values the decision to sell or close down the project. The strike price is the liquidation or resale value of the project subtracted with the cost for selling or closing down. This option mitigates the impact of poor investment decisions and raises the initial value of the project. This is comparable with an *American put option* with a payoff function given by

$$V_{\text{Abandon},t} = S_{V,t}, \tag{2.9}$$

where S_V is the salvage price.

- *Expansion Option* values the decision to make further investments in an ongoing project and thereby increase the outcome under favourable conditions. The strike price is the cost of creating the extra capacity discounted to the exercise time. This is comparable with an *American call option* with a payoff function given by

$$V_{\text{Expand},t} = E_{F,t}S_t - E_{C,t}, \tag{2.10}$$

where E_F is the expansion factor and E_C is the expansion cost.

- *Contraction Option* values the decision to reduce the scale of a projects operation. The strike price is the present value of future expenditures saved as seen at the time of exercise of the option. This is comparable with an *American put option* with a payoff function given by

$$V_{\text{Contract},t} = C_{F,t}S_t + C_{G,t}, \tag{2.11}$$

where C_F is the contraction factor and C_G is the contraction gain.

- *Option to Defer* values the decision to defer a project. For example by owing the rights to an oil field but not being obligated to build a pump. This is one of the most important options and is comparable with an *American call option.* With a payoff function given by the value of the project at the exercise time as

$$V_{\text{Defer},t} = S_t - I_t \tag{2.12}$$

where S_t is the project value and I_t is the investment cost. However, the opportunity cost of capital needs to be considered when buying the right for future investments.

- *Option to Extend* values the decision to extend the life of an asset, if possible, by paying a fixed amount. The strike price is the future value of the asset for the extended lifetime. This is comparable with an *European call option* with a payoff function given by

$$V_{\text{Extend},T} = \sum_{t=T}^{T+\Delta T} F_I(t) - E_{X,T} + \Delta T_V, \tag{2.13}$$

where $F_I(t)$ is future incomes due to extended lifetime, ΔT, E_X is the extension cost and $\Delta T_V = T_{V,T+\Delta T} - T_{V,T}$ is the difference between the terminal value of the project at time $t = T + \Delta T$ and at time $t = T$.

As can be noted, four out of five options are comparable with American options. Unfortunately, the American options are more complicated to handle in computations and simulations than European options.

There are several models to analyse a real option. The first distinction is if to model it analytically or numerically. For analytical modelling, the most common model is the B&S model introduced in 2.1, *Option Pricing Theory*. The usage of B&S models on a real options has two major drawbacks. First, the mathematics behind the B&S models are based upon sophisticated mathematical models requiring the practitioners to have advanced mathematical skills. The models are therefore commonly considered as black-box models which increases the risk for potential modelling- or computational errors [30]. The second problem is that even if the mathematical knowledge and skills are available, the B&S models are optimised for valuing one single option at the time. In ROA, the likely case is that a combination of options is to be studied [43].

Common numerical modelling models are binomial lattices, multinomial lattices and finite differences techniques. In addition, it is possible to conduct forward Monte Carlo simulations on a discretised representation of the possible decisions [42]. However, performing this type of forward analysis for American options requires a lot of effort since the option is available at all times and, if taken, will affect the future of the project. Thus the representation has to be reconstructed after a decision is taken, resulting in a very complicated and extensive model.

By using a *finite difference technique* an approximation to the PDEs in the B&S model can be found by creating a grid of possible values for the underlying asset. That is, by discretisation. The grid is then extended to span the whole life time of the option. Once the grid has been defined, the option value can be approximated by solving for the value iteratively, either by a forward or by a backward approximation moving one grid-point at the time. The two main disadvantages with this method is that the PDEs describing the option may be difficult to define and that the computational effort increases rapidly with the number of options, time to maturity and the number of discritisation points [15].

Binomial and multinomial lattices are discrete tree approximations of the stochastic processes describing the evolution of the underlying asset. At the discrete times, each state branches into two (binomial tree) or more (multinomial tree) paths, building a tree structure. As the intervals (time steps) in the tree becomes smaller the approximated solution converges to the analytical solution. The most widely applied of these are binomial lattices which was first introduced by Cox and Ross [11]. The binomial lattice has the advantage that it is intuitive and the connection between strategy and valuation can be closer connected than if the project is valued in terms of complex PDEs. Also, according to Mun [32] binomial and multinomial lattices are suitable for simulating the probability of technical success (PTS). This is of particular interest in projects that can be divided into consecutive steps, where the following steps are dependent on the success of the previous steps. A typical example is R&D in the pharmaceutical industry.

By the above reasoning the choice for this thesis falls on using binomial lattice as the analysis tool for valuation of the project. Three main advantages can be summarised as

- *Flexibility.* Any type of payoff is easily described by the binomial equations, to be presented in 2.3.5, *Real Option Value.*
- *Simplicity.* In contrast with the B&S model no advanced mathematical skills are required since the foundation of the model is elementary algebra.
- *Acceptability.* According to Mun [32] the usage of binomial lattice has made the industrial usage of ROA possible.

2.3 Real Option Analysis Process

Before presenting the ROA process a couple of symbols are introduced. The initial value of the underlying asset is denoted S_0, analogously with the asset price for financial options. However, for financial options, this value is commonly known beforehand. For example it can be a stock price. For real options this is not the case and S_0 has to be determined in some other way. According to Luehrman [28] as well as Copeland and Antikarov [10] PV is suitable as S_0. From S_0 and the given risk free interest rate, r_f, S_t can be computed for all future times t.

Further, also in analogue with the financial theory, the value of the project at any time, t, taking future options into account is denoted V_t [20]. Consequently, the present value of the underlying asset (taking future options into account) is denoted V_0.

The process of a ROA on one project can be described by the following consecutive steps, which is a modified version of the process proposed by Mun [32].

1. *Base case sNPV.* Estimate future values on variables and parameters in order to calculate the static net present value (sNPV) for the project.
2. *Real options identification.* Map the possible decisions related to the project onto corresponding options.
3. *Monte Carlo simulation on S.* A Monte Carlo simulation is conducted on the DCF model to obtain an estimated statistical volatility, σ, of the project based on alteration of the chosen input variables.
4. *Binomial lattice.* Model the development of the underlying asset as a random walk in a binomial lattice. Identify the states where the options are applicable.
5. *Real option value.* Use backward induction to find the real option value $ROV = V_0 - S_0$.
6. *Result presentation.* Evaluate the real option value with the premium and the associated risks.

2.3.1 Base Case sNPV

The base case scenario is calculated using the classical net present value approach, NPV. NPV is defined as the sum of the present values (PV) of the cash flows generated by the investment. Where the present value is computed as the future value of the expected cash flows discounted by some appropriate discount rate for every time period [20]. Commonly, there is an initial outlay related to the investment. In that case, this outlay can be seen as a negative cash flow at time zero, that is the outlay is not discounted. Assuming one cash flow per time period NPV is calculated as

$$\mathrm{NPV} = -I_0 + \sum_{t=1}^{T} \frac{E(\mathrm{CF}_t)}{(1+r)^t} \tag{2.14}$$

where I_0 is the size of the initial outlay, T is the project lifespan (commonly in years), $E(\mathrm{CF}_t)$ is the expected cash flow for time period t and r is the hurdle rate for one time period. The hurdle rate is the required internal rate of return (IRR) for a company to undertake a project. It is usually dependent on the risk of the project and also the opportunity cost of capital. However, real options have been criticised for overstating the value of a project, discrete compounding could be one source of the problem. It has been proposed by Lewis, Eschenbach and Hartman [27] that continuous compounding should be used instead. Thereby the future cash flows are discounted harder yielding a slightly lower project value. On continuous compounding form, NPV is given by

$$\mathrm{NPV} = -I_0 + \sum_{t=1}^{T} E(\mathrm{CF}_t)\mathrm{e}^{-rt}. \tag{2.15}$$

The final conclusion made by Lewis, Eschenbach and Hartman is that consistency should be ensured within a work. Hence continuous compounding is used throughout this thesis.

The sNPV is the expected NPV of a project at a point in time, ignoring the possibility of future adoption of the project. This approach does not account for the possibility to make changes in the project over time, such as for example expansion or abandonment. Consequently, the approach is considered static and once the project is started it will be ran as intended, no matter how external factors develop.

Note that the present value (PV) is taken as underlying asset, S. That is, the initial outlay, I_0, is not considered in the binomial lattice. Hence, the underlying asset is given by

$$S_0 = \mathrm{PV} = \mathrm{NPV} + I_0. \tag{2.16}$$

2.3.2 Real Options Identification

Identifying the project related options is highly project specific [32]. The options should correspond to possible decision during the project life span that may affect the value of the project. After the identification of decisions to be included in the model the decisions are mapped onto real options. A brief descriptions and the financial similarities are presented in 2.2, *Real Options*. Finally, since some options may not be applicable during the entire project life span, the time frames for each option is determined.

2.3.3 Monte Carlo Simulation on S

Different approaches may be used to estimate the volatility of the project. If seen as an input to the model, the implied volatility can be calculated from the model given the current market and option price. This has been used for example when valuing a real option to extract gold from a mine [38]. However, it requires the usage of Black's futures options model and is thereby more suitable when valuing real options with the B&S model. A more straight forward approach when using binomial lattices is the Monte Carlo method. Given the probability distributions of the (stochastic) input variables, a Monte Carlo simulations is conducted on the PV yielding an estimate of the combined volatility, σ, of the underlying asset.

The Monte Carlo simulation is based on N runs in which each input variable is given a value based on its distribution. In order to estimate the volatility, σ, the suggested procedure by Copeland and Antikarov [10] is utilised. Consider the present value, PV, of the project at time $t = t_0$ given by

$$\mathrm{PV}_{t_0} = \sum_{t=t_0}^{T} \mathrm{CF}_t \mathrm{e}^{-r_h(t-t_0)}, \qquad \text{for } t_0 = 0, 1, 2, \ldots, T. \tag{2.17}$$

The PV of the project in time step 1 can be expressed in terms of the PV at time step 0, equation (2.18), to yield an estimate of the discount rate for the project simulated with number i.

$$\mathrm{PV}_{i,t_1} = \mathrm{PV}_{i,t_0} \mathrm{e}^{\hat{r}_i} \tag{2.18}$$

where $\hat{r}_i$ is an estimate of the yearly rate of return and i indicates the order of the run. Note that $\mathrm{CF}_0 = 0$ and that the cash flows for computing PV_0 and PV_1 are generated independently. Finally, the combined volatility is given by

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (\hat{r}_i - \bar{r})^2}{N}}. \tag{2.19}$$

Here, $\hat{r}_i$ is solved from equation (2.18) as

$$\hat{r}_i = \ln \left(\frac{\mathrm{PV}_{1,i}}{\mathrm{PV}_{0,i}} \right) \tag{2.20}$$

$\bar{r}$ is the average estimated discount rate given by

$$\bar{r} = \frac{1}{N} \sum_{i=1}^{N} \hat{r}_i \tag{2.21}$$

and N is the sampling size.

The Monte Carlo approach is schematically illustrated in Figure 2.1. Each variable that are taken into consideration, p_j, is assumed to belong to a distribution, $p_j \sim P_j$. When all N runs are finished, a probability density function for the rate of return can be estimated, illustrated under *Output* in Figure 2.1. From this simulated data, the project's combined volatility can be computed by equation (2.19).

2.3.4 Binomial Lattice

A binomial lattice is an approximation of the stochastic function describing the behaviour of the project value [42]. The function is discretised in the time dimension into N steps, each of size

$$\Delta t = \frac{T}{N} \tag{2.22}$$

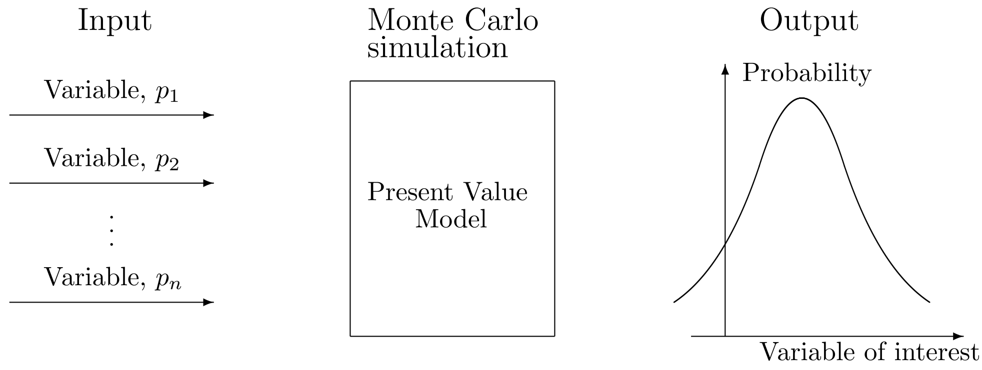


Figure 2.1: Schematic illustration of the Monte Carlo simulation. Based on a figure in [10].

where T is the project life span. In each discrete time step, the function value (value of the project) can take two directions, either go up (increase) or go down (decrease). Thereby the name binomial lattice.

The change in value for the actions up and down are described by the factors u and d, respectively [20]. If the project value at time t, S_t, goes up, the value in the following time step, $S_{t+\Delta t}$, is given by S_t and u as

$$S_{t+\Delta t} = uS_t \tag{2.23}$$

and if the value goes down

$$S_{t+\Delta t} = dS_t. \tag{2.24}$$

Consequently, $S_{t+2\Delta t} = u^2 S_t$ if the value goes up in two consecutive time steps and analogously if the value goes down. If the value goes up in one step and down in the following, $S_{t+2\Delta t} = dS_{t+\Delta t} = duS_t = udS_t$. This implies that the lattice is recombining. It is worth noting that assuming recombination makes the analysis significantly simpler to handle since the number of states, say s, in each time step is given by $s_{t+\Delta t} = s_t + 1$ and hence $s_T = 2N - 1$ where N is the number of discretised time steps. If the value is allowed to be not recombining, the number of states is instead given by $s_{t+\Delta t} = 2s_t$ and hence $s_T = 2^{N-1}$.

In Figure 2.2, an illustration of a binomial tree discretised into three steps is shown. The value of the asset, S, varies over time and can be described in terms of a set of states for each time step. In the illustration S can take four different values at time T dependent on how the market evolves. Note that these values depend only on the market and the initial value, that is it is not possible to influence the value of S between time 0 and T.

The factors u and d can be derived from the following reasoning: The risk neutral assumption states that after a time Δt, the expected value of an asset (in this case the project) should be

$$S_{t+\Delta t} = S_t \mathrm{e}^{r_f \Delta t} \tag{2.25}$$

where r_f is the continuous compounding risk free rate [42]. From this follows that

$$S_t \mathrm{e}^{r_f \Delta t} = p_u u S_t + p_d d S_t \tag{2.26}$$

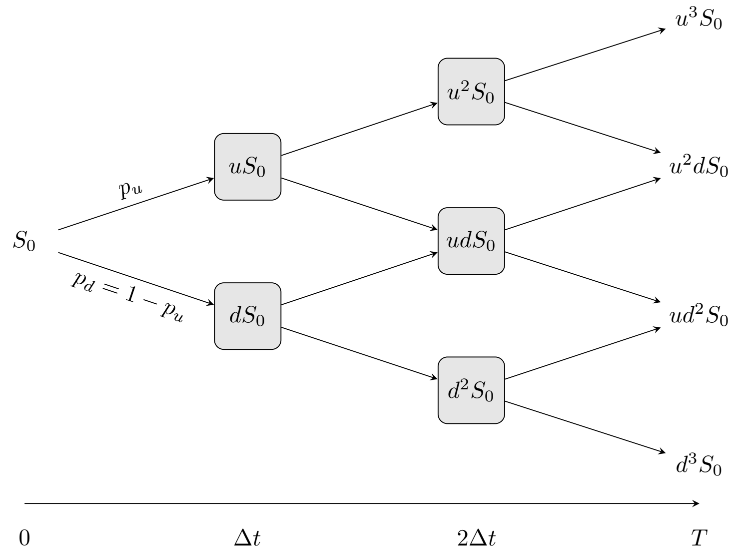


Figure 2.2: Illustration of the variation of S as described by a binomial tree. T is the life span of the accessible options related to the project.

where p_u is the risk neutral probability for an up movement and p_d is for a down movement. Since the two possibilities, up and down, are mutually exclusive it follows that

$$p_u + p_d = 1. \tag{2.27}$$

Combining equation (2.26) and equation (2.27) yields

$$p_u = \frac{e^{r_f \Delta t} - d}{u - d} \tag{2.28}$$

$$p_d = 1 - p_u. \tag{2.29}$$

To find the factors u and d, the volatility (standard deviation) of the project, σ, needs to be considered. By combining the proportional change of the project value in the time Δt, given by $\sigma\sqrt{\Delta t}$, and the definition of variance $\sigma^2 = E(S^2) - (E(S))^2$, it can be shown that

$$\sigma^2 \Delta t = p_u u^2 + p_d d^2 - (p_u u + p_d d)^2 \tag{2.30}$$

which can be used to obtain u and d. Equation (2.30) combined with equation (2.26) yields

$$\sigma^2 \Delta t = e^{r_f \Delta t}(u + d) - ud - e^{2r_f \Delta t}. \tag{2.31}$$

Combining this expression with the assumption that the variations are recombining, that is $udS = S$ which implies

$$u = \frac{1}{d} \tag{2.32}$$

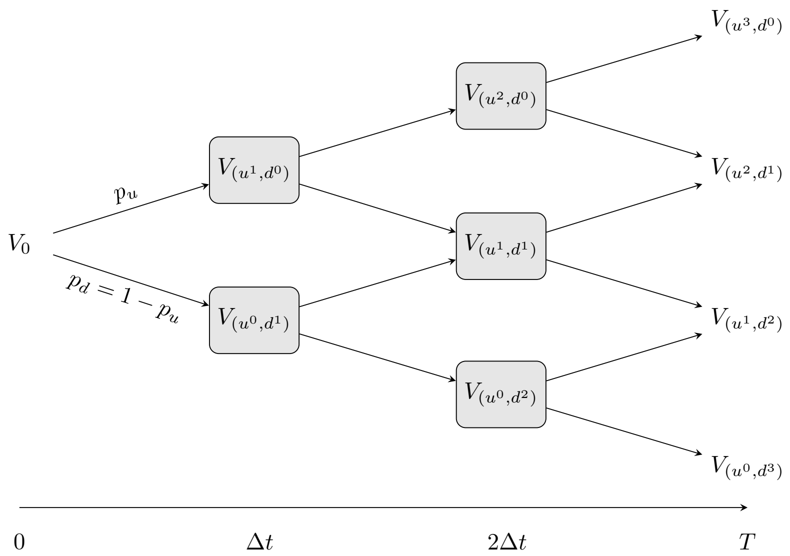


Figure 2.3: Illustration of the variation of V as described by a binomial tree. T is the life span of the accessible options related to the project.

and the Taylor expansion of $\mathrm{e}^x \approx 1 + x + \mathcal{O}(x^2)$ makes it possible to solve for u and d as

$$u = \mathrm{e}^{\sigma\sqrt{\Delta t}} \tag{2.33}$$

$$d = \mathrm{e}^{-\sigma\sqrt{\Delta t}} \tag{2.34}$$

which finalise the derivation.

2.3.5 Real Option Value

Consider again Figure 2.2. The values S at time T are considered as the possible states that S can take when the life span of the options run out. The project value at this point is denoted V_T. V_T can thus take the values $V_{(u^3,d^0)}$, $V_{(u^2,d^1)}$ and so on dependent on the path. Note that $V_{(u^2,d^1)}$ can be generated by the path u,u,d or d,u,u or u,d,u by definition when assuming recombining lattice. In Figure 2.3 the binomial tree for V (value tree) corresponding to the S-tree (asset tree) in Figure 2.2 is shown.

This is the starting point for determining the value, V. The value in the remaining nodes are computed by backward induction, as described below.

Given that no option is exercised at time t, the value V_t is in general given by

$$V_t = \left(p_u V^u_{t+\Delta t} + p_d V^d_{t+\Delta t}\right) \mathrm{e}^{-r_f \Delta t} \tag{2.35}$$

where $V^u_{t+\Delta t} := V_{t,u}$, $V^d_{t+\Delta t} := V_{t,d}$ and $p_u + p_d = 1$. However, the possibility to exercise one or more options in the time step should be considered, why the value of V_t is instead given by

$$V_t = \max\left[\left(p_u V^u_{t+\Delta t} + p_d V^d_{t+\Delta t}\right) \mathrm{e}^{-r_f \Delta t},\ V_{\mathrm{RO},t}\right], \text{ for } t < T \tag{2.36}$$

$$V_t = \max\left[S_t,\ V_{\mathrm{RO},t}\right] \qquad , \text{ for } t = T. \tag{2.37}$$

$V_{\mathrm{RO},t}$ is the total future value of the project, discounted to time t, given that one or more options are exercised at that time. Depending on the type of option, it has to be computed in different ways, but commonly the value is based on S_t. As an example, consider an *expansion option* which is assumed to increase the future incomes by 15 % to the given cost X. The value is then computed to $V_{\mathrm{Expand},t} = 1.15 S_t - X$.

The backwards induction finally gives the value of V at time $t = 0$, V_0. This is the expanded PV of the project given the defined set of options. By subtracting the initial layout I_0 the expended net present value, eNPV, is obtained. The final step is to compute the real option value, ROV, as

$$\mathrm{ROV} = V_0 - S_0 = \mathrm{eNPV} - \mathrm{sNPV}. \tag{2.38}$$

Note that ROV cannot be negative.

2.3.6 Result Presentation

The main result is ROV, which should be compared with the aggregated premiums for the options. As mentioned in the previous section, ROV cannot be negative. However, it can be less than the premium. In that case, it is not worth paying the premium (measured in strictly economical terms). Therefore ROV should be compared to the premiums of the exercised options. The net real option value is given by

$$\text{net ROV} = \text{ROV} - \text{premium}. \tag{2.39}$$

In addition to ROV, several other values and numbers are possible to extract from the simulations. The usefulness, of course, varies depending on the purpose and character of the study.

3 Method

ROA is a very problem specific methodology and the application has to be tailored for each project. This section introduces the data required for the utility system investment. Also, a brief description of how this data is processed in order to perform the analysis is included. However, the section starts off with a motivation of ROA as valuation technique.

3.1 Choice of Valuation Technique

The common approach to value an investment in Swedish companies is to perform a discounted cash flow analysis (DCF) [39]. The major disadvantage with the DCF approach is the lack of influence possibilities during the project lifespan. As mentioned in 1.1, *Background*, in a DCF analysis it is assumed that the project is performed exactly in the way it was intended and that the expected future cash flows will be as calculated. This is however not always the case for larger investments which contain uncertainties and is undertaken for a relatively large time horizon. In these cases, static methods such as DCF, will show an erroneous value of the investment.

The problematic with uncertainties and long investment horizons can be tackled by a ROA. As described in 1.1, *Background*, real options allows a more flexible thinking when it comes to investments.

Even though ROA is well suited for valuation of larger investments there are drawbacks with the method, the major ones are listed and explained below.

- Mathematically more advanced than DCF analyses.
- Data for estimations of distributions might be biased or not available.
- The estimation of the future volatility might be inaccurate due to biased data or a scenario shift.
- Difficulties in pricing of identified real options.
- Managerial decisions are assumed to be logical which is not always true.
- For smaller projects it might be an unnecessary mathematical exercise.

The basic idea of NPV and DCF is adding the positive and negative cash flows over the projects life time. ROA, on the contrary, is more mathematically advanced and requires a better understanding of statistics. For the analysis, estimations must be done on the probabilities of the market movements and the possibility to make decisions that will affect the value of the project during the project life span. Further, probability distribution for the input variables must be identified. These variables' distributions might very well be hard to find and require good statistical data to predict the future behaviours. The volatility calculated using this data might be inaccurate because of biased data or that historical data does not reflect the future behaviour. Another difficult task is the identification of the real options and the valuation of these since an over- or underestimation will affect the end result in a

Table 3.1: Required data NPV.

Symbol	**Data**
CF	Estimated cash flows
I_0	Initial cost of the investment
T_P	Life span of investment
T_D	Depreciation time
r_h	Hurdle rate
r_t	Corporate tax rate

undesired way. An important assumption in ROA is the assumption that all managerial decisions are logical with the highest profitable as objective, this is however not always true in reality. A final remark is that if the investment is of a relatively low complexity, ROA might just be a numerical exercise and not add value.

3.2 Data

As mentioned, ROA requires an extensive amount of reliable and unbiased data. Since NPV is part of ROA the quality of the data used for the NPV calculation is of equal importance. The required data, both for the NPV and the ROA, is defined and briefly analysed in this section. A more thorough analysis of the possible variations of the data over time is given in 4.4, *Monte Carlo Simulation to Estimate Volatility*.

3.2.1 Data for NPV

For the NPV, the expected yearly cash flow, CF, has to be estimated. The positive cash flows are mainly driven by the savings due to reduced energy consumption. A minor contribution comes from the tax reductions due to depreciations, determined by the corporate tax rate, r_t, and the depreciation time, T_D. The savings in energy consumption are financially valued by multiplying the market price for natural gas with the yearly amount of energy saved expressed in fuel.

The integrated utility system will also generate operation and maintenance (O&M) costs which are considered as negative cash flows and has to be estimated. The initial outlay or investment cost, I_0, can be seen as a negative cash flow, but is separated here since it is a one time outlay. Further, it takes place at time $t = 0$ and will therefore not be discounted. Finally, the life time of the investment, T_P, and the hurdle rate, r_h, are required. All data are summarised in Table 3.1.

3.2.2 Data for ROA

For ROA, the value of the underlying asset, S, in this case the investment, at time $t = 0$ has to be known. In this thesis ROA is used to value a project with no connections to the companies' other projects. As proposed by Luehrman [28], Copeland and Antikarov [10] and Svavarson [42], PV is used as S.

In order to create the binomial trees, the risk free rate, r_f, and the volatility of the underlying asset, σ, are required. The final information is the available options

Table 3.2: Required data for ROA.

Symbol	Data
S	Present value
r_f	Risk free rate
σ	Volatility of S
RO	Available real options

with related payoffs and availability as explained in 2.2, *Real Options*. A summary of required data for ROA is given in Table 3.2.

3.2.3 Technical Sub-Projects

The investment consists of five sub-projects (SP1 – SP5). These have been identified in the TSA report [17] on basis of their technical feasibility and technical independence. However, the presented potential savings can only be achieved by implementing all sub-projects. Numbers are either found in the TSA report or provided by Chalmers University of Technology as unpublished data[5]. The energy transports for the full implementation are illustrated in Figure 3.1. Note that 'fuel' refers to the combustion fuel used in the Cluster which is a mixture of different subjects, mainly natural gas. Energy and CO_2 calculations assume that price and energy density of the fuel is the same as for natural gas.

SP1 – Hot Water System 95 °C

A hot water system between Borealis Cr, Borealis PE and Perstorp. This requires investments in heat exchangers at the three sites and water pipe lines. In total the potential saving of the investment is 32.1 MW steam which today is used for heating. Replacing the steam heating with the hot water system disengage steam which can be used for other purposes. The investment cost of the hot water system is 151.2 MSEK.

SP2 – Fuel Pipe Line

Combustible residues used for steam generation are obtained through processes at Perstorp. If additional steam is delivered to Perstorp, the residues could be combusted at Borealis Cr. This would decrease the overall demand for fuel in the Cluster. The investment cost for a fuel pipe line dimensioned for 27 MW fuel is 33.8 MSEK.

SP3 – Hot Water System 79 °C

An additional hot water system working at a lower temperature allows for additionally 30.5 MW of steam heating to be replaced. By replacing steam heating in some processes with hot water, the redundant steam can be used for heating in other processes. The energy savings arises since the hot water is generated as excess heat in existing processes. In a base scenario, this hot water system only includes Borealis

[5] Roman Hackl, Eva Andersson meeting notes April 2013.

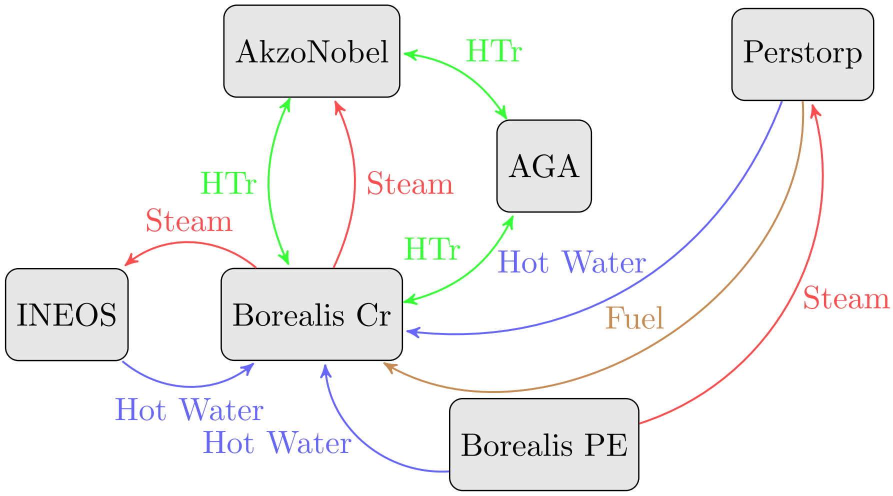


Figure 3.1: Illustration of the energy transports within the Cluster if the utility system is fully implemented. HTr is the heat transfer system below ambient temperature, SP5. Note that internal changes are not indicated. Based on a figure in [22].

Cr and Borealis PE. The total investment cost for heat exchangers and pipe lines between the sites is 187.3 MSEK.

However, this sub-project grants the possibility for an additional actor to enter the project. The hot water system can be extended to include INEOS. In that case heat exchanger investments has to be undertaken at INEOS and a pipe line between Borealis Cr and INEOS is required. The total cost for this alternative investment is 45.4 MSEK but due to INEOS entering the project the heat exchangers investment at Borealis is reduced by 54.8 MSEK. This summarise to an investment cost of 177.8 MSEK. The amount of steam that can be replaced with hot water is the same.

SP4 – Decreased steam pressure level and delivery of low pressure steam

In order to use the excess steam more efficient, heat exchangers working with low steam pressure and pipe lines for the excess steam can be constructed. This investment involves four companies. Low pressure steam is delivered from Borealis PE to Perstorp and from Borealis Cr to AkzoNobel and INEOS. The total investment cost for updates of heat exchangers and a pipeline dimensioned for 40 MW for delivery of low pressure steam to Perstorp is 187.3 MSEK. Similarly, for the involvement of AkzoNobel the cost is 27.2 MSEK for 3 MW steam. The involvement of INEOS costs 69.2 MSEK for 10 MW steam.

SP5 – Heat transfer system below ambient temperature

A system for heat transport between Borealis Cr, AkzoNobel and AGA working at temperatures below ambient can reduce the steam usage with 6.2 MW (equivalent to 7.8 MW fuel). In addition, pumps required for the current system use 2.5 MW of electricity. By implementation of the heat transfer system these pumps are redundant. Using the factor 0.4 to generate electricity from fuel this saving is valued to

6.2 MW of fuel. A pipe line between the sites and updates on heat exchangers are required to a total cost of 36.7 MSEK.

Summary

The entire project savings add up to 80.3 MW fuel to a total cost of 683.2 MSEK. An illustration of the energy transports within the Cluster, after all sub-projects are implemented, is depicted in Figure 3.1.

3.3 Data Processing

It is possible to perform a Real Options Analysis on the sub-projects as they are given. However, to best use the flexibility in ROA it is suitable to process the data for the specific purpose. A step to minimise drawbacks within an industrial cluster is to reduce the complexity, for example by reducing the number of participants. Hence an investment strategy is identified, composed of a set of investment stages aiming to reduce the number of participants in the early stage of the project. This strategy is presented and analysed in 4.1, *Investment Stages*.

Based on the investment strategy, the procedure described in 2.3, *Real Option Analysis Process* is utilised. In accordance with the theory described in 2.3.1, *Base Case sNPV*, 2.3.2, *Real Options Identification* and 2.2.2, *Option Types and Valuation Techniques*, a base case and a set of real options are identified. The motivations and detailed descriptions of the options are presented in 4.2, *Identified Options*. By estimating the required variables for calculating NPV it is possible to conduct a Monte Carlo simulation on the underlying asset, as outlined in 2.3.3, *Monte Carlo Simulation on S*. From this simulation the volatility for the entire project is obtained. At this stage, all inputs required to construct the binomial lattices are known. Hence the asset tree, describing the market development, is calculated, based on the expected present value of the project. Given the set of identified real options, the value tree is calculated using backward induction.

The simulations were performed in MATLAB with the input data given in an EXCEL spreadsheet. A brief description of the implementation is given in 4.5, *Modelling of trees*. The source code is found in Appendix A, *Software Implementation* and an example of input data spreadsheet is found in Appendix B, *Excel Spreadsheet with Option Properties*.

3.4 Presentation of Results

As described in 2.3.6, *Result Presentation*, the main result is the real option value, ROV. By investigating subsets of the available options redundant options can be identified. Only the value trees and decision trees (illustration of the decision strategy for a given market development) for the relevant options are presented.

Since an industrial cluster is considered, the most profitable investment strategy is not necessary the most desirable. Several other aspects affect the decisions taken by the Cluster. Of interest is not only the amount of money represented by ROV, but also the path to reach that value. The decision trees describe the character and extent of the collaboration and are hence valuable for future discussions within the Cluster. This further motivates an investigation of option subsets.

To strengthen the validity and reliability of the analysis the impact of crucial input variables and parameters are investigated. Naturally, there are uncertainties in the input data. By showing how the result varies with fluctuations in the input data it is possible to make use the analysis even if some inputs change in the near future. Furthermore, a sensitivity analysis shows whether or not the behaviour of the implemented model is stable and predictable or unstable and random.

From a valuation with binomial lattices only the expected value of the investment is obtained. In order to widen the understanding of the investment outcome, the distribution of the project value can be calculated. By performing a Monte Carlo simulation of random walks on the asset tree with a set of options available, the distribution of the project value given those options are found. From this distribution two very significant parameters can be read; the median of the project value, which most likely does not coincide with the expected value, and the probability that the project net present value is positive, which can be related to the risk of the project.

4 Restructuring and Option Identification

A major part of the Real Option Analysis is to quantify the project data and establish economical and technical relationships. The sub-projects presented in 3.2.3, *Technical Sub-Projects* are all technically independent. However they are economically dependent. The sub-projects can hence be implemented in any order, but the payoffs depend on the implemented sub-projects. A suggested structure of the project, aiming for a lower project complexity, is presented and motivated in this section. A base investment with possible expansions and available options is identified and quantified.

Included in this section is also a Monte Carlo Simulation on PV of the identified base investment. The resulting volatility is used for the modelling and simulation of ROA. The modelling of the trees for ROA finalises the section.

4.1 Investment Stages

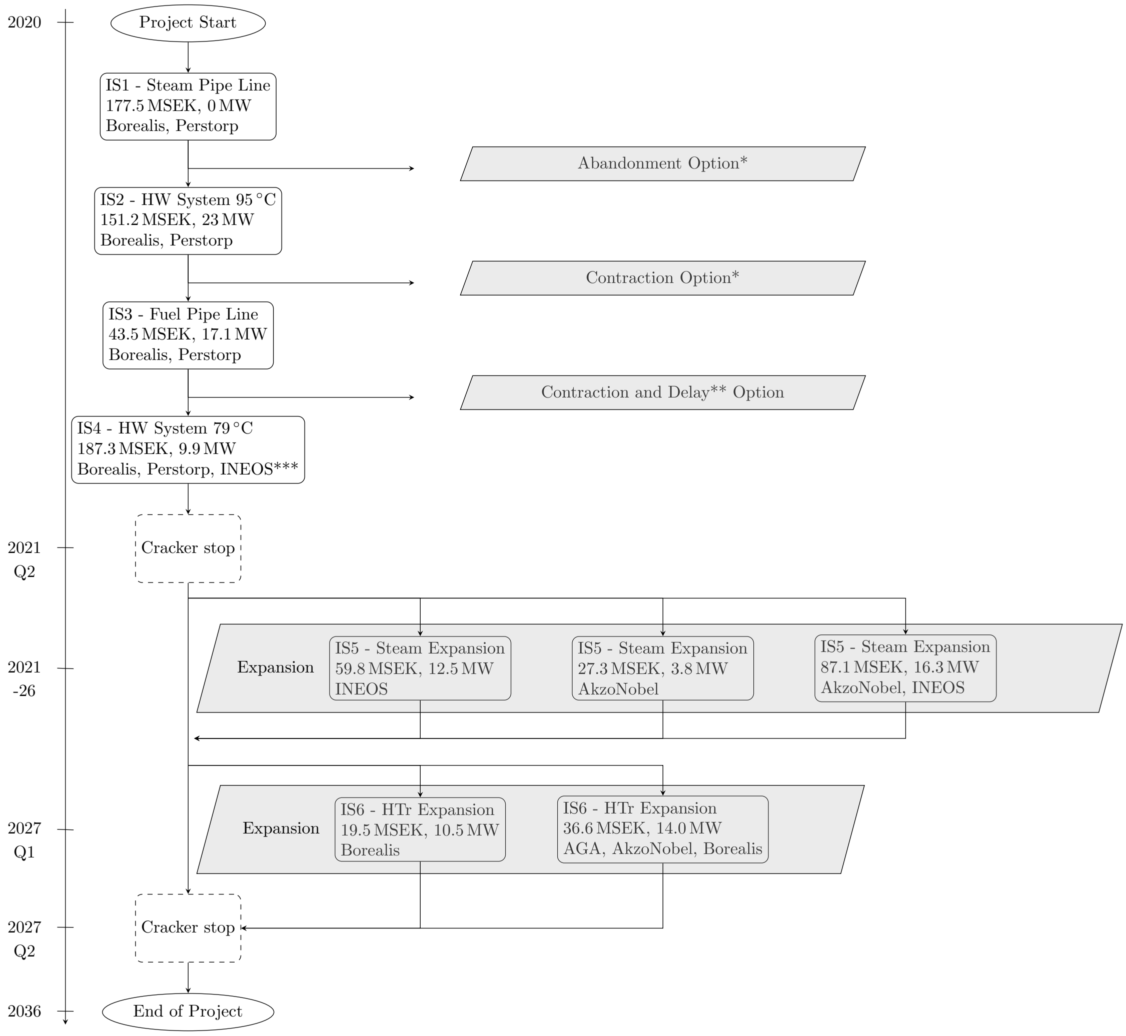
While taking part of interviews with the companies in the Cluster [24], it was concluded that the largest issue with a joint utility system investments is the necessity for the companies to cooperate. As described, a benefit with a ROA approach is the valuation of flexibility. Thus, it is beneficial to order the sub-projects, presented in 3.2.3, *Technical Sub-Projects*, in such a way that only a few companies are involved in the early stage of the project. Meanwhile, keeping the opportunity for the remaining companies to join at a later stage. As an alternative investment, Chalmers University of Technology has identified a bilateral collaboration for Borealis and Perstorp. Borealis and Perstorp are the main actors for the utility system investment and at least one of them is involved in each sub-project. Consequently, these two companies are chosen to initiate the project while INEOS, AkzoNobel and AGA are allowed to expand the project later on.

The sub-projects are reordered, split and combined into a project structure where only Borealis and Perstorp are involved in the early stage. This structure is illustrated as a flow chart in Figure 4.1 and described in details below. In total six investment stages (IS1 – IS6) are identified, where the first four are considered as a base investment and the remaining as two independent project expansions. The potential savings and the cost of each investment stage are recalculated for the given implementation order.

4.1.1 Base Investment, IS1 – IS4

The first four investment stages compose the base investment and involves only Borealis and Perstorp. However, in the fourth stage there is a two way solution where INEOS has the possibility to enter the project.

The base investment comprises several jobs at the cracker plant which can only be done during the planned maintenance stop which takes place every sixth year. The next opportunity for these jobs is in 2021, since 2015 is to close in time [7]. Although the base investment consists of four different investments, all investments will simultaneously start generate profit in 2021.



* These two options are proven reduntant and of no practical interest they are therefore not considered in the final model.
** Delay of IS4 and all possible expansions until the cracker stop in 2027. However, they are not obligated to be built.
*** Possible investment, if INEOS does not join here Borealis Cr has to invest in a more expensive heat exchanger.

Figure 4.1: Flow chart of the investment program.

IS1 – Steam Pipe Line

The steam pipe line from Borealis Cr to Perstorp in *SP4 – Decreased steam pressure level and delivery of low pressure steam* is taken separate as the first investment. In itself, this investment does not generate a profit but generates a saving potential realisable by the following investments. The investment cost is in total 177.5 MSEK.

IS2 – Hot water system 95 °C

The hot water system in *SP1 – Hot Water System 95° C* is identified as the second investment stage. However, not all of the saving potential can be realised in this stage. The full saving potential at Perstorp is 40 MW of steam (equivalent to 50 MW fuel). This requires a delivery of 27 MW fuel in terms of combustible residues to Borealis Cr. At this stage, the fuel delivery is not possible why Perstorp only can make use of $50 - 27 = 23$ MW fuel. Also, Perstorp can make use of 26.2 MW steam (or 32.9 MW in fuel equivalences) without modification of current heat exchangers. Thereby all 23 MW fuel can be used.

With this investment the project begins to generate a profit in 2021. The investment cost for the hot water system is 151.2 MSEK.

IS3 – Fuel pipe line

A fuel pipe line between Perstorp and Borealis Cr enables Perstorp to export combustible residues and thereby increase the usage of steam for heating. If, in addition, heat exchanger modifications are undertaken at Perstorp the steam usage for heating can be increased further. Through these two investments Perstorp can make use of up to 40 MW of steam. *IS2 – Hot water system 95° C* only enables 32.1 MW of steam (equivalent to 40.1 MW fuel) which is the upper limitation. Thus the potential savings for this investment is $40.1 - 23.0 = 17.1$ MW fuel. The cost of the investment can be computed by adding the entire sub-project in *SP2 – Fuel Pipe Line* with the cost for the heat exchanger updates at Perstorp in *SP4 – Decreased steam pressure level and delivery of low pressure steam* yielding 43.5 MSEK.

IS4 – Hot water system 79 °C

To make use of the base investment's full energy saving potential an additional 7.9 MW steam supply is required. This supply can be made available by undertaking *SP3 – Hot Water System 79° C*. The investment consists of heat exchanger updates at Borealis Cr and Borealis PE and a water pipe line inbetween the two sites. The total investment cost is 187.3 MSEK and the amount of steam made available is 30.5 MW which is well over the 7.9 MW required to fulfil Perstorp's demand of 40 MW.

An alternative implementation exist for this investment stage, where INEOS delivers hot water to Borealis Cr. This reduces the required number of heat exchanger updates at Borealis Cr. As described in *SP3 – Hot Water System 79° C*, the investment cost for the alternative investment is 177.8 MSEK.

4.1.2 Expansions, IS5 – IS6

Investment stages five and six are possible expansions of the base investment. IS5 is assumed to be available at any time between the cracker maintenance stop in the second quarter (Q2) 2021 and the next cracker stop in Q2 2027. IS6 involves job at the cracker plant why it is only available at the time of the cracker maintenance stop in Q2 2027.

IS5 – Steam usage expansion

The investments undertaken in *IS1 – Steam Pipe Line* and *IS3 – Fuel pipe line* allow Perstorp to make use of delivered steam instead of combustion of fuel. Similar investments can be made at INEOS and AkzoNobel. At each of the two sites, heat exchangers can be modified to make use of low pressure steam, delivered from Borealis Cr. At INEOS the total cost for this investment is 59.8 MSEK and the savings in terms of fuel is 12.5 MW. Corresponding numbers for AkzoNobel are

Table 4.1: Summary of the investment stages, the investment costs and the energy savings in terms of fuel (natural gas) given the investment order.

Investment stage		Cost [MSEK]	Savings* [MW]	Savings** [10^6 kg CO_2/year]	Ratio [W/SEK]
IS1	Steam Pipe Line	177.5	0.0	0.0	0.00
IS2	Hot Water System 95 °C	151.2	23.0	34.4	0.15
IS3	Fuel Pipe Line	43.5	17.1	25.6	0.39
IS4	Hot Water System 79 °C	187.3	9.9	14.8	0.05
	Base investment	*559.5*	*50.0*	*74.8*	*0.09*
IS5	Steam usage expansion	87.1	16.3	24.4	0.19
IS6	Heat transfer system	36.6	14.0	20.9	0.44
	Full expansion investment	*123.7*	*30.3*	*45.3*	*0.24*
	Total	**683.2**	**80.3**	**120.1**	**0.12**

* Momentary savings per investment.
** Savings in kg CO_2 per year assuming 8'400 running hours and a conversion factor 0.178 kg CO_2/kWh [4].
Remark: IS5 and IS6 are assumed fully implemented.

27.3 MSEK and 3.8 MW, respectively. Note that the investments can be undertaken separately or both, as illustrated in Figure 4.1. The investment cost for INEOS is reduced with 9.5 MSEK since it is assumed that if this expansion is undertaken, INEOS participated already in IS4 and thereby reduced the cost for IS4.

IS6 – Heat transfer system below ambient temperature

SP5 – Heat transfer system below ambient temperature is an expansion available at the time of the cracker maintenance stop in Q2 2027. There are two possible ways to implement the heat transfer system. Either, Borealis Cr updates heat exchangers and builds an internal pipe line to a total cost of 19.5 MSEK or Borealis Cr, AkzoNobel and AGA build a common heat transfer system to a cost of 36.6 MSEK. The corresponding total savings in terms of fuel are 10.5 MW and 14.0 MW respectively.

Summary

The savings realised due to the base investment (IS1 – IS4) add up to 50.0 MW of fuel for a total cost of 559.5 MSEK. The entire savings realised due to the expansions (IS5 – IS6) add up to 30.3 MW of fuel for a total cost of 123.7 MSEK if fully implemented. Table 4.1 summarises the investment stages. Note that the numbers for IS5 and IS6 are given for the fully implemented expansions.

In Table 4.2 the company involvement per investment stage is presented. This table reveals the structure of the project. The first part of the project is identified as a bilateral collaboration between Borealis and Perstorp. The bilateral cooperation identified by Chalmers University of Technology corresponds to IS1 – IS3, IS4 without participation of INEOS and Borealis' part of IS6.

Table 4.2: Company involvement per investment stage.

	AGA	AkzoNobel	Borealis	INEOS	Perstorp
IS1 – Steam Pipe Line			X		X
IS2 – Hot Water 95°C			X		X
IS3 – Fuel Pipe Line			X		X
IS4 – Hot Water 79°C			X	O*	X
IS5 – Steam Expansion		O		O	
IS6 – HTr Expansion	O**	O**	X		

X: Participation in investment stage is required.
O: Participation in investment stage is optional.

* Possible investment, if INEOS does not join here Borealis Cr has to invest in a more expensive heat exchanger.
** Participation of both companies is required if anyone participates.

4.2 Identified Options

To perform a ROA, real options have to be identified based on the investment stages. A base scenario is required, which in this case naturally is the base investment. From this base scenario it is possible to exercise different options and thereby affect the size and value of the project.

Due to the technical independence of the investment stages an abandonment option exists after the first investment stage. With the same reasoning two contraction options exist, after the second and third investment stages, respectively. The two last investment stages increases the total energy savings of the project and are identified as expansion options. Finally, the fourth investment stage can be delayed until the next cracker stop in Q2 2027, which will force a delay of the expansions.

A more thorough motivation of the chosen option types and their given properties are presented below. The numerical values of the option properties differ with the discretisation of the binomial lattices and the option's availability.

Abandonment Options

Implementing *IS1 – Steam Pipe Line* does not result in any energy savings in itself. The value of the pipe without the following investment stages are therefore zero. If the Cluster makes no further investments it is technically possible to leave the pipe in the ground. This renders in an abandonment cost of zero. Since this abandonment option is only available at an early stage, and the market movements are limited by the model, it was suspected that this option would never be exercised. This was later confirmed by the simulations.

Contraction Options

If the Cluster does not invest after *IS2 – Hot water system 95°C*, the implemented systems would together generate a small profit until they are taken out of service. A contraction option down-scaling the base investment is therefore identified after this stage. The same reasoning as with the abandonment option yields that this contraction is superfluous.

An additional contraction option is identified after *IS3 – Fuel pipe line*. This contraction affect an investment stage (IS4) with a much lower savings to cost ratio than the two preceding investment stages, as is illustrated in Table 4.1. Hence it is assumed to be of interest for the analysis. This was later confirmed by the simulations.

The payoff for a contraction option is given by equation (2.11) as $V_{\text{Contract},t} = C_{F,t}S_t + C_{G,t}$. The contraction factor, C_F, is given as the fractional increase of the project value given that the option is exercised at a certain time, t. That is, the project value is decreased with the contracted savings put in relation the remaining time of the project at the exercise date. The gain, C_G, is the savings due to unrealised investments for the base investment. C_G is decreased with an amount corresponding to the tax savings due to depreciations. To account for the discounting in the value tree and thereby taking the opportunity cost into consideration, C_G is compounded with the risk free rate. This can be formulated as

$$C_{F,t} = \frac{T_P - t}{T_P} \cdot \frac{s_{\text{Con}}}{s_{\text{Base}}} \tag{4.1}$$

$$C_{G,t} = I_{\text{Con}}(1 - d_f)\mathrm{e}^{r_f t} \tag{4.2}$$

where s_{Con} is the savings after the contraction and s_{Base} is the savings for the base investment. I_{Con} is the cost for the unrealised investments and d_f is a factor to account for the tax savings due to depreciations. The quote $(T_P - t)/T_P$ is the remaining fraction of the project. That is, the part of the project that is affected by the contraction.

Expansion Options

Two expansion investments (IS5 – IS6) exist. The first, *IS5 – Steam usage expansion*, can be interpreted as two expansion options that can be undertaken at any time between the two cracker stops. The payoff function is given by equation (2.10) as $V_{\text{Expand},t} = E_{F,t}S_t - E_{C,t}$. E_F, the expansion factor, is given by the ratio of the total project value after the expansion implementation and the value of the base investment. Hence E_F is dependent on exercise time. E_C is the expansion cost and has to be compounded with the risk free rate. Further, E_C is reduced with an amount corresponding to the tax savings due to depreciations. This can be formulated as

$$E_{F,t} = \frac{T_P - t}{T_P} \cdot \frac{s_{\text{Exp}}}{s_{\text{Base}}} \tag{4.3}$$

$$E_{C,t} = I_{\text{Exp}}(1 - d_f)\mathrm{e}^{r_f t} \tag{4.4}$$

where s_{Exp} is the savings after the expansion and s_{Base} is the savings for the base investment. I_{Exp} is the cost for the expansion investment and d_f is a factor to account for the tax savings due to depreciations.

The second expansion investment, *IS6 – Heat transfer system below ambient temperature*, can be performed in two different ways. Hence it can also be seen as two expansion options. The expansion factor, E_F, and the expansion cost, E_C, are calculated analogously with the first expansion investment. Since this investment requires work at the cracker plant it is only available in Q2 2027.

Option to Delay Sub-Projects

In *IS4 – Hot water system 79° C*, the most economically profitable alternative is the participation of INEOS. However, the complexity of the project is significantly increased with an additional actor. With the possibility to decide how to implement *IS4 – Hot water system 79° C* six years later, the collaboration of the first three investment stages can be evaluated. Therefore an option similar to the option to defer has been identified.

If the option is exercised, the effect is that neither *IS4 – Hot water system 79° C* nor the expansions can be implemented until the next cracker stop in Q2 2027. An option to defer usually refers to the delay of the entire project. In this situation this is not the case since only a sub-part of the project is deferred. Therefore equation (2.12) is not valid.

The payoff for this delay option can be calculated by considering an additional value tree, V_{Delay}, describing the delay scenario. This value tree is calculated from a specific asset tree, S_{Delay}, starting at time $t = T$ and utilising backwards induction. At the time of implementation, t_{im}, the options to invest in IS4 – IS6 exist and may be taken if profitable. For times between the exercise date, t_{ex}, and t_{im} the lost revenues have to be accounted for. This is done by treating the lost revenues as dividends and reducing the value of the asset tree corresponsively. The asset tree for the delay option, S_{Delay}, is given by

$$S_{\text{Delay},t} = S_t \qquad \text{for } t = t_{\text{ex}} \tag{4.5}$$

$$S_{\text{Delay},t,u} = u\mathrm{e}^{-q\Delta t} S_{\text{Delay},t-\Delta t} \qquad \text{for } t \in (t_{\text{ex}},\, t_{\text{im}}] \tag{4.6}$$

$$S_{\text{Delay},t,d} = d\mathrm{e}^{-q\Delta t} S_{\text{Delay},t-\Delta t} \qquad \text{for } t \in (t_{\text{ex}},\, t_{\text{im}}]. \tag{4.7}$$

For $t \notin [t_{\text{ex}},\ t_{\text{im}}]$, S_{Delay} is calculated in the same manner as S.

Summary

As discussed above the abandonment option and the first contraction options are redundant as the simulations showed that they are never exercised. However they are included in this analysis for academical reasons. If the base investment was spread over a longer time, allowing for larger marker movements between the investment stages (IS1 – IS4), the two options could be of interest. But since this is not the case, they are excluded from the remaining parts of the thesis.

The second contraction option is modelled by the delay scenario. Except for numerical errors due to the discretisation, the contraction of IS4 before the first cracker maintenance stop in 2021 is equivalent to the delay of IS4 and contraction of it at the next cracker stop in 2027. Hence the only options considered are the expansion options and the option to delay sub-projects.

4.3 Estimation of Variables and Parameters

The variables and parameters presented in 3.2.1, *Data for NPV* and 3.2.2, *Data for ROA* have to be estimated. Except from the cash flows and the initial outlay, there are four variables required for NPV, shown in Table 3.1. Each company in the Cluster has its own preferred hurdle rate and its own ideas of how to suit the rate for a specific project with respect to risk, profit, utility etcetera. In [24] the authors make the assumption that a reasonable hurdle rate for the Cluster is $r_h = 12\,\%$. The inflation is considered part of r_h.

The savings from tax reduction due to depreciations depends on the depreciation time, T_D, which is assumed to be 10 years based on a common time frame for contracts within the Cluster[6]. The corporate tax, r_t, is taken as 22 % in accordance with the Swedish tax system.

The project life span, T_P, is chosen such that the main part of the tangible assets should survive the entire T_P. Also, if any of the companies in the Cluster switch operation process it might affect the integrated utility system. Therefore, T_P is chosen defensively to 15 years.

In addition, the risk free rate, r_f, and the volatility, σ, are required for ROA. The risk free rate is estimated from a Swedish governmental bond to $r_f = 2\,\%$[7] and σ is calculated with a Monte Carlo simulation.

4.4 Monte Carlo Simulation to Estimate Volatility

To find the project volatility required for the binomial lattice, a Monte Carlo simulation is conducted in accordance with 2.3.3, *Monte Carlo Simulation on S*, where PV of the base investment is taken as the underlying asset. In the simulation, the distributions of the (stochastic) input variables are of great importance. The main drivers of the cash flows are the cost savings, which depend on the natural gas price, O&M cost and the yearly running hours. Thus these three are chosen as input variables. The savings in MW are considered constant and possible fluctuations are modelled in the fluctuations of the yearly running hours.

The natural gas consumed by the Cluster is provided through a pipeline originating in Germany. Thus historical data for German natural gas prices[8] can be used to estimate the distribution of the Swedish natural gas price. The distribution is assumed to be lognormal, motivated by the fact that the price cannot be below zero. Further, percentage changes in prices between two time periods are more realistic than changes in terms of absolute values. However, abnormally large values might occur, therefore values larger than two times the mean value are saturated. This data results in $\mu = 5.96$ and $\sigma = 0.33$ after a scaling to fit average industrial price

[6] Interview with Perstorp representative recorded for [24].
[7] `http://www.scb.se/Pages/TableAndChart____32290.aspx`
[8] `https://cdn.eex.com/document/133219/20130502_EEX_Reference_Price_EGIX.pdf`

Table 4.3: Variables required for the Monte Carlo simulation and their estimated distributions.

Variable	**Distribution**	**Properties**	**Values**
Natural gas price	Lognormal	μ	5.96
		σ	0.33
		μ'	409
		σ'	137
Yearly running hours	Normal	μ	8400
		σ	120
O&M cost	Uniform	min	1.0
		max	4.5

for the last years in Sweden, 406 SEK/MWh[9]. The mean and standard deviation of the associated normal distribution are $\mu' = 409$ and $\sigma' = 137$ respectively.

The yearly running hours are assumed to be normally distributed with a low variance based upon figures and facts found in the Cluster companies annual reports [1, 2, 6, 21, 35]. Based on normal operation conditions an assumption of 8'400 running hours is made, $\mu = 8'400$. In order to not exceed the yearly amount of hours within three standard deviations, $\sigma = 120$. The O&M cost is taken as a normal rule-of-thumb value with a point estimate of 3 % of the initial layout [17]. To handle yearly variations a uniform distribution of the O&M costs with possible values between 1 and 4.5 % of the initial investment cost is assumed. The input variables, assumed distributions and properties are summarised in Table 4.3.

The expected rate of return is given by equation (2.20) why PV has to be computed. Taking values from 4.3, *Estimation of Variables and Parameters*, gives $PV_0 = 926$ MSEK for the base investment when assuming annual cash flows calculated using equation (2.17), natural gas price 406 SEK/MWh, 8'400 yearly running hours and O&M cost 3.0 % of the initial layout.

The Monte Carlo simulation, depicted in Figure 4.2, results in a volatility $\sigma = 13.4\,\%$ and a mean value $\mu = 12.0\,\%$ for 100'000 trials. The mean value is used to confirm the Monte Carlo simulation since it should equal the hurdle rate.

4.5 Modelling of trees

The asset tree is implemented in accordance with 2.3.4, *Binomial Lattice.* Note that for the option to delay sub-projects an additional asset tree is required, where the lost revenues due to the delay is considered. This tree is implemented as described in 4.2, *Identified Options.*

The calculated project value is affected by the time step size. A very small time step implies that the cash flow is modelled as almost continuous and a larger project value is obtained since the cash flows are, on average, discounted a shorter time. The size of the time should reflect the actual period of payment. Assuming monthly payments of natural gas is reasonable. This gives a total of 97 time steps in the

[9] `http://www.scb.se/Pages/TableAndChart____212959.aspx`, where the Cluster is within the I5 category.

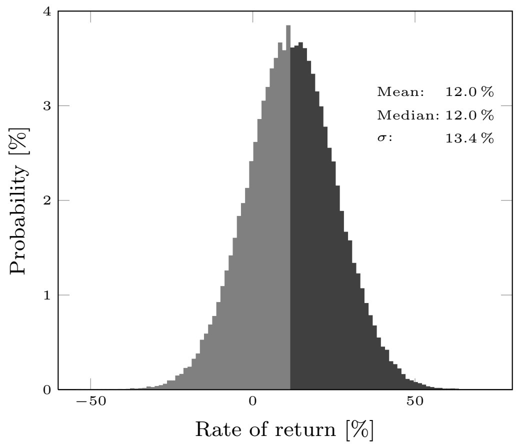


Figure 4.2: Histogram from Monte Carlo simulation of rate of return. Dark gray indicates values above mean.

binomial lattice. Naturally, the discretisation for the PV should be the same as the discretisation of the trees in ROA since PV is used as input S_0. Hence, the same time step size is used. Note that this PV differs slightly from PV calculated on a yearly basis for the Monte Carlo simulation to estimate the project volatility.

The identified options are implemented in separate value trees, in total four trees. In the first, the contraction options and the abandonment option are modelled. The abandonment option is modelled as a contraction options with $C_F = 0$ and $C_G = 0$. In the second and third value trees, the expansions IS5 and IS6, respectively, are modelled. The option to delay sub-projects is modelled in the last value tree, based on the modified asset tree specified for the purpose. Note, the savings due to INEOS' participation in IS4 are modelled as a cost reduction for INEOS in IS5 since INEOS is assumed to participate fully or not at all. This is verified by the simulation.

To achieve the total value tree for the entire project, including all available options, it is possible to combine the four trees. Similarly, it is possible to combine a subset of trees to obtain the project value given the subset of available options. However, this always results in the most economically profitable investment strategy where the less profitable options are veiled by the most profitable. For joint investments decisions may be taken on non-economical bases. It is therefore of interest to investigate how the different options affect the project value. Hence, the value trees are presented and analysed individually.

5 Simulation Results

Once the combined volatility for the project is known, an expected project value can be generated by simulations on the implemented tree models. The results are illustrated as tree plots and expressed in numerical values as real options values (ROV). The two identified scenarios, expansion and delay, are treated separately as well as combined.

5.1 Interpretation of Tree Plots

The results from the simulations are plotted as value trees, asset trees and decision trees. Value trees are coloured blue and the corresponding asset trees are plotted behind in red for comparison (cf. Figure 5.1a). If no options are exercised the two trees overlap and the asset tree is hidden by the value tree. On the other hand, if an option is exercised the value tree will increase in value. This is illustrated as a positive offset of the value tree. The vertical distance between the leftmost corner of the trees is the added value due to the exercised options at the time of the project start up. That is the real option value, ROV.

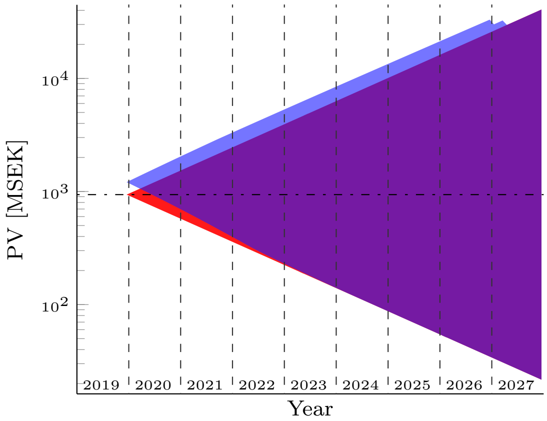
Note that since the value trees are computed using backward induction, the value at any given node in the tree is purely based on the expected future. Hence, the decisions are independent on paths. From the definition of backward induction it follows that exercising an option in one time step voids the possibility to exercise the option in future time steps. Consequently, it is only the value in the very first node (the leftmost corner) that can be guaranteed accurate. The value of the nodes at $t \in (0, T)$ are used in the backward induction and therefore indicates how much an exercised option affects the project value at a certain time.

The decision trees show the optimal option to exercise in any given time and market situation (cf. Figure 5.1b). Hence, an option is exercised the first time it appears in the decision tree. A path dependent simulation of the project evolution is presented in 6, *Sensitivity Analysis*. Recall that the descretisation time step is $\Delta t = 1$ month.

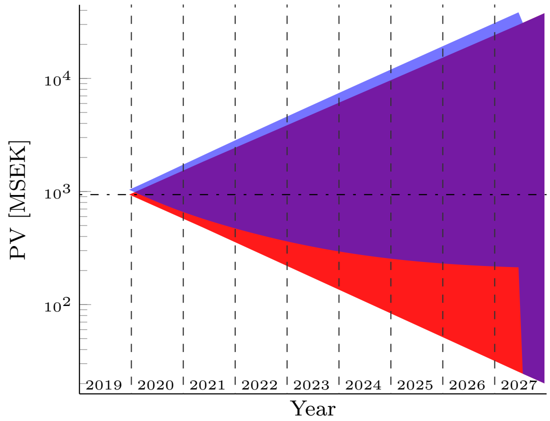
5.2 Redundant Options

If *IS4 – Hot water system 79° C* is first delayed and then not implemented at all, it will have the same economical impact as if the contraction option of *IS4 – Hot water system 79° C* was chosen. With this in mind it is clear that this contraction option is redundant and the tree for this contraction options is therefore not shown.

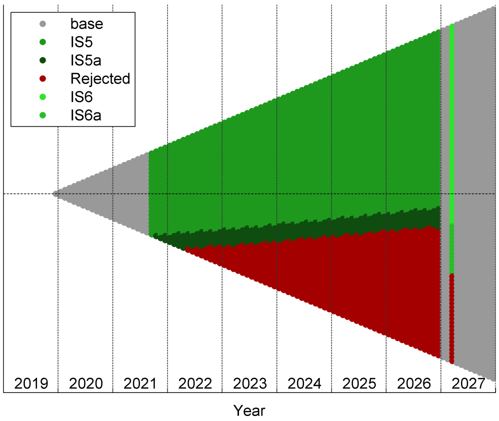
The contraction option of *IS3 – Fuel pipe line* is never exercised in the simulations and is therefore proven worthless. The same applies for the abandonment option. This is due to their high investment cost and low payoff. When the initial value of the natural gas price is within the investigated range, these options are never exercised. However, they could be of interest if the initial natural gas price is lowered drastically and the market suffers a bad development. But in that case the narrow time window renders in a rejection of the whole project instead. Therefore these two options are considered of no practical importance and are not treated further in this thesis.



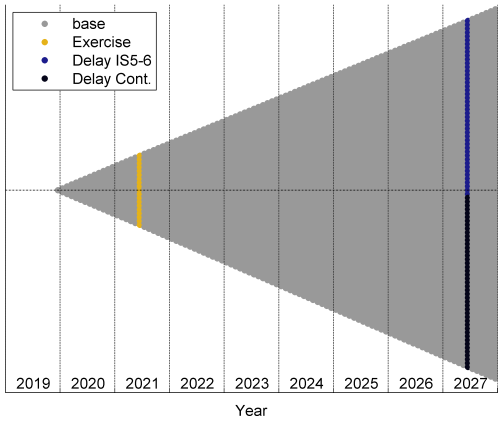
(a) Increased value due to exercised expansion options is seen as an offset.



(b) Increased value due to exercised delay option is seen as an offset.



(c) IS5 is fully implemented. IS6 is fully implemented for a good market and partly for a decreasing market and not implemented at all for a drop in the market.



(d) For a good and slightly decreased market IS4 is implemented at the next cracker stop as well as IS5 and IS6 fully. If the market has a bad development it is most profitable not to invest further.

Figure 5.1: In (a)-(b) the value trees (blue) and the asset trees (red) are shown for the expansion and delay scenario. Corresponding decision trees are illustrated in (c)-(d).

5.3 Evaluation of Expansion Trees

The value tree for the expansion options combined is presented in Figure 5.1a. Note that this tree represents the value of the project given that; the two expansions are available in the given time windows, they can be implemented independently of each other and no other options exist. Two distinct positive changes in the value tree can be identified. These are the end times for the expansion options, illustrated in the decision tree in Figure 5.1c.

The first set of expansion options, originating from *IS5 – Steam usage expansion*, are available at all times between Q3 2021 and Q4 2026. It is found that this expansion is implemented in its full form involving both INEOS and AkzoNobel, denoted IS5 in the figure, in the majority of the possible states. Notable are the nodes located at Q3 2021. When conducting the project, it is always profitable to implement this expansion at full scale in all states at this time. Therefore the INEOS steam expansion shown profitable later on will not be exercised since it has already been implemented, assuming logical managerial decisions. However, if the most profitable decision in 2021 is not taken, it is possible to reach a state where it is not profitable to implement the expansion at all. This can be seen in Figure 5.1c as nodes denoted 'Rejected'. In a quite narrow transition phase the expansion is implemented in a smaller scale, only involving INEOS denoted IS5a. It can be concluded that the expansion of only AkzoNobel is not the most profitable decision for any market state and the corresponding option is therefore never exercised.

The second set of expansion options, derived from *IS6 – Heat transfer system below ambient temperature*, are only available in Q1 2027. Recall that this is just before the second maintenance stop at the cracker plant, in Q2 2027. These options are not profitable to exercise at all for a bad market development, as is illustrated in the figure as 'Rejected'. The limit is found at a node where the value of the underlying asset is only 19 % of its initial value. By assuming that yearly running hours and O&M costs are kept constant, this corresponds to a decrease in natural gas price by 81 %, or a natural gas price of 77 SEK/MWh. For an intermediate to good market the full scale of the expansion is undertaken, involving both Borealis Cr, AkzoNobel and AGA denoted IS6 in Figure 5.1c. The lower limit for this scenario is a value of the underlying asset of 51.2 % of its initial value. By the same reasoning, this corresponds to a natural gas price of 210 SEK/MWh. A transition phase exists where the expansion is most profitable to implement partly, that is at Borealis Cr only, denoted IS6a.

The total value of the utility system investment, given the base investment and the expansion options, is 1'225 MSEK.

5.4 Evaluation of Delay Trees

In Figure 5.1d the exercised delay options given the market situation are shown. The options marked 'Exercise' indicates when the decision to delay has to be taken due to the first cracker stop. The actual implementation is before the second cracker stop in Q2 2027. Even if the market goes slightly down it is from an economical point of view favourable to implement *IS4 – Hot water system 79° C* as well as fully implement the two expansions. If a more substantial drop in the market is encountered there are no economical incitements to invest in IS4 and the following expansions.

In Figure 5.1b the value tree for the delay scenario reveals a small increase in PV of the project if *IS4 – Hot water system 79° C* is delayed until the next cracker stop. The difference between the value tree and the asset tree in Q2 2027 is due to different reasons depending on the market. Given a decreased market, the value increase is due to prevented losses by not implementing IS4. If the market has had a positive development the difference is due to the extra revenues generated by the implementation of the two expansions IS5 and IS6. The limit between these cases are found at a market drop of 20 % which by the same reasoning as in the evaluation of the expansion trees corresponds to a natural gas price of 325 SEK/MWh. Note the usage of a logarithmic scale in the figure why the difference between the value tree and the asset tree for a bad market appears to be larger than for a good market. This is not the case, the difference in 2027 for the worst market is $\sim$ 210 MSEK and $\sim$ 900 MSEK for the best market. The effect of the lost incomes due to the unrealised implementation of IS4 is included in the asset tree in Figure 5.1b. It is however not visible in the figure since the decrease is comparably small and the asset tree is partly hidden behind the value tree.

The total value of the utility system investment, given the base investment and the option to delay, is 1'048 MSEK.

5.5 Combined Value Tree

The two value trees are combined to find the total value of the utility system investment when considering all available options. An additional value tree, V_{Final}, ending at the exercise time, t_{ex}, of the delay option tree is created using backward induction

$$V_{\text{Final},t} = \max\left[V_{\text{Delay},t}, V_{\text{Expansion},t}\right], \quad \text{for } t \in [2020,\ t_{\text{ex}}]. \tag{5.1}$$

This results in $V_{\text{Final}} = V_{\text{Expansion}}$ for all nodes except for the node corresponding to the worst market development where $V_{\text{Final}} = V_{\text{Delay}}$. This node corresponds to a drop in the market of 50 % which with the previous reasoning corresponds to a drop in natural gas price from 406 SEK/MWh to 203 SEK/MWh over this time period.

When considering the most profitable combination of all available options the total project value becomes 1'225 MSEK. Rendering in an eNPV of 666 MSEK. Note that this is the same value as for the expansion scenario. This is because the impact of the one single node where the delay scenario is more profitable on the final value is very small.

5.6 Real Option Value

The real option value (ROV) is given by equation (2.38) where $S_0 = \text{PV}$. With a discretisation time step of $\Delta t = 1$ month, PV = 949 MSEK is obtained. This value is larger than PV calculated for the Monte Carlo simulation in 4.4, *Monte Carlo Simulation to Estimate Volatility* in accordance with the effect of different discount periods.

For the integrated utility system investment

$$\text{ROV} = 1'225 - 949 = 276\,\text{MSEK}. \tag{5.2}$$

This corresponds to a scenario where all options are considered. Considering only the expansion scenario the real option value is 276 MSEK. When considering only the delay scenario, the real option value is 99 MSEK.

6 Sensitivity Analysis

An analysis of the uncertainties' impact on the real option value (ROV) is conducted to establish which uncertainties are of greatest importance. A more thorough analysis is included for the initial natural gas price.

The section is finalised with a simulation of 100'000 random walks[10] for the expansion and delay scenarios to estimate the distribution of the project value. These simulations are a good complement to eNPV calculated with ROA since eNPV is the most likely estimate and the random walks reveals the distribution of possible outcomes.

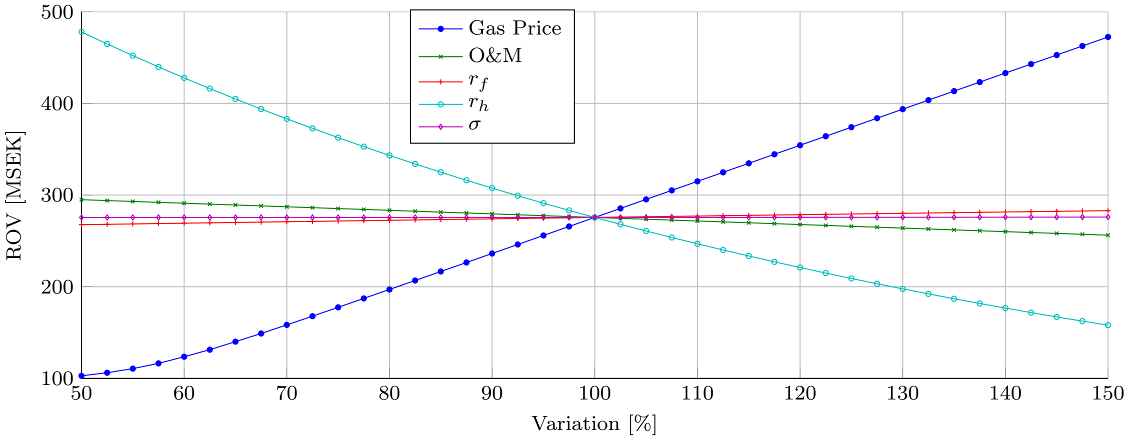
6.1 Impact of Uncertainties on ROV

An analysis is conducted to investigate the impact of the natural gas price, yearly running hours, O&M costs, risk free rate, r_f, hurdle rate, r_h and the volatility, σ on the real option value. The result for the expansion and delay scenarios combined is shown in Figure 6.1a. Varying the yearly running hours with a percental change is equivalent to varying the natural gas price with the same percental change. Hence the impact of the yearly running hours can be seen from the graph denoted 'Gas Price'. Note however that the yearly running hours are limited to 8'760 hours which corresponds to an increase with a little more then 4 %.

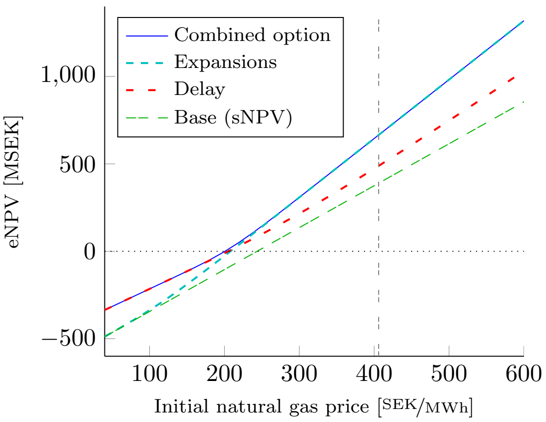
The impact of the O&M costs is as expected – increased costs yield a lower profit. However, since the cost is small compared to other cash flows, the impact is small too. Hence it can be concluded that the final value is insensitive to a possibly erroneous assumption of the size of the O&M costs. Also the sensitivity of the real option value due to the risk free rate, r_f, is very small. The impact is reversed as compared with the O&M costs – an increased risk free rate gives an increased real option value. According to the theory presented in 2.1, *Option Pricing Theory* this describes how the real option value is affected for call options. Both the expansion options and the option to delay (which is similar to an option to defer) are identified as call options. Thus the validity of the model can be strengthened further.

The volatility, σ, prove to have a very small impact on the real option value. In fact, the difference is hardly noticeable at all and is so small that numerical errors due to discretisation and rounding errors might be of the same magnitude. In [40] the author concludes that a volatility increase does not always guarantee a value increase in the ROA framework. With this in mind a simple sensitivity analysis was carried out where the ROA model was altered. A simulation with all expansion factors reduced to a tenth of the original values revealed a significant impact of the volatility. The numerical results from this short analysis is not shown here. However, the result can still be used to motivate the almost evanescent impact of the volatility on the real option value. A final remark is that the volatility had a larger impact when only considering contraction options (put) compared to the expansion options (call).

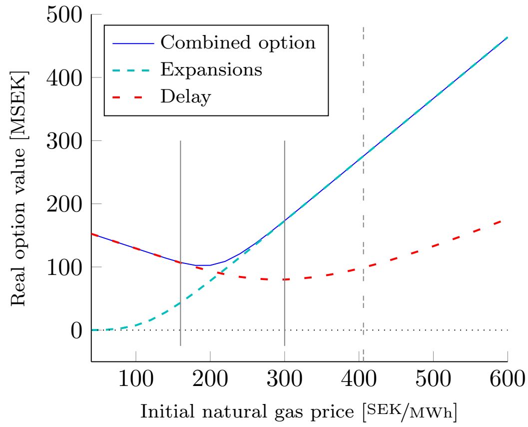
[10] A random walk is a mathematical formalisation of a path that consists of a succession of random steps [34]. It is a widely spread concept within chemistry, biology, game theory and finance among others.



(a) Sensitivity analysis on the real options value



(b) eNPV



(c) Real option value

Figure 6.1: Uncertainties' impact on real option value (a). eNPV (b) and real option value (c) as functions of the initial natural gas price. The assumed natural gas price of 406 SEK/MWh is indicated as well as the interval for the combined scenario.

It can be seen that the hurdle rate and the natural gas price have the largest impact on ROV. However, the fluctuation of the hurdle rate is not as interesting as the natural gas price fluctuations since the hurdle rate is known once a project decision is taken. The natural gas price on the other hand, is affected by circumstances not controlled by the Cluster and is therefore investigated more thoroughly.

Since the volatility is estimated based upon historical data a future prediction is only valid if no scenario changing events occur. This would be for example a rise in natural gas price due to increased taxation or legislations. However the future might go in the opposite direction due to the exploration of shale gas, mainly in the US[11], which make many experts believe that a fall in natural gas price will be a fact in a few years. A simulation of the eNPV for several initial values of the natural gas price spanning from 40 SEK/MWh to 600 SEK/MWh with a step size of 20 SEK/MWh has been performed. The result is illustrated as a plot in Figure 6.1b where the eNPV

[11] `http://www.eia.gov/naturalgas/`

is plotted against the initial market price of the natural gas. It should be noted that the analysis is conducted on the *initial* natural gas price, which should not be confused with the scenario of the assumed initial natural gas price (406 SEK/MWh) and a decreasing market. The impacts of a decreasing or increasing market is analysed in 6.2, *Random Walks*.

From the graph in Figure 6.1b it can be seen that the combined expansion and delay scenario is always the most profitable. For a high natural gas price the expansion scenario and the combined scenario converge. That is, the impact of the option to delay sub-projects decreases when the natural gas price increases. Analogously, the delay scenario and the combined scenario converges for low natural gas prices. In Figure 6.1c, limits for when the scenarios have converge within an error of about 1 % are shown. The limits are 160 SEK/MWh and 300 SEK/MWh, respectively. On the outside of these limits, either of the two scenarios can be considered adequate while a combination of the scenarios has to be considered within the limits.

The graphs in Figure 6.1c show the real option value, given by equation (2.38), for the different scenarios. The real option value for the expansion scenario grows linearly with the natural gas price for high natural gas prices. That is, the higher the natural gas price is, the more profitable is it to expand the project. For a low natural gas price, the real option value converges to zero, which indicates that no expansion options are exercised.

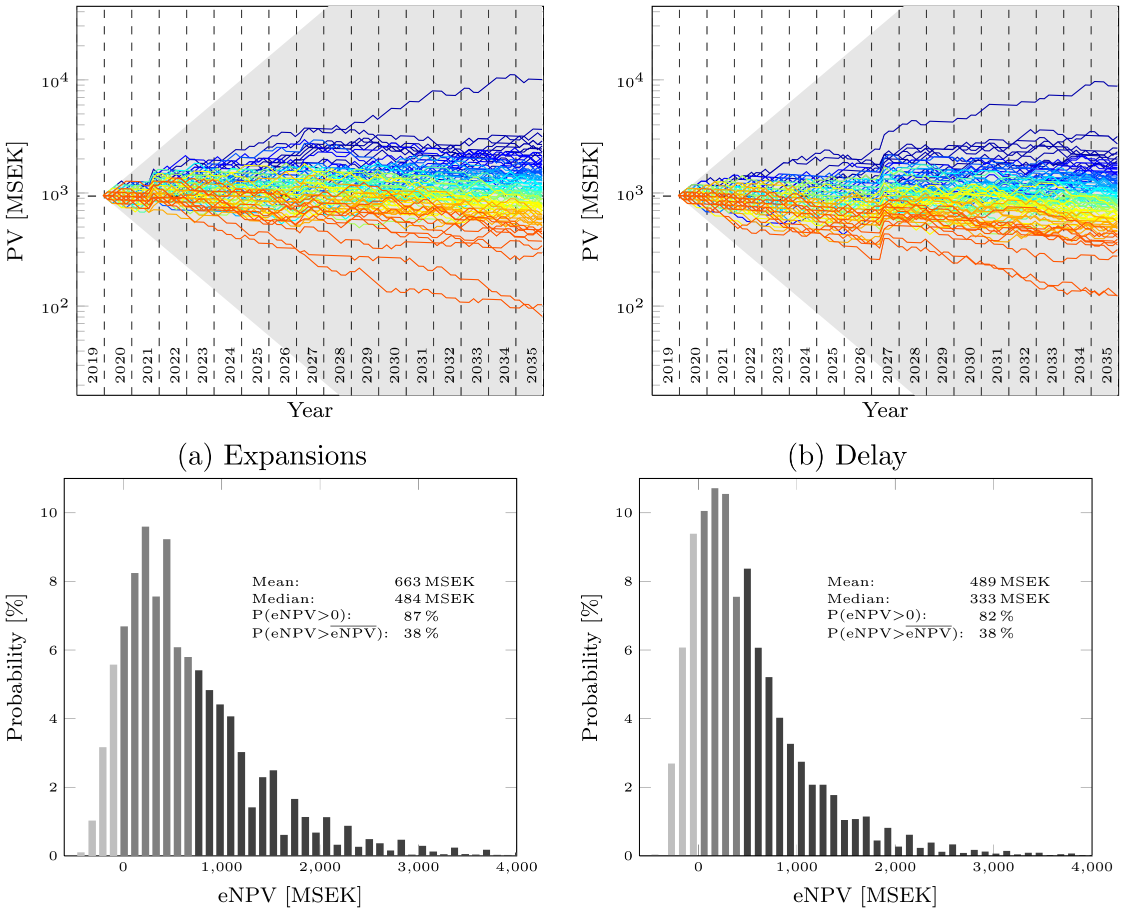
From Figure 6.1b it can be concluded that eNPV is larger for the expansion scenario than for the delay scenario for all natural gas prices that result in a positive sNPV. That is, the delay scenario is only favourable compared to the expansion scenario when eNPV indicates that the project should not be undertaken at all. Note that for natural gas prices around 210 SEK/MWh the difference in ROV between the expansion scenario and the delay scenario is small.

Further, the graphs reveals that the delay scenario always yields a higher expected NPV than the base scenario. Also, the limiting natural gas price for which the project's NPV becomes negative can be reduced from about 245 SEK/MWh to 205 SEK/MWh by considering the delay scenario. Therefore, delaying IS4 – IS6 is a good defensive strategy. It can also be seen that for a natural gas price around 100 SEK/MWh, the losses can be heavily reduced by the delay scenario. Mainly due to the unrealised investment of IS4 for a bad market development.

The graph in Figure 6.1b indicates that if the initial natural gas price is believed to decrease below 200 SEK/MWh (assuming all other variables being kept constant) the decision to undertake the project cannot be supported by economical gains.

6.2 Random Walks

By performing a forward simulation of several random walks in the asset tree, for the entire project life time and with the options available, an estimated distribution of the eNPV is found. This gives an indication of how sensitive the project value is to the market movements which is not captured by the value tree. Also, the random walks are conducted using forward simulation why the decisions become path dependent. Recall that backward induction implies that a change in the value tree voids the future values. A random walk, on the contrary, describes a possible



(a) Expansions (b) Delay

(c) Expansions (d) Delay

Figure 6.2: Random walk simulations for the expansion scenario and the delay scenario. Paths are shown in (a) and (b). In (c) and (d) are the estimated distributions for eNPV for the two scenarios. Light gray indicates value is below zero and dark gray indicates value is above the mean value, $\overline{\text{eNPV}}$.

path, where a change in value (for example due to an implementation of an option) affect future values and decisions.

The values at the end of the paths are the present value of the project given the specific path (market development). The eNPV calculated from the value tree with backward induction is the expected return of the project weighting the possible outcomes together with their probabilities. The mean value from the random walk simulation should therefore match this value. A perfect match is only obtained when performing infinitely many random walks but even for a smaller number of trails the idea can be used to verify the simulation.

By subtracting the initial investment cost from the simulated values and plot the results an estimation of the distribution of eNPV can be obtained. The estimated distribution is a good indication of the spread of the possible project outcomes. In Figure 6.2a and Figure 6.2b the paths for 100 random walks are illustrated for the expansion scenario and the delay scenario, respectively. These 100 paths are taken

Table 6.1: Summary of the results from the random walks.

Scenario	**Mean**	**Median**	**P(eNPV > 0)**	**P(eNPV > $\overline{\text{eNPV}}$)**
Expansion	663 MSEK	484 MSEK	87 %	38 %
Delay	489 MSEK	333 MSEK	82 %	38 %

evenly distributed from a simulation with 100'000 random walks. The shaded gray area in the background is the asset tree for the project life time. Note that the extremes of the tree is left out since no paths reaches these regions. A further note is that all values are given in present values for the project start, $t = 0$. Histograms of the eNPV for a simulation of 100'000 random walks are depicted in Figure 6.2c and Figure 6.2d.

From the random walk simulation several properties of the distribution of eNPV can be deduced. An important number is the probability that the project returns a positive eNPV. This is not captured in the value tree where only the expected value of eNPV is obtained. Measuring how large part of the samples result in a positive eNPV gives a good estimate of this number. As shown in Figure 6.2c and 6.2d, the probability is 87 % for the expansion scenario and 82 % for the delay scenario. Thus, it can be concluded that the delay scenario is more likely to generate a negative eNPV than the expansion scenario. Note that this does not contradict the result from the sensitivity analysis on the natural gas price presented in Figure 6.1b and 6.1c. The negative eNPV is caused by different reasons. In the first analysis the low eNPV is due to a low natural gas price at the *project start* while in this case the low eNPV is due to a decrease of the natural gas price *over time*. Which analysis is the most important to consider depends on the circumstances.

An additional property of interest is the probability that the eNPV is larger than the expected eNPV (estimated by the average value of the random walks). The histograms for the random walks show that the means and medians are not obtained for the same value, in fact the median is significantly lower for both scenarios. Hence, the probability to obtain an eNPV larger than the expected eNPV is less than one half. This in turn implies the existence of a few random walks resulting in a very large eNPV. The eNPV calculated with backward induction in the value tree does not reveal how likely it is to obtain a value larger than the expected eNPV. By measuring the number of samples larger than the mean value the probability for this can be estimated. It is calculated to 38 % for both scenarios. Hence, almost two third of the random walks yielded an eNPV below the expected eNPV for both scenarios. With this in mind, it becomes obvious that the expected eNPV is amplified by a set of very large outliers, which might not be very realistic. In a more careful analysis the expected value should therefore be reduced in order not to over estimate the project value.

A summary of the indicators is presented in Table 6.1. $\mathrm{P}\left(\text{eNPV} > 0\right)$ is the probability that a scenario will return a positive eNPV and $\mathrm{P}\left(\text{eNPV} > \overline{\text{eNPV}}\right)$ is the probability for an eNPV larger than the average eNPV, denoted $\overline{\text{eNPV}}$.

7 Discussion

Real Option Analysis is an optimisation of the expected cash flows for an investment, similar to option analysis where the time series of the underlying stocks are the value drivers. Therefore, in the final value tree combining all available options, the expected cash flows are maximised. Further, the most profitable decision is taken at each state. Such a decision making might be a valid assumption when analysing an isolated investment in a single company; as has been shown by numerous previous studies. However, in an industrial cluster the most economically profitable decision is not always the most desirable. Involvement of several companies increases the complexity of the decision processes and the risk handling. The logical decisions, assumed by the ROA model, might impose a large risk for a company not directly benefited by the same investment. This company, if powerful enough, can therefore steer the project in a sub-optimal direction or even shut it down. Also, the logical decision might not be taken due to narrow time windows. When several companies must collaborate, the built in inertia can lead to missed opportunities for exercising an option. Hence it is valuable to consider also the (economically) sub-optimal strategies.

The scenario chosen by ROA is the most profitable scenario, yielding the largest eNPV and thereby the largest real option value. As discussed in 6.1, *Impact of Uncertainties on ROV*, the most profitable scenario is a combination of the expansion scenario and the delay scenario. Recall that given the initial natural gas price of 406 SEK/MWh, the expansion scenario gives more or less the same eNPV as the combined scenario. This is since the delay scenario only has a minor effect on the eNPV for this initial natural gas price.

By intentionally choosing the delay scenario over the combined scenario the complexity of the project is reduced to the cost of a decreased profit. The character of this investment, with the six year time window opportunity due to the cracker maintenance stops, indicates that it might be wise to split the investment into two stages. The main advantage with the identified delay scenario is that only the two main actors, Borealis and Perstorp, are involved in the investment at the first cracker stop. Delaying the last investment of the base investment, *IS4 – Hot water system 79°C*, would also postpone the involvement of INEOS. This is crucial since it is still unknown if INEOS will receive a chlorine production permit for the coming years. If not they will no longer have the capability to be a partner of the utility system in the same scale as assumed in this thesis. By avoiding an early involvement of INEOS the risk of the project is reduced.

The difference between the real option value for the delay and expansion scenarios can be interpreted as a premium. This is the premium the Cluster has to pay for reducing the project complexity and choosing a more defensive strategy. The premium (p_{LC} = premium for lower complexity) is found to be

$$p_{\mathrm{LC}} = \mathrm{ROV}_{\mathrm{Expansion}} - \mathrm{ROV}_{\mathrm{Delay}} = 276 - 99 = 177\,\mathrm{MSEK}. \tag{7.1}$$

It has been suggested that a third part makes the utility system investment and distribute the fuel and steam among the companies in the Cluster. This strategy have several positive implications such as; each company would only contract the third part instead of all companies in the Cluster and the risk is taken by the profiting actor. By letting the investor take part of the ROA, the identified options and decision strategies can be used to find a business model that all parts agree on and are comfortable with. The structuring and identification process of ROA could further aid the third part with the identified involvement of the companies and the possible flexibility in the project.

Unfortunately for the third part, ROA does not model changes in the cluster companies' markets. Yearly running hours are modelled with a probability distribution but the actions of a company are not considered in the model. All companies are assumed to have the same yearly production rate no matter how the market evolves. This is not necessarily true. If a company's market changes it might affect the savings obtained from the integrated utility system. As a worst case scenario a company has to shut down partly or entirely, decreasing the utility system or even make it useless. On the other hand, if a company's market goes up an expansion of the production site might be realised and further expansion options might appear. Also, it is not very likely that all companies within the cluster will have the same product portfolio and running the same processes in the future. This is a further motivation why the project life time is limited to 15 years.

The entire analysis is conducted assuming today's natural gas price and the estimations of the investment costs given in today's monetary value. However, the project start is assumed to take place at year 2019. This does not imply any errors since no money has to be secured for the project today. The shift of "year zero" with six years is thus only a shift in time which implies that the value should be compounded and discounted six years in each direction resulting in the same value. The money required for the project in six years can be used within other projects until then, why no opportunity costs have to be considered for these years. As was concluded in the sensitivity analysis, the impact from the volatility on the project value is vanishingly small. Thus a reasonable change in the natural gas market does not affect the model as long as the average price is not changed. If the average natural gas price is changed within these six years, the sensitivity analysis reveals how the project value is affected.

A final remark is that the two options not treated in this thesis, the abandonment and the first contraction option, were identified to highlight the possibility and flexibility in the ROA framework. These would have had a practical value if the investment were spread over a longer time horizon. If this had been the case, a reaction to a bad market development would have been the exercise of either the contraction or the abandonment option. Exercising either of these options could also be a reaction to internal events such as an early evaluation of the collaboration between the two main actors.

8 Concluding Remarks

This thesis contributes with the

- Identification of investment scenarios for the integrated utility system.
- Insight of how Real Option Analysis can be utilised to structure an investment and value different strategies within an industrial cluster.

Two distinct scenarios, an expansion and a delay scenario, and a combination scenario has been identified. The combination scenario is the most profitable for a natural gas price in the interval 160-300 SEK/MWh. For prices above this interval the expansion scenario is adequate and below these limits the delay scenario is adequate. The expansion scenario is more aggressive and generates a higher expected present value of the project given the initial natural gas price of 406 SEK/MWh. However, it comes with the price of a higher complexity and requires a higher degree of collaboration within the Cluster in the early stage of the project. The delay scenario renders in a lower expected present value of the project but reduces the complexity of the project significantly compared to the expansion scenario. The premium for intentionally choosing the delay scenario is calculated to 177 MSEK. It also provides the opportunity to evaluate the collaboration before involving more than the two main actors Borealis and Perstorp. The involvement of INOES is thereby postponed which due to the uncertainty of their chlorine production permit can be desirable.

When undertaking an investment in an industrial cluster, achieving the most profitable solution is not always the main objective. It can also be the fulfilment of a sustainability vision. Since ROA is an optimisation of the underlying cash flows it will always maximise the economical benefits, regardless of positive effects from other strategies that cannot be expressed in economical profit. Despite this limitation the ROA framework offers a process for identification of economical and technical independent parts of the project which displays the companies' involvement per part. If the set of available options is split into subsets, several scenarios can be modelled and simulated. Utilising the ROA framework, the scenarios can be compared and evaluated properly. Finally, the premium for choosing a less profitable strategy can be calculated and valued.

8.1 Future Works

Interesting subjects for future work has been identified as

- An investigation of the impact of changes in properties of the identified real options.
- Modelling of the companies markets as part of a modified ROA for a third actor investment.

A more thorough analysis of the impact of the properties on the identified real options to investigate the importance of an accurate estimate of investment costs and potential energy savings. This would aid in the decision process by identifying which sub-projects are most important to estimate correctly. Such an analysis would allow project prospecting hours to be spend more efficiently.

For a third part, ROA does not model changes in the cluster companies' markets. Production levels are modelled with probability distribution but the actions of an actor are not considered in the model. If a company's market changes it might affect savings obtained from the integrated utility system. As a worst scenario, a company has to shut down partly or entirely leave the utility system. On the other hand, if a company's market goes up an expansion of the production site might be realised and further expansion options might appear. A more advanced ROA where these market movements are modelled in parallel is an interesting topic for future research.

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A Software Implementation

A.1 Main Routine with Function Calls

```
% Main program with function calls

clear variables
close all
clc


%% Import Excel file
excelFile           = 'Options.xlsm';
opt                 = readOptions(excelFile);
n                   = opt.lt/opt.dt;
dt                  = opt.dt;
rh                  = 8400*ones(1,n);
rh(opt.t <= 1.5)    = 0;              % no incomes until Q2 2021
price               = 406e-6*ones(1,n);
om                  = 0.03*ones(1,n);
om(opt.t <= 1.5)    = 0;              % no o&m until Q2 2021

% Overrun pv with pv based on the actual discretisation
opt.pv              = npv(dt,dt*rh,price,om*dt);


%% S-tree
[S pu]       = treeS(opt.pv,opt.sig,opt.rf,opt.T,opt.dt);
[Sd pud]     = treeS(opt.pv,opt.sig,opt.rf,opt.T,opt.dt,...
    opt.available(15,:),opt.option(15).ddiv);
opt.pu       = pu;


%% V-trees
% contraction
con              = opt;
con.option       = con.option(1:3);
con.available    = con.available(1:3,:);
[Vc Oc]          = treeV(S,pu,con);
% expansion1
exp1             = opt;
exp1.option      = exp1.option(4:6);
exp1.available   = exp1.available(4:6,:);
[Ve1 Oe1]        = treeV(S,pu,exp1);
% expansion2
exp2             = opt;
exp2.option      = exp2.option(7:8);
exp2.available   = exp2.available(7:8,:);
[Ve2 Oe2]        = treeV(S,pu,exp2);
% exp1 + exp2
Oe12             = Oe1;
for k = 1:1:size(Oe1,2)
    for l = 1:1:k
        if ~strcmpi(Oe2{l,k},'base')
            Oe12{l,k} = Oe2{l,k};
        end
    end
end
Ve12             = Ve1 + Ve2 - S;
% defer
def              = opt;
def.option       = def.option(9:15);
def.available    = def.available(9:15,:);
[Vd Od]          = treeV(Sd,pu,def);


% Plot results
```

```
%% Value trees
% contraction
plotTree(S,Vc,opt.t,opt.y0);
% expansion1
plotTree(S,Ve1,opt.t,opt.y0);
% expansion2
plotTree(S,Ve2,opt.t,opt.y0);
% exp1 + exp2
plotTree(S,Ve1+Ve2-S,opt.t,opt.y0);
% delay
plotTree(Sd,Vd,opt.t,opt.y0);


%% Manual patch plot of V
%V        = Ve12;
%Ss       = S;
V        = Vd;
Ss       = Sd;
t        = opt.t + opt.y0 - (opt.t(2)-opt.t(1))/2;
patchT   = [t,t(end:-1:1)];
patchSt  = zeros(2,size(Ss,2)-1);
patchVt  = patchSt;
for k = 2:1:size(Ss,2)
    patchSt(:,k-1)  = [Ss(1,k);Ss(k,k)];
    patchVt(:,k-1)  = [V(1,k);V(k,k)];
end
patchS   = [Ss(1,1),patchSt(1,:),patchSt(2,end:-1:1),Ss(1,1)];
patchV   = [V(1,1),patchVt(1,:),patchVt(2,end:-1:1),V(1,1)];

figure
set(gca,'yscale','log')
hold on

p1 = patch(patchT,patchS,[1 .1 .1],'edgecolor','none');
p2 = patch(patchT,patchV,[.1 .1 1],'edgecolor','none','facealpha',0.25);

% Plot years
x    = get(gca,'xlim');
y    = get(gca,'ylim');
for k = x(1):1:x(2);
    plot([k k],y,'--','color',[.2 .2 .2],'linewidth',0.5)
end

% Zero market development
plot(x,[S(1,1) S(1,1)],'-.k')

% Add labels
xlabel('Year')
ylabel('PV [MSEK]')

% Set y-axis
ylim([0.75*min(min(S)) 1.1*max(max(max(S)),max(max(V)))])

% Nicer figure
set(gca,'xticklabel',[])
years    = get(gca,'xtick');
xx       = years(1:end-1) + diff(years)/5;
years    = years(2:end);
for k = 1:1:length(years)
    text(xx(k),0.9*min(min(S)),num2str(years(k)));
end



%% Decision trees
oList           = {opt.option.name};
% contraction
plotOption(S,Oc,opt.t,opt.y0,oList);
% expansion1
```

```
plotOption(S,Oe1,opt.t,opt.y0,oList);
% expansion2
plotOption(S,Oe2,opt.t,opt.y0,oList);
% exp1 + exp2
plotOption(S,Oe12,opt.t,opt.y0,oList);
% defer
plotOption(Sd,Od,opt.t,opt.y0,oList);



%% RANDOM WALKS

% Enlarges S-trees to entire lifetime
[Slong pu]        = treeS(opt.pv,opt.sig,opt.rf,opt.lt,opt.dt);
available         = zeros(1,size(Slong,2));
available(1:length(opt.available(9,:))) = opt.available(9,:);
ddiv              = opt.option(9).ddiv;
[Sdlong pud]      = treeS(opt.pv,opt.sig,opt.rf,opt.lt,opt.dt,...
    available,ddiv);

% Fix O to match lifetime
Oe12long                                  = cell(size(Slong));
Odlong                                    = Oe12long;
[Oe12long{logical(triu(ones(size(Slong))))}]  = deal('base');
Oe12long(1:size(Oe12,1),1:size(Oe12,2))   = Oe12;
[Odlong{logical(triu(ones(size(Sdlong))))}]   = deal('base');
Odlong(1:size(Od,1),1:size(Od,2))         = Od;


% Monte Carlo simulation

% Choose expansion 1+2...
Swalk    = Slong;
Owalk    = Oe12long;
% ...or delay
% Swalk    = Sdlong;
% Owalk    = Odlong;

I0       = 559.5;                         % initial layout
nrw      = 50000;                         % number random walks
walk     = zeros(nrw,size(Swalk,2));      % the walks
for k = 1:1:nrw
    walk(k,:) = randomWalk(Swalk,Owalk,opt);
end

% Exract values/properties of distribution
disp([' '])
disp(['min:     ',num2str(min(walk(:,end)))])
disp(['max:     ',num2str(max(walk(:,end)))])
disp(['mean:    ',num2str(mean(walk(:,end)))])
disp(['median:  ',num2str(median(walk(:,end)))])

% Plot histogram
[nr xr] = hist(walk(:,end),100);
figure
bar(xr-I0,nr/nrw*100);
xlim([-600 4000]);
xlabel('NPV [MSEK]')
ylabel('Probability [%]')
xpos     = diff(get(gca,'xlim'))*[.5 .65];
ypos     = diff(get(gca,'ylim'))*[.9 .83 .76 .69];
text(xpos(1),ypos(1),'Mean:')
text(xpos(2),ypos(1),sprintf('%4.0f MSEK',mean(walk(:,end)) - I0))
text(xpos(1),ypos(2),'Median:')
text(xpos(2),ypos(2),sprintf('%4.0f MSEK',median(walk(:,end)) - I0))


% Pick a subset of walks for plotting
[~,sortInd]       = sort(walk(:,end));
walkS             = walk(sortInd,:);
```

```
ss              = 100;
id              = [1,round(linspace(2,nrw-1,ss-2)),nrw];
walkP           = walkS(id,:);
[~,sortInd]     = sort(walkP(:,end));
walkP           = walkP(sortInd,:);
col             = flipud(jet(10));

% Plot random walks
figure
kk  = 1;
t   = 0:opt.dt:opt.dt*(size(Swalk,2)-1);
t   = t + opt.y0 - (opt.t(2)-opt.t(1))/2;
for k = round(linspace(1,ss-10,10))
    semilogy(t(1:2:end),walkP(k:k+9,1:2:end),'color',col(kk,:));
    hold on
    kk = kk + 1;
end

% Set y-axis
ylim([0.75*min(min(S)) 1.1*max(max(S))])

% Plot years
x   = get(gca,'xlim');
y   = get(gca,'ylim');
for k = x(1):1:x(2);
    plot([k k],y,'--','color',[.2 .2 .2],'linewidth',0.5)
end

% Zero market development
plot(x,[S(1,1) S(1,1)],'-.k')

% Add labels
xlabel('Year')
ylabel('PV [MSEK]')

% Nicer figure
set(gca,'xticklabel',[])
years   = get(gca,'xtick');
xx      = years(1:end-1) + diff(years)/5;
years   = years(2:end);
for k = 1:1:length(years)
    text(xx(k),0.9*min(min(S)),num2str(years(k)));
end

% Add tree surface
tpatch  = [t(1), t(end), t(end), t(1)];
spatch  = [Slong(1,1),Slong(1,end),Slong(end,end),S(1,1)];
patch(tpatch,spatch,[.9 .9 .9],'edgecolor','none')

set(gca,'children',flipud(get(gca,'children')))
```

A.2 Monte Carlo Simulation

```
function [] = monte()
%MONTE performs a Monte Carlo simulataion to obtain the project volatility
%
%   [] = MONTE()
%
%
%   Copyright 2013 - Andreas Furberg, Mattias Haggaerde

I0      = 559.5;

% Inputs to NPV
T       = 16;
dt      = 1;
n       = T/dt;

% Running hours from normal distribution
muH     = 8400;
sigmaH  = 120;

% Gas price from lognormal distribution
gasMean = 406e-6;
data    = [24.33    24.3    22.05   23.31   25.73   26.45   28.89   28.24...
    25.43   32.15   32.11   27.15   22.92   22.99   19.09   12.87   11.81...
    11.36   10.89   9.49    9.13    10.18   12.83   11.85   11.88   13.62...
    13.46   11.89   13.07   16.4    19.04   19.72   18.65   18.75   19.06...
    19.65   23.11   22.68   21.73   24.19   23.71   23.16   22.87   21.96...
    22.43   25.85   25.71   24.92   23.28   22.19   23.92   24.68   24.73...
    24.38   23.7    24.27   24.78   25.63   26.98   27.4    27.66   26.86...
    25.97   26.79   27.04];
data    = data / mean(data) * gasMean;
mus     = lognfit(data);
mu      = mus(1);
sigma   = mus(2);

% O&M cost from uniform distribution
ma      = 0.045;
mi      = 0.010;


% Monte Carlo simulation
N   = 100000;
pv0 = zeros(1,N);
pv1 = pv0;
for k = 1:1:N

    % First run

    % Running hours
    runH                    = dt*normrnd(muH,sigmaH,[1,n]);

    % Gas price
    gas                     = lognrnd(mu,sigma,[1,n]);
    gas(gas>2*gasMean)      = 2*gasMean;        % Remove extremes

    % O&M
    om                      = dt*((ma-mi)*rand(1,n) + mi);

    % NPV
    [pv0(k),~]              = npv(dt,runH,gas,om);

    % Second run

    % Running hours
    runH                    = dt*normrnd(muH,sigmaH,[1,n]);

    % Gas price
```

```
    gas                     = lognrnd(mu,sigma,[1,n]);
    gas(gas>2*gasMean)      = 2*gasMean;        % Remove extremes

    % O&M
    om                      = dt*((ma-mi)*rand(1,n) + mi);

    % NPV
    [~,pv1(k)]              = npv(dt,runH,gas,om);

end

r       = log(pv1./pv0);
rbar    = mean(r)
sigma   = std(r)
sigmay  = sigma*sqrt(1/dt)

% r
rp = r;
figure
[nh xout]    = hist(rp,100);
bar(xout*100,nh/N*100,'edgecolor','b','facecolor','b')
xlabel('Rate of return [%]'),ylabel('Probability [%]')
xpos    = get(gca,'xlim');
xpos    = xpos(1) + diff(xpos)*[.7 .85];
ypos    = get(gca,'ylim');
ypos    = ypos(1) + diff(ypos)*[.9 .83 .76 .69 .62];
text(xpos(1),ypos(1),'Mean:')
text(xpos(2),ypos(1),sprintf('%4.1f %%',mean(rp*100)))
text(xpos(1),ypos(2),'Median:')
text(xpos(2),ypos(2),sprintf('%4.1f %%',median(rp*100)))
text(xpos(1),ypos(3),'\sigma:')
text(xpos(2),ypos(3),sprintf('%4.1f %%',std(rp*100)))

% NPV
figure
npv1        = pv0 - I0;
[nn xxout]  = hist(npv1,100);
bar(xxout,nn/N*100,'edgecolor','b','facecolor','b')
xlabel('NPV_0 [MSEK]'),ylabel('Probability [%]')
xpos    = get(gca,'xlim');
xpos    = xpos(1) + diff(xpos)*[.65 .8];
ypos    = get(gca,'ylim');
ypos    = ypos(1) + diff(ypos)*[.9 .83 .76 .69];
text(xpos(1),ypos(1),'Mean:')
text(xpos(2),ypos(1),sprintf('%4.0f MSEK',mean(npv1)))
text(xpos(1),ypos(2),'Median:')
text(xpos(2),ypos(2),sprintf('%4.0f MSEK',median(npv1)))

% Check NPV > 0
[m s] = normfit(npv1);
m/s

end
```

A.3 NPV

```
function [pv0 pv1 cpv] = npv(dt,runH,gas,om,r)
%NPV computes the present value at t = 0 and t = dt to be used for
%computing the volatility with a Monte Carlo simulation.
%
%   [pv0 pv1 cpv] = NPV(dt,runH,gas,om)
%
%   INPUTS:
%   dt       - Time step size
%   runH     - Running hours per time step vector
%   gas      - Gas price per time step vector
%   om       - O&M cost per time step vector as % of I_0
%   r        - Hurdle rate
%
%   OUTPUT:
%   pv0      - Present value at t = 0
%   pv1      - Present value at t = dt
%   cpv      - Cumulative present value
%
%   Copyright 2013 - Andreas Furberg, Mattias Haggaerde


% Input for manual run
% T        = 16;
% dt       = 1;
% n        = T/dt;
% runH     = dt*8400*ones(1,n);
% gas      = 406e-6*ones(1,n);
% om       = dt*0.03*ones(1,n);


% Parameters
nt               = length(runH);
T                = nt*dt;
t                = dt:dt:T;
%r               = 0.12;
mw               = 50;
I0               = 559.5;
tax              = 0.22;
dep              = zeros(1,nt);
depT             = 10;
dep(1:depT/dt)   = I0/(depT/dt);

% Discount factors
disc             = exp(-r*t);


% Cash flows
% ==============================

% No incomes the firs periods (until Q3 2021)
runH(t <= 1.5)   = 0;


% No O&M the first periods
om(t <= 1.5)     = 0;

% Adjust for yearly counting
if dt == 1
    runH(2)      = runH(2)/2;
    om(2)        = om(2)/2;
end

% Revenues
in1      = mw*runH.*gas;
% Due to depreciation
in2      = tax*dep;
```

```
% O&M
out     = I0*om;

% Sum up FCF
fcf     = in1 + in2 - out;

% Discounted FCF
dfcf    = fcf.*disc;

% PV0, PV1 and cumulative PV
pv0     = sum(dfcf);
pv1     = pv0/disc(1);
cpv     = cumsum(dfcf);

end
```

A.4 Read Option Data from Excel

```
function opt = readOptions(file)
%READOPTIONS read the time frame, time step size and options from the
%Excel-template and return a structure to be used in the ROA.
%
%   opt = READOPTIONS(file)
%
%   INPUTS:
%   file     - input file name
%
%   OUTPUT:
%   opt      - Options structure
%
%
%   Copyright 2013 - Andreas Furberg, Mattias Haggaerde



% Read input file
% file              = 'Options.xlsm';
[~,~,data]       = xlsread(file,'MATLAB','C7:Q43');

% Base investment: 2-10, Additional investment: 12:20 (end)
% rows
indOpt           = 1:21;
% columns
indName          = 1;
indStE           = 2:5;
indExp           = 7:8;
indCon           = 10:11;
indDef           = 13:15;


% Set common parameters
opt.y0                   = data{35,2};          % project start
opt.dt                   = data{31,8}/12;       % time step
opt.T                    = data{32,8};          % options life time
opt.t                    = 0:opt.dt:opt.T;      % time vector
opt.rf                   = data{25,8};          % risk neutral rate
opt.sig                  = data{26,8};          % volatility
opt.pv                   = data{27,8};          % present value
opt.lt                   = data{37,2};          % total lifetime
% available options
opt.available            = false(length(indOpt),length(opt.t));

%In t, 0 indicates end of y0, 1 indicates last period of year1 and so on...


% Initialize option fields
opt.option.name          = '';          % option name
opt.option.type          = '';          % option type
opt.option.start         = [];          % option exercise start time
opt.option.end           = [];          % option exercise end time
opt.option.ef            = [];          % expansion factor
opt.option.ec            = [];          % expansion cost
opt.option.cf            = [];          % contraction factor
opt.option.cg            = [];          % contraction gain
opt.option.df            = [];          % defer factor
opt.option.ddiv          = [];          % yearly dividend rate
opt.option.dc            = [];          % defer cost
opt.option.det           = [];          % defer exercise time
opt.option.dexp          = [];          % defer expiration



% Set options
for k = indOpt
```

```
    opt.option(k).name          = data{k,indName};
    opt.option(k).start         = data{k,indStE(1)} - (opt.y0+1) + ...
        data{k,indStE(2)}/4;
    opt.option(k).end           = data{k,indStE(3)} - (opt.y0+1) + ...
        data{k,indStE(4)}/4;
    opt.available(k,:)          = logical((opt.t >= opt.option(k).start)...
        .* (opt.t <= opt.option(k).end));

    if ~isnan(data{k,indExp(1)})
        opt.option(k).type      = 'expansion';
        opt.option(k).ef        = data{k,indExp(1)};
        opt.option(k).ec        = data{k,indExp(2)};
    elseif ~isnan(data{k,indCon(1)})
        opt.option(k).type      = 'contraction';
        opt.option(k).cf        = data{k,indCon(1)};
        opt.option(k).cg        = data{k,indCon(2)};
    elseif ~isnan(data{k,indDef(2)})
        opt.option(k).type      = 'defer';
        opt.option(k).df        = data{k,indDef(1)};
        opt.option(k).ddiv      = data{k,indDef(2)};
        opt.option(k).dc        = data{k,indDef(3)};
        opt.option(k).det       = opt.option(k).start;
        opt.option(k).dexp      = opt.option(k).end;
    else
        opt.option(k).type      = '';
    end

end


% Remove empty rows
for k = fliplr(1:size(opt.available,1))     % remove from the end
    if ~any(opt.available(k,:))
        opt.available(k,:)  = [];
        opt.option(k)       = [];
    end
end



end
```

A.5 Payoff functions

A.5.1 Expansion

```
function val = expansion(St,ef,ec)
%EXPANSION computes the value of the expansion option.
%
%   val = EXPANSION(St,ef,ec)
%
%   INPUTS:
%   St       - Asset value
%   ef       - Expansion factor
%   ec       - Expansion cost
%
%   OUTPUT:
%   val      - Value
%
%
%   Copyright 2013 - Andreas Furberg, Mattias Haggaerde

val = ef*St - ec;

end
```

A.5.2 Contraction

```
function val = contraction(St,cf,cg)
%CONTRACTION computes the value of the contraction option.
%
%   val = CONTRACTION(St,cf,ci)
%
%   INPUTS:
%   St       - Asset value
%   cf       - Contraction factor
%   cg       - Contraction gain
%
%   OUTPUT:
%   val      - Value
%
%
%   Copyright 2013 - Andreas Furberg, Mattias Haggaerde

val = cf*St + cg;

end
```

A.5.3 Delay

```
function val = defer(St,df,dc)
%DEFER computes the value of the defer option.
%
%   val = DEFER(St,df,dc)
%
%   INPUTS:
%   St       - Asset value
%   df       - Defer factor (cf expansion factor)
%   dc       - Defer cost (cf expansion cost)
%
%   OUTPUT:
```

```
%    val       - Value
%
%
%    Copyright 2013 - Andreas Furberg, Mattias Haggaerde

val = df*St - dc;

end
```

A.6 Plot Tools

A.6.1 Plot Value Tree

```
function h = plotTree(S,V,t,y0)
%PLOTTREE plots the asset tree and the value tree for comparison.
%Logarithmic y-axis.
%
%   h = PLOTTREE(S,V,t,y0)
%
%   INPUTS:
%   S        - Asset tree
%   V        - Value tree
%   t        - Time vector
%   y0       - Year 0
%
%   OUTPUT:
%   h        - Figure handle
%
%
%   Copyright 2013 - Andreas Furberg, Mattias Haggaerde


% Open figure
h   = figure;
set(gca,'yscale','log')
hold on

% Time scale
dt  = (t(2) - t(1))/2;
t   = t - dt + y0;

% Plot tree nodes
semilogy(t,S','.r')
semilogy(t,V','ob')

% Plot years
x   = get(gca,'xlim');
y   = get(gca,'ylim');
for k = x(1):1:x(2);
    plot([k k],y,'--','color',[.2 .2 .2],'linewidth',0.5)
end

% Zero market development
plot(x,[S(1,1) S(1,1)],'-.k')

% Add labels
xlabel('Year')
ylabel('PV [MSEK]')

% Set y-axis
ylim([0.75*min(min(S)) 1.1*max(max(max(S)),max(max(V)))])

% Nicer figure
set(gca,'xticklabel',[])
years   = get(gca,'xtick');
xx      = years(1:end-1) + diff(years)/5;
years   = years(2:end);
for k = 1:1:length(years)
    text(xx(k),0.9*min(min(S)),num2str(years(k)));
end
end
```

A.6.2 Plot Decision Tree

```
function [pv0 pv1 cpv] = npv(dt,runH,gas,om,r)
%NPV computes the present value at t = 0 and t = dt to be used for
%computing the volatility with a Monte Carlo simulation.
%
%   [pv0 pv1 cpv] = NPV(dt,runH,gas,om)
%
%   INPUTS:
%   dt       - Time step size
%   runH     - Running hours per time step vector
%   gas      - Gas price per time step vector
%   om       - O&M cost per time step vector as % of I_0
%   r        - Hurdle rate
%
%   OUTPUT:
%   pv0      - Present value at t = 0
%   pv1      - Present value at t = dt
%   cpv      - Cumulative present value
%
%   Copyright 2013 - Andreas Furberg, Mattias Haggaerde


% Input for manual run
% T         = 16;
% dt        = 1;
% n         = T/dt;
% runH      = dt*8400*ones(1,n);
% gas       = 406e-6*ones(1,n);
% om        = dt*0.03*ones(1,n);


% Parameters
nt                = length(runH);
T                 = nt*dt;
t                 = dt:dt:T;
%r                 = 0.12;
mw                = 50;
I0                = 559.5;
tax               = 0.22;
dep               = zeros(1,nt);
depT              = 10;
dep(1:depT/dt)    = I0/(depT/dt);

% Discount factors
disc              = exp(-r*t);


% Cash flows
% ============================

% No incomes the firs periods (until Q3 2021)
runH(t <= 1.5)    = 0;


% No O&M the first periods
om(t <= 1.5)      = 0;

% Adjust for yearly counting
if dt == 1
    runH(2)       = runH(2)/2;
    om(2)         = om(2)/2;
end

% Revenues
in1      = mw*runH.*gas;
% Due to depreciation
in2      = tax*dep;
```

```
% O&M
out      = I0*om;

% Sum up FCF
fcf      = in1 + in2 - out;

% Discounted FCF
dfcf     = fcf.*disc;

% PV0, PV1 and cumulative PV
pv0      = sum(dfcf);
pv1      = pv0/disc(1);
cpv      = cumsum(dfcf);

end
```

A.7 Sensitivity Analysis

A.7.1 Sensitivity Analysis on Natural Gas Price

```
% Sensitivity Analysis for gas price

clear variables
clc


% Import Excel file
excelFile            = 'Options.xlsm';
opt                  = readOptions(excelFile);
optOrig              = opt;              % local copy of original
n                    = opt.lt/opt.dt;
dt                   = opt.dt;
price                = 406*ones(1,n);    % gas price
rh                   = 8400*ones(1,n);   % running hours
om                   = 0.03*ones(1,n);   % o&m cost
r                    = 0.12;             % hurdle rate
I0                   = 559.5;            % initial outlay

% Set the parameters to investigate
paraNam              = {'Gas Price';'O&M';'r_f';'r_h';'\sigma'};

% multiple parameters
vari                 = 0.5:0.025:1.5;          % 50% -- 150%
paraVal              = [406;0.03;0.02;0.12;0.134];

% only gas price
% vari                 = 40/406:20/406:600/406;
% paraVal              = 406;

for loopPara   = 1:1:length(paraVal)

    opt                  = optOrig;
    paraM                = repmat(paraVal,1,length(vari)).*...
        ones(length(paraVal),length(vari));
    paraM(loopPara,:)    = vari*paraVal(loopPara);

    for loopK = 1:1:length(vari)

        % Set the parameters
        price                = paraM(1,loopK)*1e-6*ones(1,n);     % MSEK
        if size(paraM,1) > 1
            om                   = paraM(2,loopK)*ones(1,n);
            opt.rf               = paraM(3,loopK);
            r                    = paraM(4,loopK);
            opt.sig              = paraM(5,loopK);
        end

        % Overrun pv with pv based on the actual discretisation
        opt.pv               = npv(dt,dt*rh,price,om*dt,r);




        % S-tree
        [S pu]       = treeS(opt.pv,opt.sig,opt.rf,opt.T,opt.dt);
        [Sd pud]     = treeS(opt.pv,opt.sig,opt.rf,opt.T,opt.dt,...
            opt.available(15,:),opt.option(15).ddiv);
        opt.pu       = pu;



        % V-trees
        % expansion1
        exp1             = opt;
```

```
        exp1.option      = exp1.option(4:6);
        exp1.available   = exp1.available(4:6,:);
        [Ve1 Oe1]        = treeV(S,pu,exp1);
        % expansion2
        exp2             = opt;
        exp2.option      = exp2.option(7:8);
        exp2.available   = exp2.available(7:8,:);
        [Ve2 Oe2]        = treeV(S,pu,exp2);
        % exp1 + exp2
        Oe12             = Oe1;
        for k = 1:1:size(Oe1,2)
            for l = 1:1:k
                if ~strcmpi(Oe2{l,k},'base')
                    Oe12{l,k} = Oe2{l,k};
                end
            end
        end
        Ve12             = Ve1 + Ve2 - S;
        oList            = {opt.option.name};
        %plotOption(S,Oe12,opt.t,opt.y0,oList);

        % defer
        def              = opt;
        def.option       = def.option(9:15);
        def.available    = def.available(9:15,:);
        [Vd Od]          = treeV(Sd,pu,def);

        % Combined tree
        combEnd          = find(strcmpi('defe-Exercise',Od(1,:)),1,'first');
        Sc               = 0*S(1:combEnd,1:combEnd);
        [Sc(:,end) ii]   = max([Ve12(1:combEnd,combEnd) ,...
            Vd(1:combEnd,combEnd)],[],2);


        comb             = opt;
        comb.t           = comb.t(1:combEnd);
        Vc               = treeV(Sc,pu,comb);

        % Extract values
        ROV(loopPara,loopK)      = Vc(1,1) - opt.pv;

        % Additional values for gas price analysis
        % eNPVc(loopPara,loopK)    = Vc(1,1) - I0;
        % eNPVe12(loopPara,loopK)  = Ve12(1,1) - I0;
        % eNPVd(loopPara,loopK)    = Vd(1,1) - I0;
        % NPV(loopPara,loopK)      = opt.pv - I0;

    end
end


% eNPVc
figure
hold on
plot(vari'*100,ROV')
legend(paraNam,'location','northwest')
ylabel('ROV [MSEK]')
xlabel('Variation')


%% Specific for the gas price only analysis

% eNPV
figure
hold on
plot(paraM(1,:)',[eNPVc(1,:)',eNPVe12(1,:)',eNPVd(1,:)',NPV(1,:)'])
plot([paraM(1,1) paraM(1,end)],[0 0],'--k')
legend('eNPVc','eNPVe12','eNPVd','NPV')
ylabel('NPV [MSEK]')
xlabel('Gas Price [SEK/MWh]')
```

```
% ROV
figure
hold on
plot(paraM(1,:)',[eNPVc(1,:)'-NPV(1,:)',eNPVe12(1,:)'-NPV(1,:)',...
    eNPVd(1,:)'-NPV(1,:)'])
plot([paraM(1,1) paraM(1,end)],[0 0],'--k')
legend('eNPVc','eNPVe12','eNPVd')
ylabel('ROV [MSEK]')
xlabel('Gas Price [SEK/MWh]')
```

A.7.2 Random Walk

```
function walk = randomWalk(S,O,opt)
%RANDOMWALK performs a random walk in the asset tree S.
% (Only a selected subset of the options are impemented.)
%
%   walk = randomWalk(S,O,opt)
%
%   INPUTS:
%   S       - Asset tree
%   O       - Option tree
%   opt     - Option struct
%
%   OUTPUT:
%   walk    - Project value for the RW
%
%   Copyright 2013 - Andreas Furberg, Mattias Haggaerde


% Initialise
oList       = {opt.option([6:9,12]).name};  % extract options to include in RW
pu          = opt.pu;                       % probability for up-movement
n           = size(S,2);                    % number of time steps
nt          = opt.T/opt.dt+1;               % number time steps, option life
t           = 0:opt.dt:opt.dt*(size(S,2)-1);% time vector
u           = exp(opt.sig*sqrt(opt.dt));    % up-movement factor
d           = 1/u;                          % down-movement factor
q           = 0;                            % divident rate for delay
dt          = opt.dt;                       % time step size
addT        = (opt.lt - opt.T)/opt.dt;      % additional time steps after T

% Which options are voided due to implementation of others
void                = false(length(oList));
% Steam expanison
void(1,[1,4,5])     = true;
% HTr expansion
void(2,[2,3,4,5])   = true;
void(3,[2,3,4,5])   = true;
% HW79 delay, exercise
void(4,[1,2,3])     = true;
% HW79 delay, implementation
void(5,[1,2,3,4,5]) = true;

% Random walk
down        = rand(1,n-1) > pu;     % up and down movement vector
h           = 1;                    % actual state
s           = zeros(1,n);           % path
s(1)        = S(1,1);               % assuming no available option in first node

visited     = zeros(1,6);

% Loop time
for k = 2:1:n

    % Update stage, market up or down
```

```
    if down(k-1)
        h       = h + 1;
        s(k)    = s(k-1)*d*exp(-q*dt);          % adjust for div
        %S(h,k)   = S(h-1,k-1)*d*exp(-q*dt);
    else
        s(k)    = s(k-1)*u*exp(-q*dt);          % adjust for div
        %S(h,k)   = S(h,k-1)*u*exp(-q*dt);
    end

    % Check if option is taken
    if strcmpi(O{h,k},['expa-',oList{1}])           % Steam expansion

        % Void options
        [oList{void(1,:)}]       = deal('used');
        % Compute path value
        s(k)                     = s(k) + S(h,k) * (opt.option(6).ef - 1) * ...
            (nt - k + addT + 1) / (nt - opt.option(6).end/opt.dt + 1 + addT) - ↩
            ...
            opt.option(6).ec * exp(-opt.rf*(sum(opt.available(6,:))-1)*opt.dt);

        visited(1)       = visited(1) + 1;

    elseif strcmpi(O{h,k},['expa-',oList{2}])   % Htr Borealis expansion

        [oList{void(2,:)}]       = deal('used');
        s(k)                     = s(k) + S(h,k) * (opt.option(7).ef - 1) - ...
            opt.option(7).ec;

        visited(2)       = visited(2) + 1;

    elseif strcmpi(O{h,k},['expa-',oList{3}])   % HTr Borealis Akzo AGA

        [oList{void(3,:)}]       = deal('used');
        s(k)                     = s(k) + S(h,k) * (opt.option(8).ef - 1) - ...
            opt.option(8).ec;

        visited(3)       = visited(3) + 1;

    elseif strcmpi(O{h,k},'defe-Exercise')      % HW79 Borealis Akzo AGA, ↩
        exercise date

        [oList{void(4,:)}]       = deal('used');
        q                        = opt.option(9).ddiv;

        % Adjust value for delay dividend
        s(k)                     = s(k)*exp(-q*dt);
        S(h,k)                   = S(h,k)*exp(-q*dt);

        visited(4)       = visited(4) + 1;

    elseif strcmpi(O{h,k},['defe-',oList{4}])       % H79 not build

        q                        = 0;
        s(k)                     = s(k) + S(h,k) * (opt.option(9).df - 1) - ...
            opt.option(9).dc;

        visited(5)       = visited(5) + 1;

    elseif strcmpi(O{h,k},['defe-',oList{5}])       % HW79, Steam, HTr all

        q                        = 0;
        s(k)                     = s(k) + S(h,k) * (opt.option(12).df - 1) - ...
            opt.option(12).dc;

        visited(6)       = visited(6) + 1;
    end
end

walk = s.*exp(-opt.rf*t);
end
```

B Excel Spreadsheet with Option Properties

Table B.1: Numerical values for option properties.

Options in the utility system investment in the Cluster

	Start time		End time		Expansion		Contraction		Defer		
Option Name	Year	Quarter	Year	Quarter	Factor	Cost	Factor	Gain	Factor	Yearly Div	Cost
Abandon	2020	2	2020	2			0.0000	.0 MSEK			
Contr.Fuel	2020	3	2020	3			0.5106	205.2 MSEK			
Contr.HW79	2020	4	2020	4			0.8241	167.3 MSEK			
IS5a	2021	3	2026	4	1.1289	60.2 MSEK					
IS5b	2021	3	2026	4	1.0387	27.5 MSEK					
IS5	2021	3	2026	4	1.1676	87.7 MSEK					
IS6a	2027	1	2027	1	1.1050	19.7 MSEK					
IS6	2027	1	2027	1	1.1400	37.1 MSEK					
Delay Cont.	2021	2	2027	2					0.9043	1.234%	-190.6 MSEK
HW79+Htr.BAA+St.INEOS	2021	2	2027	2					1.2567	1.234%	98.1 MSEK
HW79+Htr.BAA+St.Akzo	2021	2	2027	2					1.1720	1.234%	65.0 MSEK
Delay IS5-6	2021	2	2027	2					1.2930	1.234%	125.9 MSEK
HW79+Htr.B+St.INEOS	2021	2	2027	2					1.2228	1.234%	80.7 MSEK
HW79+Htr.B+St.Akzo	2021	2	2027	2					1.1380	1.234%	47.6 MSEK
HW79+Htr.B+St.INEOS-Akzo	2021	2	2027	2					1.2591	1.234%	108.5 MSEK

Investment	**Cost**
St.Pipe	177.5 MSEK
HW95	151.2 MSEK
Fuel	43.5 MSEK
HW79	187.3 MSEK
St.INEOS	59.8 MSEK
St.Akzo	27.3 MSEK
HTrB	19.5 MSEK
HTrBAA	36.6 MSEK

Additional Input	
Risk neutral rate	2.0%
Volatility	13.4%
Time resolution	1.00 months
Option time frame	8 years

	year	**quarter**
Cracker stop 1	2021	2
Cracker stop 2	2027	2

Time	
Project starts (year 0)	2019
Project ends (last year)	2035
Project life time	16
Depreciation factor	0.1243