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A real option approach to investments in an LNG-regasification plant

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Abstract

This thesis looks at the value of having the option to buy gas on the world Liquified Natural Gas-market rather than just relying on one distributor via pipeline. The world market for natural gas is characterized by rigid distribution methods and there is no short term flexibility of destination for the seller and almost no possibility for buyers to buy gas on a competitive market.

The investment is evaluated using real option analysis. The computational method for the valuation is Monte Carlo simulations and pipeline gas prices and Liquid Natural Gas prices will be modelled through stochastic modelling and the prices are assumed to be characterized by mean reversion and price convergence. The model will be developed following Yepes Rodríguez (2008) model of natural gas price progression. The main conclusion is that he value of investing in a regasification facility is found to be positive and that LNG regasification facilities a financially viable investments to diversify natural gas markets.

Abbreviations

Bcm - Billion Cubic Meters

LNG - Liquified Natural Gas

NPV - Net Present Value

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1 Introduction

1.1 Background

In 2016 when the topics of discussion surrounding energy is mostly about renewable energy, it might seem odd to dive in to the world of natural gas. But in 2015 23.8% of all primary energy consumption in the world came from natural gas. It is not green and it may be argued that it is unethical to use natural gas, but no matter what the argument might be it is still being extracted from the ground and consumed at a higher level than ever before (BP Statistical review, 2016).

Natural gas is a hydrocarbon gas mixture, mostly methane, that occurs naturally in many places around the world. It can be found at a number of different depths with varying difficulties of extraction. Natural gas sources are usually described as conventional or unconventional. Conventional gas reserves are found in relatively shallow pockets that can be drilled easily. Unconventional gas reserves are more expensive and harder to extract and include shale gas and coal bed methane. Shale gas was up until recently not financially viable to extract. With recent technological break throughs such as directional drilling and hydraulic fracturing technology, commonly knows as fracking, a lot of this shale gas is now more easily accessible and a financially viable to extract. This has led to a natural gas boom in the United States, with natural gas production soaring in the last decade and prices falling as a result.

The transportation of Natural gas from the well to consumer market can be done in a gaseous state through pipelines or in a liquid state by specially designed ships to overseas markets. And since natural gas is generally not consumed where it is extracted the developments in liquified natural gas (hereafter LNG) has opened up a whole new market, for both sellers and buyer.

1.2 LNG

LNG has been around for over a century and the first commercial facility for liquefaction of natural gas was completed in 1940 by the East Ohio Gas Company. After that the evolution of LNG was slow and mostly used for remote locations without pipeline connections. In the 1990's the industry started taking off and even more so in the new millennia. Today countries use it for both shaving peak energy loads and for base load supplies. A country like Japan, which have no pipeline connection supplying natural gas, rely solely on LNG to meet its natural gas demand. LNG transportation is generally less costly than pipeline transportation between places located further than 1,500 km with large off-shore pipelines and further than 3,000 km for large on-shore pipelines (von Hirschhausen et al., 2008).

1.3 World trade of gas and energy

In 2015 world consumption of natural gas amounted to 3468.3 billion cubic meters (hereafter bcm). About 70% of that consumption occurred in the country where it was extracted and exports were 1042.4 bcm. Out of the exports, 32.45% (338.3 bcm) was LNG delivered by tanker. (BP statistical Report 2016)

The supply chain for natural gas has for most of its history been characterized by bilateral long-term contracts with delivery through pipelines. This has been been done in order to cover the enormous cost of building the delivery infrastructure, pipelines. Pipelines have been necessary because under normal conditions natural gas have a relatively low energy density therefor other means of distribution were not financially viable. Oil and petroleum products can easily be loaded on to a ship or truck and be transported to virtually any place in the world because it is liquid at normal temperatures and has a high energy density. This results in excess natural gas reserves around the world and LNG can solve this problem.

A problem with most alternatives to oil based energy sources is the problem of easy and low cost/energy unit distribution and of a standardized quality of the product. This results in a lack of a liquid spot market and futures market where buyer and sellers can both buy and sell the physical product but also hedge against price fluctuations. Let’s take biomass for example, biomass can be a great source of clean energy both for electricity production and for central heating of cities and individual homes. However, biomass comes in a wide variety of different qualities. Differences in moisture content, energy content and sulphur levels just to name a few, mean that a standardized market do not occur and biomass is therefore mostly sold through bilateral contracts. Natural gas does not have the same problems as biomass with the variability of the quality of the product being the problem, but rather an infrastructure problem. Since transportation of natural gas has for a long time has mostly been done through pipelines, distributing countries have a monopoly power when the buyer does not have an alternative source of natural gas. This means that if you are a big buyer, Germany for example, you might have pipelines from multiple producers, Russia and Norway, and the market is exposed to competition. But if you are a small or isolated country, like the baltic countries, you don't have multiple options and the seller gets monopoly power. This becomes evident when observing import prices for European countries. The countries in the former eastern block, many of these countries have Russia as their only source of natural gas pay much higher prices than western countries. The Ukraine payed USD 427 in 2012 and the average price of gas paid by Gazprom’s clients in the EU was USD 385 (Kononczuk, 2015). Looking at the price difference between countries in Europe the import price of gas is in general higher in the eastern parts of Europe than in western Europe even though the gas has traveled further get to the west than to the east.

1.4 Lithuania - the energy independence project

In 2014 Lithuania decided to move towards LNG as a compliment to pipeline distribution from Russia's Gazprom. Lithuania decided to sign a 10 year leasing arrangement with a buy option, for a 290 meter ship acting as a Floating Storage and Regasification Unit, FSRU, and signed delivery contracts with Norwegian Statoil. The vessel has a high enough capacity to supply the entire baltic region with natural gas and pipelines between the countries are being upgraded to facilitate the increased trade in the region. Lithuania's contract with Gazprom expired at the end of 2015 but Lithuania saw a 20% reduction of their import prices from Russia even before this.

The Lithuanian action can serve as a good example of how LNG can be a way to disrupt monopolies. This might be the way for other countries dependent on a single supplier of natural gas to get a price reduction or to diversify their delivery sources and use the opportunities of lower priced gas from other sellers.

1.5 Investing

While looking at investment decisions a company or an individual may take many different approaches. But it all boils down to one question. Is the benefit greater than the cost? And if the benefit is greater then we invest. But that one question holds layers of complexity and at the core of all those layers rest the question of uncertainty. No matter how well we think we know the future or understand the probable outcomes, there is always some uncertainty about the outcome. In order to understand or to even grasp this uncertainty, investors have been using different methods ranging from gut feeling to Net Present Value (NPV) to complex real option valuations. The choice of method is based on the time available, knowledge of the investor and the size of the investment. More often than not this has been done by trying to estimate some kind of average situation in the future, whether it be the market price of a good or the demand for a service. Most investors understand that this is only an estimate of a likely outcome but the inability, in most methods, to take probability distributions and volatility in to account is often misleading (Trigeorgis, 1996).

In colleges and universities world wide the method of NPV has been the prevailing method taught for decades now. Net present value, the discounted future cash flows minus the initial investment, would be too blunt of a method to properly estimate the value of investing i a regasification plant. It would not be able to capture the volatile nature of natural gas prices and would give no idea about the the worst and best case scenarios or their probabilities.

Investing in an LNG regasification plant should be evaluated not through the common NPV-method, but should take into account the value of the option to switch between the LNG and pipeline. This option would be a multi-asset compound option, an option on options, an option on a spread option to be precise (Yepes Rodriguez, 2008. Copeland and Antikarov, 2003).

1.6 Options

The valuation and pricing of options was developed in the 1970's by Merton, Black and Scholes. The Black-Scholes formula is now widely used and taught in finance classes world wide. In the beginning the application was only used to price financial options where volatility was easily observable and prices publicly known.

The idea of an option is, like the name imply, that you have the option to invest or not to invest depending on the market condition. Options come in many ways, shapes and forms, but the general idea is that you have the right, but not the obligation, to buy or sell something at a certain price at a specific time ie., european option, or to buy or sell the underlying asset before a certain time i.e., american option. The right to buy is called a call option and to sell is called a put option.

The ground breaking paper by Black and Scholes was published in 1973 and the term ”real option” was later coined by Stewart Myers at MIT (Mitsloan.mit.edu, 2016). The concept of real options is very similar but the underlying asset is not a financial product but rather an investment in a tangible asset. If you are given the right, but not the obligation, to buy a house in one year at a pre-agreed price, the fundamental features of this deal are the same as a european call option and its value can be calculated in the same way. Since the first application of real options the way in which it is being used has expanded drastically and to this day there are a myriad of articles and papers written on the subject.

1.7 Aim

Are LNG regasification facilities a financially viable investment to diversify natural gas markets?

The question for this research is:

Are LNG regasification facilities a financially viable investment to diversify natural gas markets?

The research also aims to:

- Determine whether energy independence can be cheaper than energy dependence.

1.8 Outline

The rest of this thesis will be organized as follows. Section 2 will present the theory behind real options, describe different applications and discuss other valuation methods and their pitfalls. Section 3 will be the method part and will present the specific scenario to be studied, the model and collection of data. Particular attention will be given to the modelling of prices and the assumptions made will be discussed and motivated. A section on the ethical perspective will also be included. Section 4 will present the proposed model and the results. In section 5 an analysis of the results will be given and the results will be put in context, discussion of validity and provide ideas for future research on the subject.

2 Theory

2.1 Net Present Value

NPV is at the moment, and has been for a long time, the most common way to evaluate investment opportunities and is still the most commonly taught way of valuing an investment. The method relies on discounting all future cash flows to T=0 and then making a decision wether the investment is worth while. Common rule of thumb is that if the NPV is positive the investment should be carried out. NPV is calculated with the following formula:

$$NPV = -I_0 + \frac{CF_1}{1+r} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + ... + \frac{CF_T}{(1+r)^T} \tag{2.1}$$

$$NPV = \sum_1^T \frac{CF_i}{(1+r)^i} - I_0$$

Where I = Investment, CF = Cash Flow i the given period, r = Discount rate and T = time, duration of the project.

2.2 Problems with NPV

The allure of NPN is also its major shortcoming, you only have to estimate one scenario for the future cash flows. Given that future cash flows are dependent on a vast number of factors it is almost impossible to be certain that you have the right number. Even if you get a good estimate of the value of the investment there is no indication of the probability of a deviation from that scenario or any indication of the magnitude of that deviation. It is only a snapshot of a possible future outcome. The discount rate tries to account for some of that risk but still gives no understanding of the distribution of outcomes. The discount is composed of two parts, the risk free rate, usually given by government bonds interest rates plus a premium adjusting for the riskiness of the project considered. The riskier a project is the higher the discount rate is and given by the above formula the future cash flows need to be higher in order for the NPV to be positive. Another problem with NPV is that it does not take managerial flexibility in to account. Say that you are investing in a factory and halfway through the build you realize that the demand has increased so you expand the build to meet the new demand. Having the opportunity to do this obviously has value but how do you measure that? Using a NPV approach to the appraisal of an investment opportunity does not allow to properly consider the value attached to managerial flexibility and thats where the real option approach comes in.

2.3 Real Option Analysis

Real option can deal with some of the shortcomings of NPV without being too complex to comprehend. It is more complex than NPV but even at its most basic level provide more information than NPV without being too complex. Most investment opportunities has some kind of option built in to them. The option to abandon the investment or the option to expand or contract production depending on market conditions. Given that most investments has an element of optionality, real option analysis, ROA, can take in to account the value of this option or in some cases options. The literature is filled with applications and methods to cover almost all possible investment decision. There are three main ways of performing real option valuation. Binomial tree, Black-Scholes and Monte Carlo simulations.

2.3.1 Binomial Tree Approach

The binomial tree is the most basic method out of the three but can be expanded to the point were in converges with Black-Scholes. The method finds the option price by building a tree where the price can either go up or down with a given probability, usually the risk neutral probability. The option value is then calculated at the end nodes, where the value is its intrinsic value, the price of the asset minus the exercise price for a call option or zero, which ever is greater. Then the next step in the backward induction is to calculate the discounted, at the risk free rate, weighted average of the two end nodes, at time T, are connected to the node at T-1.

This is then replicated all steps of the tree and the price is the weighted average of the present value of the option all the way back to T=0.

2.3.2 Black-Scholes method

Black-Scholes method was introduces by Fisher Black and Myron Scholes in a 1973 paper that revolutionized the trading in options and derivatives. The model only requires one parameter that cannot be observed in the market, the future volatility of the underlying asset. This has made the model very popular and has been found to be reasonably close to the actual market prices for options. The adaptation for real options is not always as straight forward as for financial options given the lack of liquid markets for a lot of investments.

The Black-Scholes option pricing for the evaluation of a call-like option is as follows:

$$C = S * N(d_1) - K * e^{(-rt)} * N(d_2) \tag{2.2}$$

$$d_1 = \frac{\ln(S/K) + (r + s^2/2) * t}{s\sqrt{t}} \tag{2.3}$$

$$d_2 = d_1 - s\sqrt{t} \tag{2.4}$$

where,

C: call option price

S: current stock price

t: time to maturity

K: strike price

r: riskfree interest rate

N: cumulative standard normal distribution

s: future standard deviation of stock returns, volatility

As is shown by the formula, the main parameter that is can not simply be observed in the market is future volatility. Usually past volatility is assumed to be the same as future volatility. An assumption that might turn out to be very wrong.

One of the assumptions in Black-Scholes model is that the log prices follow a random walk which is normally distributed. There has been modifications to allow for a drift but if the probability distribution for the underlying asset has a different distribution Black-Scholes might not do you any good even with this modification.

2.3.3 Monte Carlo Simulation

Monte Carlo Simulation of option prices is the most ”free” method and does not demand a certain distribution of the variables. The option price is found by building a model for the price progression including at least one stochastic variable. The discounted profit function, including the stochastic variable, is simulated thousands of times to give an accurate mean and standard deviation. The profit function need to include the option, e.g. if prices are too low plant shuts down for a time period and variable cost and income will be zero for that time period. Given that you decide what the function looks like you can choose the stochastic variable to be drawn from any distribution that best matches the market condition of the asset. Previously this was an expensive method due to the fact that it demanded enormous computer capacity but with the developments in IT over the last decades theses simulations can be run with a standard computer and spread sheet-software.

The first use of the Monte Carlo method was presented in the 1940s by mathematician Stanislaw Ulam, working on nuclear weapons in the United States. The method was used to simulate the way neutrons moved through different materials. Since then Monte Carlo simulations has been used in almost every discipline dealing with quantitative research from physics, climate research, computer game development to economics and finance in order to simulate randomness.

In real option analysis Monte Carlo simulations are used to simulate a model in which at least one of the variables is stochastic, e.g prices or demand. When simulations are done, the average discounted future cash flows minus the initial investment are then seen as the value of the investment. Every investment has its own function for future cash flows and getting that function as precise as possible will in turn give the best result.

2.4 Literature Review

In writing this thesis the aim is to determine the value of investing in a facility for LNG regasification using real option analysis. The literature on options in general is vast and the application of real options has a history of extensive research. LNG on the other hand is relatively new and the literature is not as extensive as in other applications. This is in part due to the fact that data is hard to come by. The same thing can be said for the companies building the infrastructure to transport natural gas in all its forms.

The modern literature on options started with a paper by Black and Scholes (1973). *The Pricing of Options and Corporate Liabilities* set the foundation of which almost all option theory rests on (this paper has been cited over 30 000 times according to the science database jstor.com). In 1997 Myron S. Scholes was awarded the Nobel Memorial Prize in Economic Sciences for his contributions to option pricing, Fischer Black had passed away at this point.

This noteworthy and formative paper derives the formula for calculating the price of a European option. The Black-Scholes model made the trade in options and other derivative instruments legitimate investments and its importance can not be underestimated. Since the publication of this article a lot has happened and modifications have been done in order to adapt the fundamental formula to realistic market conditions.

The adaptations of the formula to valuate real option rather than financial options happened as early as in 1970 and in 1994 Dixit and Pindyck wrote the book *Investment under Uncertainty* on the subject. Dixit and Pindyck give a thorough overview of the method with both theory and practical examples. The application of option pricing models to price real world investments was a relatively new method at the time. The book goes through many types of real option situations, how to reason around the investment and the derivation of models. This book provides the mathematical derivations needed to move from the general case and apply it under specific circumstances. In 2003 Copeland and Antikorov wrote *Real Options, Revised Edition: A Practitioner's Guide.* The book is, as mentioned in the title, a practitioner's guide to real option analysis and gives a comprehensive overview of real options and in which settings it is applicable. The book goes through many of the same subjects as Dixit and Pindyck do in their book but is up to date on the latest development in the literature and has a more applied approach. They give a good explanation on the mindset of using real option and the ability to see options in places where it is not obvious. The book also illustrates the use of Monte Carlo-simulation for real option analysis that will be used to estimate the value of investing in this thesis.

The foundation for any option valuation is to make estimates for the future price of the underlying asset. For a traditional financial options this could be to estimate the price for a stock with vast amounts of historical data and an easily observable market price in the stock market. But in real option analysis this is often not the case. This thesis aims to valuate an investment in a LNG regasification facility and the main variables that affects profitability are the future price of LNG and the future price of pipeline gas, or rather the difference between the two. So to build the model one must integrate the stochastic movements of commodity prices. In Eduardo S. Schwartz's article *The Stochastic Behavior of Commodity Prices: Implications for Valuation and Hedging* this is done constructing and testing three different models for the stochastic behaviour of commodity prices. Schwartz set up three different models, a one-factor model, a two-factor model and a three-factor model and test them against historical prices of two commercial commodities, copper and oil, and one precious metal, gold. The author assumes a strong mean reverting trend for the two commercial commodities. The assumption of mean reversion is based on the fact that when the equilibrium price is relatively high, the supply will increase and drive prices down. And when the opposite is true when the equilibrium price is relatively low, the supply will decrease and drive prices up. The paper is mostly focused on pricing futures of theses commodities but as the author states *"The stochastic behaviour of commodity prices plays a central role in the models for valuing financial contingent claims on the commodity, and in the procedures for evaluating investments to extract or produce the commodity." (SCHWARTZ, 1997)* The pricing formula for the futures contracts for each corresponding model are then derived.

The one-factor model assumes that the spot price of the commodity is stochastic. The two-factor model also adds the convenience yield as a stochastic variable and on top of that the three-factor model treats the discount rate as stochastic.

To estimate the spot price and convenience yield of a commodity the author use futures prices. The futures contract closest to maturity is used as a proxy for spot price. The convenience yield is computed by using two futures with different time to maturity. These techniques demands a liquid futures market for the underlying asset, which is present for copper, oil and gold, however there is no liquid futures market for LNG so that part will not be applicable to this thesis. Schwartz show in his paper that the two- and three-factor models do a better job at predicting prices. The article also emphasize the difficulties associated with finding relevant data to make correct estimations.

In a 1997 paper Schwartz and colleague Cortazar publish the paper *Implementing a Real Option Model for Valuing an Undeveloped Oil Field* where they valuate an undeveloped oil field by presenting a no arbitrage model for its value and numerical solutions. The result is that a significant part of the value of an undeveloped oil field may occur due to the option do delay investments to an optimal time. This part of the value would not appear in a traditional net present value valuation. They also find that the option part of the oil field value decrease when the price of oil go up.

One factor that plays a big part in the price evolution of commodities like LNG is mean reversion. In the article *Mean Reversion in Equilibrium Asset Prices: Evidence from the Futures*

Term Structure, Bassembinder et. al. (1995) provide evidence of mean reversion in several commodities markets. They use price data from futures contracts with different delivery horizons to test if investors expect mean reverting markets. Using futures markets rather than historical spot prices gives the advantage of more available data since some markets do not have reliable information on actual prices.

The authors look at eleven different futures market, financial, agricultural, metals and crude oil. They find that financial products do not present mean reverting properties while metals have some significant mean reversion but very low levels. However, agricultural products and crude oil show signs of strong mean reversion. This is of interest for this thesis since gas prices are often linked to oil prices.

Yepes Rodríguez (2008) looks a valuation of the arbitrage opportunities that occur between the European and the US LNG markets using real option valuation in his article *Real option valuation of free destination in long-term liquefied natural gas supplies*. Yepes Rodríguez goes through a lot of the limitations when looking at LNG investments. The lack of public data and the time intervals of this data. He argues well for why these limitations are acceptable and develop a model for the option value. The paper's objective is to give an estimate of the value of being able to redirect LNG vessels to another market, the US, when prices are higher than in the originally intended market. The author use a real option approach and treats this option to switch destinations as a multi-asset compound option. The main part of the paper looks at the modelling of LNG prices and gives a comprehensive guide on the subject as well as pitfalls and benefits to different kinds of modelling. The findings of this article is that the destination flexibility on a yearly bases has an expected value of 0.68 $/MBtu and that the option of delivering to the US. market is exercised 57% of the time. The conclusion is that destination flexibility is an important aspect of long-term LNG supplies. Yepes Rodríguez paper look at a situation similar to this thesis, I will be looking at buying-flexibility rather than selling-flexibility and the model for the price evolution of LNG will be used to model the price of gas in this thesis.

3 Method

In this thesis a real option model using Monte Carlo simulations will be developed to put a value on the investment in a LNG regasification-plant in Europe to use LNG as a complement to natural gas from pipelines. The hypothesis is that this will lower prices and disrupt the monopoly power of the distributer. In the european case this is Russia, who may benefit from having a certain market power in Eastern and as long as this cost is lower than the alternative cost of switching provider or energy type.

To study this I will use a scenario, similar to that of Lithuania, of a rented Floating Storage and Regasification Unit, FSRU. Renting a FSRU can be done at a cost considerably lower than building a facility on shore and the of knowledge about the process can be outsourced to the company responsible for the ship.

3.1 Data

The natural gas market isn't known for its transparency, price data is not abundant, therefore some compromises will have to be made in comparison to an ideal situation The same can be said for the companies responsible for renting out the FSRU. The BP Statistical Review of World Energy 2016 provide annual average prices for imports of Russian pipeline gas. The U.S. Energy Information Administration have publicly available data on LNG exports prices. This data will be used to construct the model. Given the fact that german prices are exposed to competition, Germany also have a pipeline connection from Norway, the prices on which this model will be based on are considerably lower than those paid by countries in eastern Europe. This is not a problem since if this investment is deemed profitable based on german price data the profits would be even higher in a country with a higher price point of pipeline gas.

The data on LNG export prices is the annual average. This drives the assumption that the decision to go with LNG or pipeline gas is updated on a yearly basis. Although this assumption is not ideal it is not unreasonable to assume that importers plan how much to gas to buy one year in advance. If the model provides a positive value of the investment, data on monthly or daily prices would only lead to an even greater opportunity to save money by switching between pipeline gas and LNG.

The rental cost for the FSRU will be taken from a report by the firm King and Spalding Energy Law Exchange. This estimate of rental cost is the best publicly available figures.

3.2 Modelling

The modelling of the real option value by using Monte Carlo simulations for this investment starts with the price behaviour of both LNG and Pipeline gas. Describing the price evolution of a commodity that is traded on a liquid market, like electricity or crude oil, one might rely on time series analysis in trying to best estimate the future prices. But when data is scarce the use of a stochastic process is preferred. A basic stochastic model could look like this Weiner process:

$$P(\Delta t) = P(0) * e^{\left[\left(\mu - \frac{\sigma^2}{2}\right)\Delta t + \left(\sigma\sqrt{\Delta t}\right)Z\right]} \tag{3.1}$$

where

P(0) = Price at time 0

P(t) = Price at a future time, t

Delta t = a small increment in time

mju = expected return

sigma = expected volatility

Z = A random number sampled from the standard normal distribution

The famous Wiener process was devised by Black and Scholes in their 1973 paper mentioned above. This process has many properties that make it attractive to users, one being that is is a Markov process, meaning that it does not require a historic data but only the present price predict future prices. The Weiner process however has a tendency to drift far from its origin over time because variance increase linearly with time (Dixit and Pindyck, 1994). The non stationary property is suitable for stocks but not for commodities that tend to move around an equilibrium level the long term. A level that might shift due to shocks but does not tend to drift far from its mean. In order to deal with that diversion a mean-reverting term must be added to the model.(Bessembinder et al., 1995. Yepes Rodriguez, 2008)

Here is a simple model of a mean reverting stochastic process:

$$P_t = P_{t-1} * \left(\alpha * \ln(\bar{P} / P_{t-1}) + \sigma * Z \right) \tag{3.2}$$

Where,

α= speed of mean reversion

$\bar{P}$ = mean price

$\ln(\bar{P}/P_{t-1})$=mean reversion term

σ = standard deviation

Z=random number from the standard normal distribution

t = a point in time between time 0 and T

The mean reversion is introduces by dividing the mean by the price in the previous time period. If the price at t-1 is lower than the mean, then the number is going to be greater than 1 and will have a positive affect on the price at time t. And in the opposite is true if the price is higher than the mean. The speed of this effect is determined by the constant that is multiplied with the mean reversion term, α in this case.

In order to model prices of assets with time-varying volatility there is a whole family of models named ARCH, Autoregressive Conditional Heteroscedasticity, first developed by Engle. (Engle, 1982) The ARCH models volatility as a deterministic function of past returns. A variety of modifications have been done since 1982 and provides great flexibility that can compensate for a leptokurtic distribution of returns. Excess kurtosis, with observations many standard deviations from the mean, should be impossible when the assumption of normality is present, which has been shown in many markets. For ARCH-type modelling there is a need for extensive historical data to estimate parameters and is therefore not possible when modelling LNG prices. (Yepes Rodriguez, 2008)

3.3 Ethical Perspective

The ethical perspective of natural gas can certainly be discussed. On the one hand, natural gas is a fossil fuel that result in CO^2 emission that contribute to global warming. The countries exporting natural gas are often not democratic with blatant disregard for human rights and what the profits are used for in the exporting country can definitely be questioned. On the other hand, the demand for energy is at record levels in the global market with emerging countries demanding even more. This energy is often produced by burning coal, a cheap but incredibly dirty source of energy. Natural gas can replace a lot of coal power and the environmental effect of natural gas are half those of coal so that the net effect is lowered. It is only a transitional fuel but that transition will take a while and taking gas of the table for energy production will result in increased coal burning and that will have a large negative effect on greenhouse gas emissions.

If this research show that LNG imports would make natural gas cheaper we would assume an increase of consumption in places where a shift from solely relying on gas via pipeline to importing LNG would occur. This shift would not be undertaken if LNG investments would not lower the price of gas. However, countries dependent on one distributer with monopoly power would greatly value energy independence. Both from a financial standpoint but also from a geopolitical point of view.

Economics as a discipline and economists as practitioners should describe the world in an accurate way so that the public can make informed decisions. To stay away from controversial subjects out of fear of being perceived as unethical would be a disservice to the profession and to the society.

4 Empirical Study and Results

4.1 Presentation of the model

There will be two equations to model the price evolution of natural gas in Europe. One for pipeline hub prices and one for the price of LNG.

The model will be similar to the one used by Yepes Rodriguez in the article *Real option valuation of free destination in long-term liquefied natural gas supplies*, from 2008. This application will flip the situation suit the needs of a buyer rather than a seller.

The option part in this model will be the option to buy the natural gas with the lowest cost each year. If the pipeline gas is cheaper than importing LNG, then the FSRU would stand idle for that time period. The idle ship still cost money but that is a sunk cost and the profit maximizing decision is to buy the gas with the lowest cost.

The price for pipeline gas and LNG is also assumed not to drift too far apart. After the 1980's deregulation of the natural gas market in the U.S. price convergence was evident (King and Cuc, 1996). The correlation found in the data between LNG and pipeline prices are 0.65 and the term i therefore included.

The proposed discrete time model for the price evolution will look as follows:

$$P_{Pipeline} = P_{t-1} * \left(\alpha * \ln\left(\bar{P} / P_{t-1} \right) + \sigma_{pipeline} * Z_{pipeline} \right) \quad (4.1)$$

$$P_{LNG} = P_{t-1} * \left(\beta * \ln\left(P_{Pipeline} / P_{t-1} \right) + \sigma_{LNG} * Z_{LNG} \right) \quad (4.2)$$

Where,

α= speed of mean reversion pipeline gas

β = speed of the convergece

$\bar{P}$ = Mean price

$\ln(\bar{P}/P_{t-1})$=mean reversion term

$\ln(P_{pipeline}/P_{t-1})$=convergence term

σ = standard deviation

Z=random number from the standard normal distribution

t = a point in time between time 0 and T

4.2 Variables and parameters

For the numerical computations the mean price and standard deviation of the returns are both calculated using historical price data from the United States Energy Information Administration and the BP statistical review (bp.com, 2016. Eia.gov, 2016). The use of historical volatility as a proxy for future volatility can be questioned and therefor multiple levels of volatility will be tested with the historical volatility as the base scenario. The constants α and β were estimated by Yepes Rodriguez in his paper and will be taken from there.

The duration of the project is set at 20 years, this seems to be standard project duration for FRSU's according to King and Spalding Energy Law Exchange News letter from 2015. The fixed cost for the project also comes from the estimations by King and Spalding. (Weems et al. 2015) The variable cost for turning LNG from its liquid state to a gaseous state that can be delivered to consumers are estimated to be USD 0.35 per million cubic feet (shareholdersunite.com, 2008). The sources for the cost can be questioned but is the best data that can be found through public sources.

The discount rate, as mentioned earlier, is one parameter that could affect the investment. In theory it should be the risk free interest rate, government bonds, plus a risk premium. Estimating the risk premium for an investment in a LNG regasification facility is almost impossible to do with any kind of accuracy. The industry is relatively new and the use of FSRUs is even newer so the data is just not available. However, in a feasibility study made for investing in FSRUs in Myanmar the authors used 12%.(The Japan Research institute et al. 2014). 12% will also be used here as the base scenario. However three different discount rates will be tested. One lower rate, the rate of German government bonds with 20 years to maturity, to illustrate a scenario where we would consider the investment risk free. The last rate will be a 25% discount rate, a level where we would see the project as very risky.

The volumes used for the numerical computation is 4 billion cubic meter per annum or zero if the price of pipeline gas is lower than that of LNG. 4 bcm is a normal capacity for a FRSU, and the actual capacity for the FSRU *Independence* that Lithuania is renting at the moment.

4.3 Actual model

Setting up the actual discounted profit function is done in two steps. First, the fixed cost of renting the FSRU need to be discounted back to T=0 at the proposed discount rate, this will be seen as the initial investment. Second, we need to sum up and discount each years cash flow. The cash flow in a given year will be the excess revenue, compared to just having the pipeline connection, minus the variable cost of regasification. If this number is negative the value will be zero. The full function can be viewed below.

$$\Pi = \left(\sum_{t=1}^{T} MAX : \frac{\left(\left(P_t^{pipeline} * \left(\alpha * \ln \left(\overline{P^{pipeline}} \Big/ P_{t-1}^{pipeline} \right) + \sigma_{pipeline} * Z_{pipeline} \right) - P_t^{LNG} * \left(\beta * \ln \left(P_{t-1}^{pipline} \Big/ P_{t-1}^{LNG} \right) + \sigma_{LNG} * Z_{LNG} \right) \right) * V - V * C_t^v \right)}{(1+\delta)^t}, 0 \right) - \left(\sum_{t=1}^{T} \frac{C_t^F}{(1+\delta)^t} \right)$$

(4.3)

Where,

Π=Discounted excess profit compared to staying with just pipeline gas

P_t = Price at time t

α= Speed of mean reversion pipeline gas

β = Speed of the convergece

$\overline{P}$ = Mean price of pipeline gas

$\ln(\overline{P^{pipeline}}/P_{t-1}^{pipline})$=Mean reversion term

$\ln(P_t^{pipeline}/P_{t-1}^{LNG})$=Convergence term

σ = Standard deviation

Z=Random number from the standard normal distribution

t = time from t_0

V = Total gas volume per annum

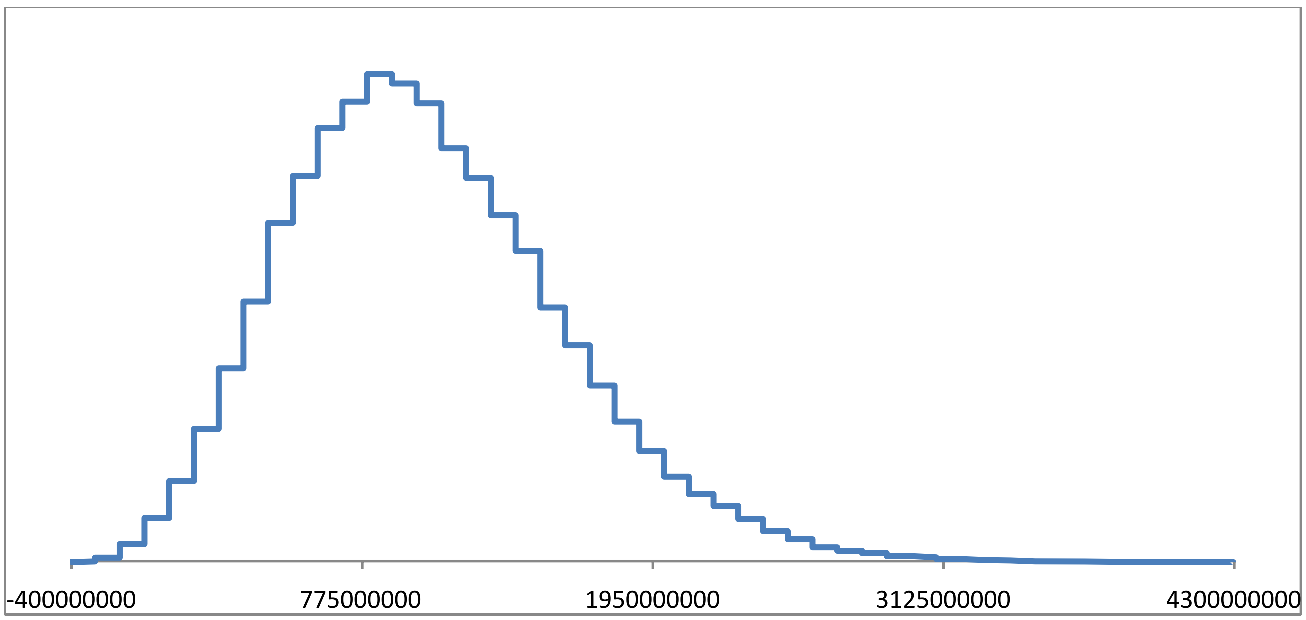
C_t^v = Variable cost

C_t^F = Fixed cost

δ = Discount rate

4.4 Running the simulation

In calculating the value of the real option using Monte Carlo simulations the model is recalculated with 100 000 iterations to give an accurate estimate of the value of the investment. When doing real option analysis using Monte Carlo simulations, the average outcome from the simulations is considered the theoretical value of the investment. The



Graph 1

results for the base scenario are the following:

Average	US$	1,040,214,482.84
SD	US$	556,881,150.53
Max	US$	4,200,141,620.71
Min	US$	-395,867,842.24

Table 1.

In this base scenario, where the discount rate is 12% and the standard deviation for pipeline and LNG are 22% and 15,7%, the expected discounted excess profit of the investment would sum to USD 1,040,214,482.84.

4.5 Sensitivity test

When the parameters σ change the results are the following:

Standard Deviation	Scenario 1, base scenario Historical St. Dev.	Scenario 2 Pipeline & LNG +10%	Scenario 3 Pipeline +10%, LNG -10%	Scenario 4 Pipeline -10%, LNG +10%	Scenario 5 Pipeline & LNG -10%
Average	US$1,040,214,482.84	US$ 1,528,692,124.15	US$ 1,131,617,629.32	US$ 1,204,013,275.53	US$ 635,704,596.26
SD	US$ 556,881,150.53	US$ 851,544,399.32	US$ 604,071,375.99	US$ 678,838,750.11	US$ 266,326,896.57
Max	US$4,200,141,620.71	US$ 9,607,000,012.99	US$ 6,112,881,097.85	US$ 5,201,178,239.70	US$1,986,700,697.52
Min	US$ -395,867,842.24	US$ -422,583,773.05	US$ -231,745,116.86	US$ -422,583,773.05	US$ -225,690,575.04

Table 2.

When the volatility of both prices increase by 10 percentage points, scenario 2, we see a substantial increase in the expected value by more than 50 percent. the opposite is true when the volatility of both prices are reduced by 10 percentage points in scenario 5. Scenario 3 and 4, where the price volatility for one type of gas go up by 10 percentage points and the other go down by 10 percentage points, we still se an increase in the expected value. The model show positive values for all the tested levels of volatility.

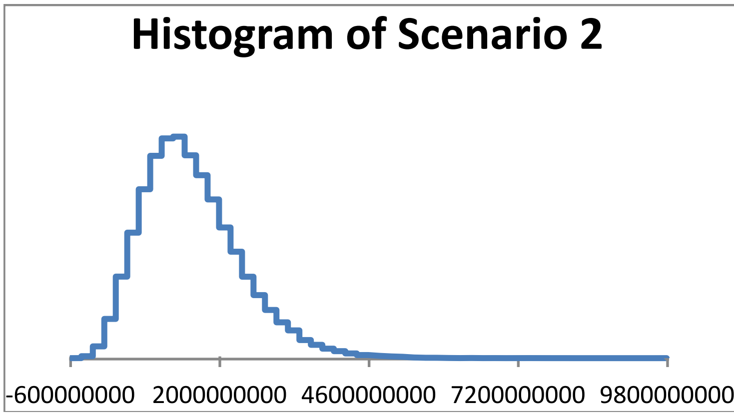
When the parameter δ changes the results are the following:

Discount rate	Scenario 1 δ=12%	Scenario 6 δ=0.334%	Scenario 7 δ=25%
Average	US$ 1,040,214,482.84	US$2,568,547,924.93	US$ 548,948,320.66
SD	US$ 556,881,150.53	US$1,294,138,466.25	US$ 346,302,453.55
Max	US$ 4,200,141,620.71	US$10,581,860,714.36	US$2,921,816,886.21
Min	US$ -395,867,842.24	US$-1,052,016,451.14	US$ -206,636,985.76

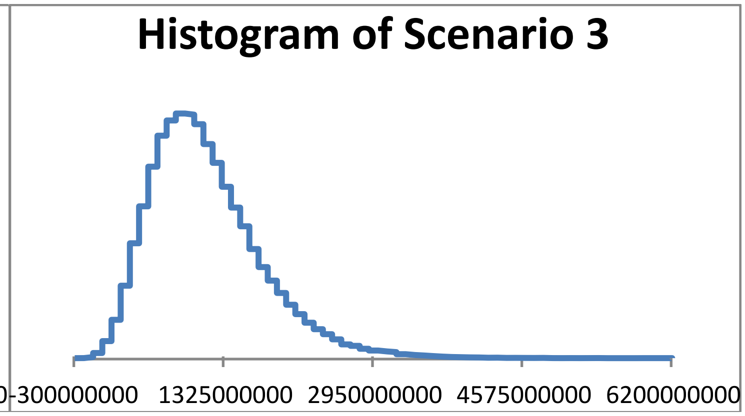
Table 3.

The results from a change in the discount rate are the opposite of those in the volatility. When the discount rate increase the expected value of the investment decrease. A higher discount rate corresponds with a high risk and therefore the future cashflows are seen as more uncertain. With the yield rate of 20y German bonds, 0.334% the expected value of the investment increase with a factor of 2.5 compared to the base scenario. Since the price volatility is held constant the standard deviation stay around 50% of the expected value.

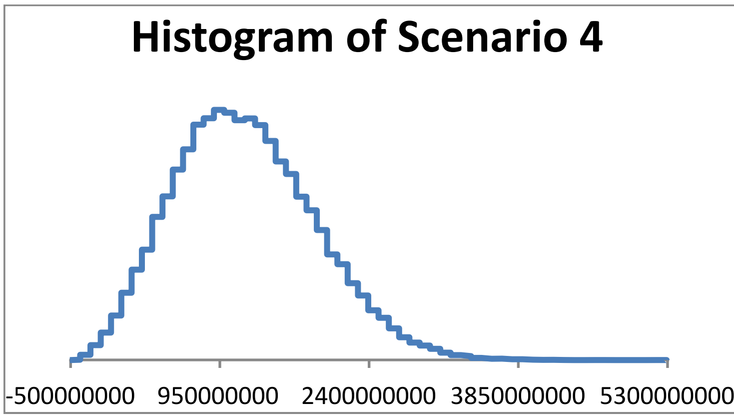
The histograms of the distributions for scenarios 2-7 can be found on the next page.



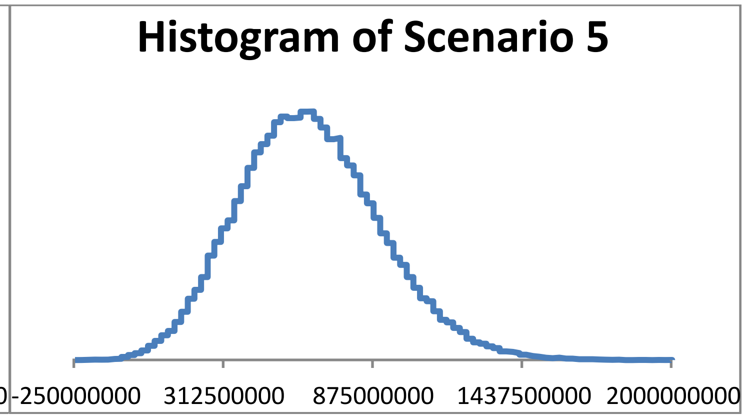
Graph 2.



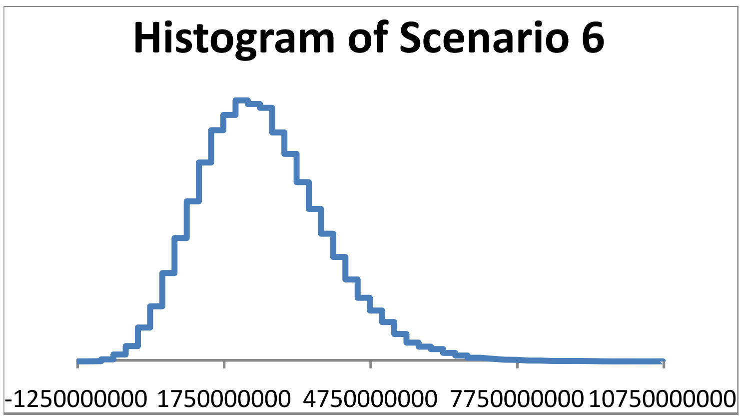
Graph 3.



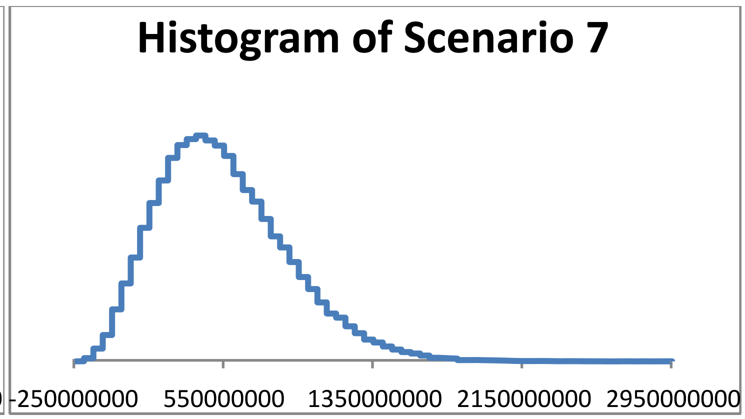
Graph 4.



Graph 5.



Graph 6.



Graph 7.

5 Analysis and Conclusions

The aim for this thesis was to develop a model for valuing the investment in a LNG regasification plant in Europe and the research question was:

Are LNG regasification facilities a financially viable investment to diversify natural gas markets?

The research also aim to:

- Determine whether energy independence can be cheaper than energy dependence

The results show that the estimated discounted monetary value of going from a single provider of natural gas, to investing in an LNG regasification facility has positive value of USD 1,040,214,482.84.

To put that into perspective, in 2013 the Ukraine consumed 43.3 bcm and paid on average 10.9% more than Germany and if they rented a FSRU and replaced 4 bcm per annum of pipeline gas from Russia with LNG the cost savings would be substantial. (Kononczuk, 2015. bp.com, 2016)

With the technical developments in the past few decades in the LNG-field combined with the technical development in directional drilling and hydraulic fracturing leading to increasing extraction of natural gas in the United States, the situation for large exporters to the set prices well above marginal cost might be over. It has already started in the Baltic countries and more FSRUs are in production destined for Europe. This research shows that it is not only a worthwhile investment to secure energy independence but has great possibilities of being a sound investment from a financial standpoint.

5.1 Energy independence

The question of energy independence has not been discussed at great lengths in this research since it is a quantitative approach to evaluate the economic value of natural gas supplies with LNG. However it impossible not to discuss the implication on the geopolitical climate in Eastern Europe. Events like the Ukrainian gas crisis in 2009 resulted in natural gas deliveries being suspended for 13 days in January of 2009 and completely turning off gas supplies to large parts of south eastern Europe would have less of an impact if the delivery sources were diversified.

From a game theoretical perspective stand point it is interesting to note that If countries start investing in infrastructure for LNG it is possible that Russian export prices will fall in countries where the import prices are above the price of LNG. If this happens, the LNG infrastructure might stand idle for the most part and the investment in and of it self might not be profitable but as a whole, the cost of gas would be lowered as a consequence of the investment. The Lithuanian example tells us that this is a likely outcome of the investment as Gazprom lowered their cost by 20% because of the investment (Hovland, 2014). Even a credible threat of investing could lead to lower prices.

5.2 Internal Validity

The internal validity of this thesis is threatened by a few different factors. The first and biggest factor is the lack of public price data. The only available price data on prices in Europe is yearly averages for the past 30 years. Most of those years prices might not be of interest simply due to the scale of trading at that point. The world trade in LNG is a whole different industry than it was in the 1980's. The other main threat would be the lack of definitive information on costs, volumes and other important facts about regasification facilities from trustworthy public sources. However, the real option valuation of the investment is not done to put a definitive value on the investment but rather to illustrate, firstly how to do this valuation and secondly to the hypothesis that energy independence is a financially viable option with LNG.

5.3 External validity

The results might be generalizable, however each country and region has its own specific factors to take in to account, but the model can easily be adapted to take those factors into account. And given the conservative assumptions made in regards length of time between price changes and the use of German pipeline prices, which are considerably lower than most of the countries in Eastern Europe, the general conclusion that the rental of a FSRU is a good investment is valid. The discounted value of the investment should be even higher when the difference in price between LNG and pipeline gas is higher.

5.4 Possible future research on the subject

Further studies on the subject should be done with more complex and extensive models for prices taking into account the supply side function including gas reserves, confirmed and unconfirmed, and the demand side function. If more precise data on cost are available this would probably give a more accurate estimate.

A study comparing investing in, buying or renting, FSRU or an on-shore facility would also be a good place to take this research further.

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