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Abstract

The development in the natural gas markets throughout the past two decades is likely to have made an impact on the market characteristics. Commodity market financialization in the early 2000s and the shale gas revolution beginning around 2005 are the most significant developments worth mentioning. In this thesis we will investigate the impact on market integration between the US and the UK markets in the period February 1997 to March 2018. The US and UK markets are represented by Henry Hub and NBP prices, respectively. Furthermore, we will analyze the futures market efficiency in both markets, and how the efficiency have been affected by the development. We consider contract maturities of 1 through 8 months.

By using the Augmented Dickey-Fuller test, we found that most of the time series variables are non-stationary processes with order of integration equal to one. As a result we used the Gregory-Hansen test of cointegration with an unknown structural break and determined a statistically significant breakpoint in the cointegration relation between Henry Hub and NBP spot prices in October 2008. Further investigation with the Johansen test of cointegration revealed that the markets co-moved in the period February 1997 - October 2008, but that this co-movement has disappeared since. In our analysis of the futures market efficiencies we found that all futures contract prices are cointegrated with the respective spot price. In the Henry Hub futures market, the contract with 1 month maturity fulfilled the Law of One Price prior to the breakpoint and contracts with maturity 1-5, and 7 months did so after the breakpoint. No Henry Hub contracts were unbiased predictors of the future spot price. In the NBP futures market, there were no contracts fulfilling the Law of One Price prior to the breakpoint, but all contracts did so in the post period. NBP futures contracts with maturity 1 and 3 months were statistically significant in supporting the unbiasedness hypothesis in the period post breakpoint. As a result, both markets have improved their efficiency, especially the NBP market, but they are still to a great extent inefficient.

Acknowledgment

Working with the Masters Thesis have been a joyous and recreational experience. We appreciate the opportunity of enhancing our knowledge in a topic of interest. Commodity markets are perpetually evolving and the natural gas markets have grown in academic prominence.

We would like to direct particular thanks to the people that have enabled us to accomplish our Masters of Science degrees in Industrial Economics at the University of Stavanger. The knowledge and guidance from Atle Øglend has been a pivotal component to the successful culmination of a comprehensive and opulent thesis in the abstruse field of econometric analysis. Further gratitude should be given to our family and treasured ones. Your love and judiciousness fuels our prosperity.

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Nomenclature

α Intercept coefficient or Gregory-Hansen test slope coefficient

β Slope coefficient or Gregory-Hansen test trend coefficient

ϵ_t Error term at time t

γ_i ADF-test parameter

μ Gregory-Hansen test intercept

ϕ ADF test root

$\phi_{t\tau}$ Dummy variable for structural break

d Order of integration

d_t ADF-test constant

E_{t-j} Expected value given the available information at time $t-j$

$F_{(t-j)|t}$ Futures contract price at time $t-j$ with delivery in month t

$F_{t|t}$ Futures contract price at time t with delivery in month t

p Number of lags

S_t Spot price at time t

y_t Dependent variable

1 Introduction

1.1 Background

During the 1980s, the natural gas markets in the US and the UK underwent major deregulation. The purpose of the deregulations were to induce higher international trading volumes and market efficiency. The Henry Hub natural gas futures were listed on the New York Mercantile Exchenge in 1990[1], and the National Balancing Point natural gas futures were listed on the International Petroleum Exchange (now Intercontinental Exchange) in 1997[2]. The deregulations provide a mean to the convergence of natural gas prices in the international market.

From the historically low commodity prices in 1998[3], the commodity markets boomed until the financial crisis in 2008. Institutional investors, such as pension funds and hedge funds, use commodities in their investment portfolio to reduce risk related to the financial markets. However, as the capital flow from institutional investors grew from $15 to $200 billion in the 2003-2008 period there have been raised concerns about the increasing correlation and volatility spillover from the stock markets to the commodity markets.[4] Natural gas is no exception to this. In addition to this phenomenon, there have been a tremendous increase in natural gas production in the US, from the disruptive technology that has created the so-called shale gas revolution.[5] The US shale production has changed both the global natural gas and oil trade, and the detailed effects remain a topic of interest among researchers.

Natural gas futures market efficiency in the US have been studied by several (e.g. Ergen and Rizvanoghlu (2016), Movassagh and Modjtahedi (2005), de Roon et al. (2000)). The research on the UK market is less comprehensive (e.g. Haff et al. (2008), Mazighi (2005)). The consensus is that the futures markets are in essence inefficient. As equal commodities in different markets are expected to converge in price if there exist possibilities of trade, the natural gas markets around the world are expected to be integrated. The literature on integration of regional markets (both within the US and in Europe) are comprehensive (e.g. Asche et al. (2001), Walls (1995), de Vany and Walls (1993)), but less research has been dedicated to the global market integration, although some exist (Li et al. (2014), Siliverstovs et al. (2005)).

1.2 Purpose of the Thesis

The purpose of the thesis is to contribute to the literature on natural gas markets. We will search for empirical evidence of market integration between the US and UK natural gas markets in the period from February 1997 to March 2018, and investigate possible structural breaks. As far as the authors of this thesis are aware, there has not been any previous studies of structural breaks in the market integration relation between the US and UK natural gas markets. The literature on NBP futures market is scarce, which is why we will analyse the futures market efficiency at NBP and compare this to the Henry Hub market. Furthermore, we will look at the futures market efficiency in relation to the possible structural break in market integration. The motivation for the research is the changes caused by commodity market financialization and the shale gas revolution. The questions answered by this thesis is of importance to decision makers within hedging and investment, as decisions often are based on the assumption that the futures price is an unbiased predictor of the future spot price.

1.3 Econometric Approach

The econometric approach is determined by the fact that the time series variables are not stationary, but rather I(1)-processes[1]. This eliminates the possibility of using the traditional Box-Jenkins modeling approach. We will choose optimal lags by evaluating the Akaike Information Criterion and test for unit roots with the Augmented Dickey-Fuller test. In order to test the cointegration relationships we will use the Johansen test of cointegration. This provides the opportunity to test

[1] I(1)-processes are stationary at first difference

for the Law of One Price and the unbiasedness hypothesis. The identification of a statistically significant breakpoint will be conducted with the Gregory-Hansen test of an unknown structural break in a cointegration relationship.

1.4 Limitations

There are several limitations to the econometric approach that should be made clear. The time series of Henry Hub and NBP prices are listed in different currencies. This can be accounted for by exchange rate pass through, but have not been conducted in this thesis. One should also be aware that the results are dependent on the sample length and sample interval from the data collected. Similar analyses with shorter time periods, could ultimately yield differing results. Another limitation is the number of lags included in the econometric models. There are no clear way of determining the lags, however, in this thesis we will consistently use the Akaike Information Criterion as the basis for lag selection. The number of lags affect autocorrelation as well as the statistical power of the tests. In our results we found some signs of the time series variables being stationary processes. We have not accounted for this by tailoring the approach and this can affect the reliability of the results.

1.5 Thesis Structure

The rest of the thesis will be structured as follows: 2 Natural Gas Markets, 3 Literature Review, 4 Data, 5 Methodology, 6 Results and Discussion, and finally 7 Concluding Remarks.

2 Natural Gas Markets

In this section we aim at providing a sound understanding of the natural gas markets. The analytical work of this thesis is inevitably linked to the real world, and it is thus important to take a holistic approach. The natural gas markets that are of special interest to this thesis are the US and the UK markets. These markets are among the most mature and well developed natural gas markets, and it is thus valuable to consider the formation and the history of the markets as we later will conduct time series analysis on our dataset. We will also elaborate on the specific futures contracts of which this thesis is based on. Furthermore, we will consider the supply and demand determinants of the natural gas market, as these are integral to the pricing and market dynamics.

2.1 US Natural Gas Market

Spot markets for natural gas in the US emerged when the Federal Energy Regulatory Commission (FERC) allowed pipelines[2] to become contract carriers in 1985[3]. In the years prior to this change in regulations, the pipeline operators had to act as merchant carriers.[12] The main difference between contract carrier and merchant carrier is that when operating as a contract carrier you do not have to own the gas of which you are transporting, whereas you would have been required to when operating as a merchant carrier. As a result, the operators of the pipelines today can transport the natural gas to markets on contracts from customers. Another main reason for why spot markets did not exist prior to 1985 is that the regulations required the natural gas to be sold through long-term contracts.[1] With the current regulations, the natural gas markets functions like any other commodity market. The customers can buy the commodity and suppliers of transportation provide the shipment.

When the markets became deregulated, the expectation was that the prices at different markets throughout the US would converge within the limits of transporta-

[2]In this case interstate pipelines (i.e. pipelines crossing state boundaries).
[3]The regulation was through Order 436

tion and arbitrage costs. However, as pointed out by de Vany and Walls (1993), there were concerns about poor coordination between purchases and transportation, risk aversion with regards to trusting the spot market, overly volatile prices, and many more. In the end, the market proved to transition efficiently and the theory of arbitrage described the situation well[12]. A connected pipeline grid was evolved and worked as one of the mechanisms that enabled arbitrage trading. The natural gas customers were given the opportunity to trade and combine transmission rights on most pipelines, which resulted in effective arbitrage.[15]

2.1.1 New York Mercantile Exchange

Natural gas futures contracts became tradeable in the US on April 3. 1990. The contracts are traded on the New York Mercantile Exchange (NYMEX). The proposition was made in 1984 to the Chicago Futures Trading Commission (CFTC).[1]

The futures contracts are standardized and come with certain specifications. The quantity is set to 10 000 MMBtu[4] with a possible deviation of 2 %. The price is given in dollars and cents, with a minimum price fluctuation of \$0.001. When the maturity of the futures contract approaches, the term spot month starts 10 business days before the last day of trading in the contract. The delivery point of the contracts are Henry Hub in Erath, Louisiana. Henry Hub is a pipeline interchange and the reason NYMEX proposed this location is due to its proximity to producing and consuming areas. Henry Hub consists of 9 interstate pipelines, 4 intrastate[5] pipelines and a gathering system[6]. The transmission of gas is conducted in a first-come first-served manner. A customer who is currently transmitting gas cannot be interrupted by higher priority customers.[1] The location of Henry Hub can be seen in Figure 1, along with interstate and intrastate pipelines.

[4]MMBtu: million british thermal units.

[5]Intrastate pipelines do not cross state boundaries.

[6]A gathering system controls the flow with pumps and other equipment.

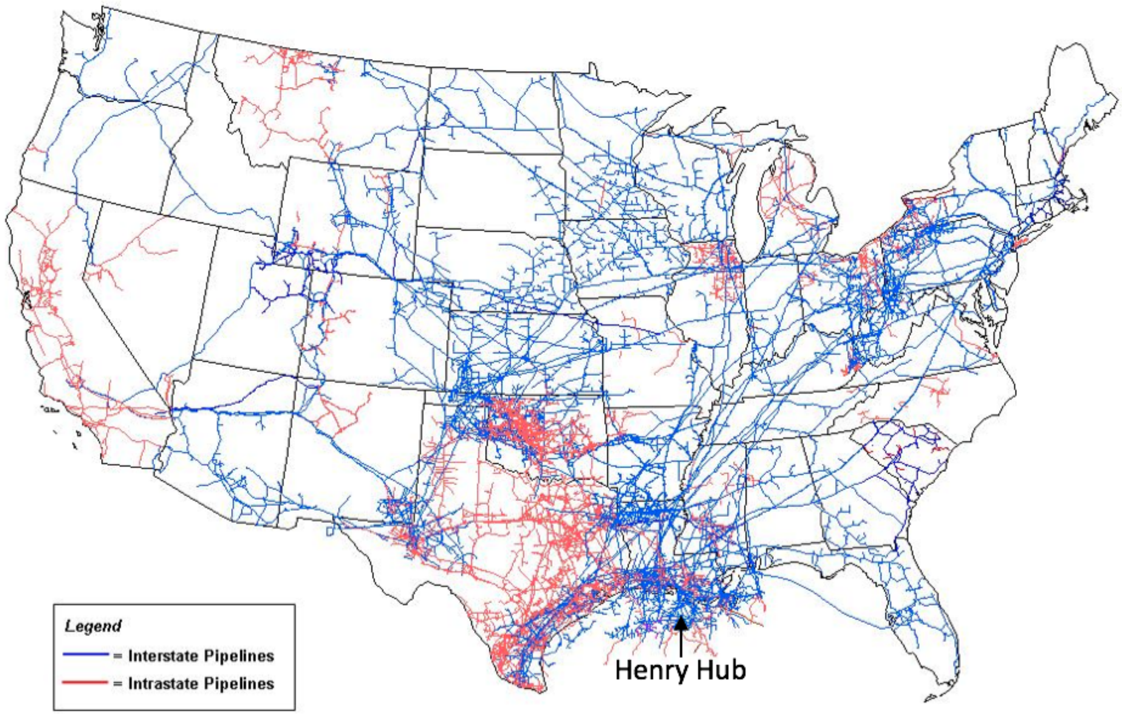


Figure 1: *The US natural gas pipeline network.[16]*

2.1.2 Historical Incidents in the US Market

The historical development of the Henry Hub spot price can be seen in Figure 2. There are several spikes and dips, of which there exist a consensus in the interpretation among experts.

2001 - California electricity crisis

An energy crisis that was the culmination of several incidents: Low hydroelectric availability and an overall increase in demand for energy resulted in a substantially and sudden increase in natural gas demand. This, coupled with supply problems because of inefficient regulations and a rupture of the largest interstate pipeline leading to capacity reductions, made prices spike.[17]

2005/2006 - Hurricane Katrina and -Rita

During the latter half of 2005 the hurricanes Katrina and Rita ravaged through the Gulf of Mexico. The hurricanes destroyed and damaged offshore platforms, processing facilities and pipeline segments setting parts of the natural gas supply out of

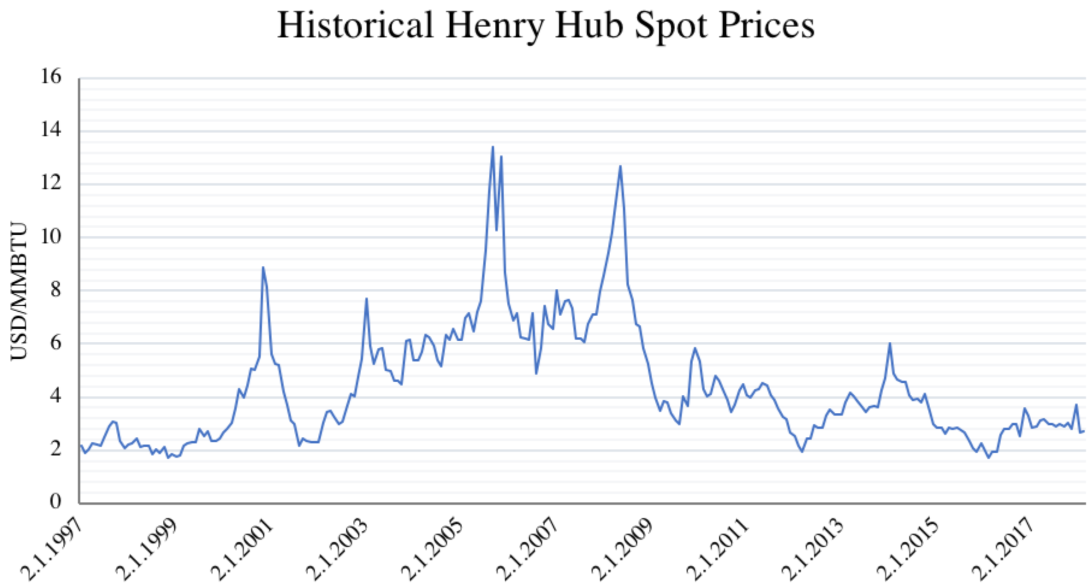


Figure 2: *Historic price of Henry Hub natural gas spot.*

play for a period. This caused pressure on the supply side and prices spiked.[17]

2008/2009 - Financial crisis

The financial crisis that started in 2008 affected most markets. The natural gas market was no exception and prices fell considerably. With the crisis going on, natural gas consumption was reduced while production and storage remained at high levels, which contribute to the price drop.

2014 - Oil crisis

The gas marked reacted with a price drop to oil crisis that started around the beginning of 2014 because of oversupply.

2.2 UK Natural Gas Market

The natural gas market in the UK was to a great extent deregulated in the 1980s. The European Union (EU) has put pressure on the various European governments to enable competition in the natural gas industry.[10]

Natural gas delivered to the UK enters the National Transmission System (NTS). The NTS consist of 7 beach reception terminals, 3 LNG importation terminals, 10 storage sites, and 23 compressor stations.[18] Natural gas in the UK is traded on the National Balancing Point. Unlike Henry Hub in the US, this is not a precise physical place, but rather a notional hub. The NBP functions as if it was a point in the national transmission system (NTS)[7] of which all the gas in the pipeline grid flow through.[18] This is for accounting and balancing purposes, and makes the possibility of trading easier.[9] The NBP has been a market place since 1994, and the main trading location for spot natural gas in the UK since 1996.[19]

2.2.1 Intercontinental Exchange

In 1997, the futures contracts in the UK were formally listed on the International Petroleum Exchange (IPE).[2] The International Petroleum Exchange has later changed its name to the Intercontinental Exchange (ICE). The delivery point of the natural gas is at the NBP. The contracts are specified with either month, quarter or season. The possibility of trading will end 2 days before the first date of the calender month of which the gas will be delivered. One contract consist of 1 000 therms of gas per contract period, e.g. 1 000 therms per day for a month in a monthly contract. Thus, a monthly contract may comprise of 28 000 - 31 000 therms, depending on the month. The price is given in punds sterling and pence per therm, with a minimum price fluctuation of 0.01 pence per therm.[20]

2.2.2 Historical Incidents in the UK Market

The historical development of the NBP spot price can be seen in Figure 3.

2006 - The Rough gas storage facility fire

In February 2006, a fire started at the offshore storage facility Rough. The fire was of such a significant size that the facility had to be shut down. Rough accounted for over 80% of the total UK storage capacity and was put out of action for greater

[7]Operated by the National Grid

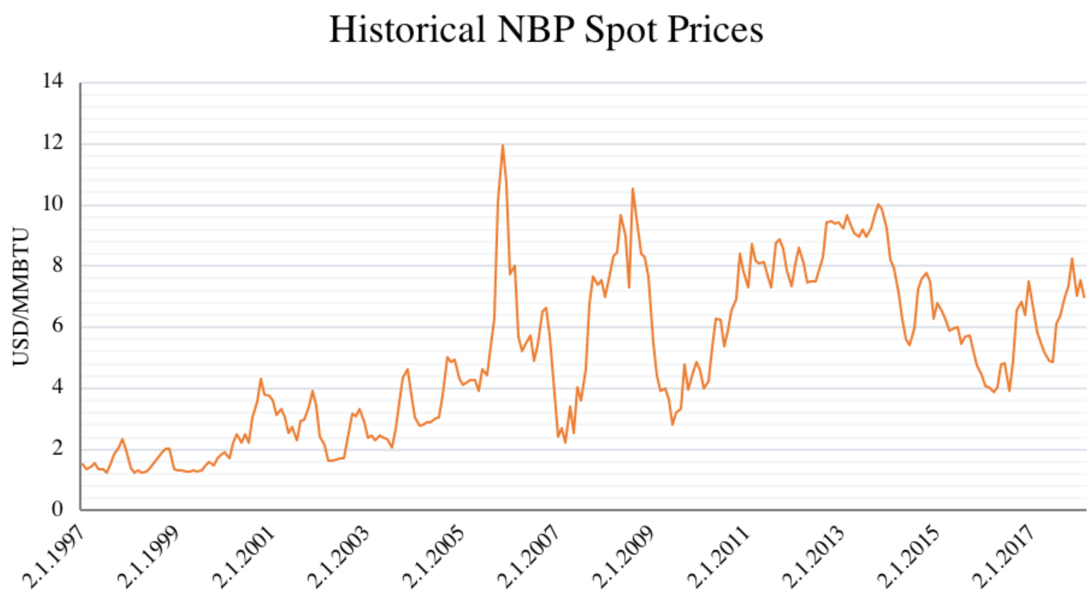


Figure 3: *Historic price of NBP natural gas spot.*

parts of 2006 (partly out of action going into the winter months). Having such an important storage facility sidelined put pressure on the supply side.[21] In addition to this event, the transportation into the UK experienced bottlenecks on the capacity. This further drove down the supply.[9] Accordingly, the natural gas prices spiked during this period.

2006 and 2009 - Russia-Ukraine gas disputes

Russia and Ukraine have been in conflict over natural gas supplies, prices and debts through their respective national petroleum companies for over a decade. In 2006 Russia stopped the supply to the pipeline going through Ukraine because they could not agree on prices. Another supply cut-off came in 2009 when the two countries again could not agree on price and supplies. Since Russia is the largest supplier of natural gas in Europe these disputes led to pressure on supply and increased prices on natural gas hubs in Europe.[22]

2008/2009 - Financial crisis

The UK natural gas market experienced similar effects as the US market. However, because of this negative trend in the market, the price spike from the Russia-Ukraine dispute was less noticeable.

2012 - Russian supply interruptions

During January 2012 Russia experienced an unusually cold winter which increased the domestic demand of natural gas. With the increased demand they had difficulties with providing the amount of natural gas they were committed to export. This lead to a supply shortage in Europe and price spikes on the hubs.[23]

2014 - Oil crisis

The UK market experience similar effects as in the US market. However, since NBP prices are linked to oil prices while the Henry Hub uses gas-on-gas pricing, the UK market experienced a more dramatic drop than the US market.

2.3 Demand

With natural gas showing to be a flexible and reliable energy source the global gas demand has been growing for the last decades. The primary demand for natural gas comes from the power, industrial, residential, commercial and transportation sectors. The power sector is the largest component of the global demand, but there is an on-going change where the industry and commercial sector has been providing most of the growth in global demand. The demand from the power sector is expected to gradually decline because of relative prices to substitutes and emission costs. The growing global demand the last years have largely been coming from Asia where China has drastically increased their import levels of natural gas to reduce the amount of smog in their cities, and the Fukushima incident has made Japan compelled to replace nuclear energy with natural gas in their energy mix.[25]

2.3.1 Weather

The demand for natural gas is heavily affected by the weather, especially for the residential sector. This is because most of the natural gas consumed by the resi-

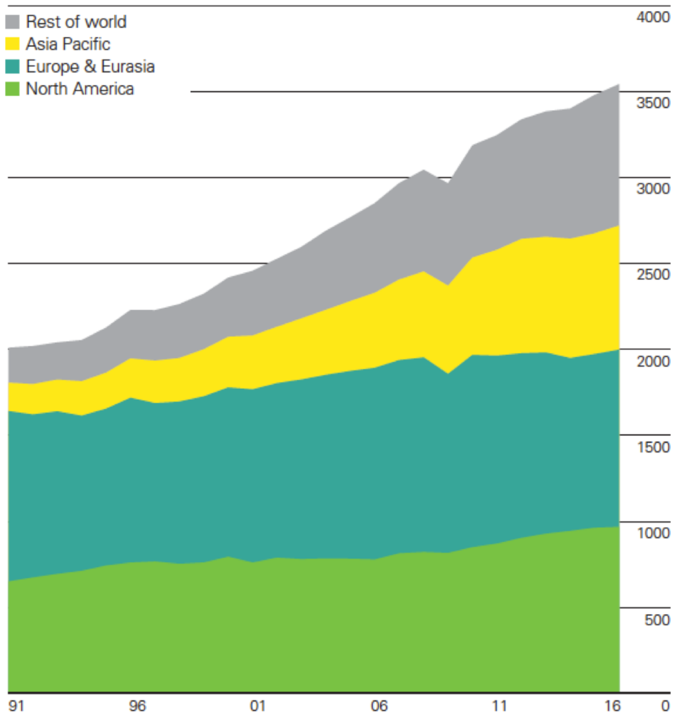


Figure 4: *Natural gas demand by region (in billion cubic meters).[24]*

dential sector is used for heating and cooling purposes. Cold winters will increase the amount of heating needed and therefore increase the demand. A warmer winter on the other hand will have less need of heating and will lower the demand. A mild winter can therefore counteract the coming price increase if there is a supply shortage going into the winter. This is in fact what happened during the winter of 2005/2006 in the US market after the hurricane destructions.[17]

2.3.2 Substitutes and Greenhouse Gas Emissions

Other than for heating purposes, natural gas is a major resource for the industrial and power sector. However, natural gas competes with other energy sources that can be used in production processes and for electricity production. The demand is therefore decided by the relative prices of these substitutes[8]. Furthermore, the world is trying to move towards a greener energy mix to accommodate the problems with global warming. In Europe there is therefore an extra cost [9] with using resources

[8]Substitutes such as coal and renewable energy sources.
[9]Extra cost related to the European Union Emissions Trading System (EU ETS)

that contribute to increased emission of greenhouse gases. This cost affects the cost of using gas fired generators relative to for instance coal fired generators for power production. Since coal emits considerably more carbon dioxide than natural gas, a gas fired generator will be favored in terms of greenhouse emission costs.

However, in the same way that natural gas is a cleaner resource than coal, there are resources that are cleaner than natural gas. The primary contenders here are nuclear and renewable energy. Even though natural gas holds a major share in most countries energy mix there are examples where nuclear and renewable energy has reduced the demand for natural gas in the power sector significantly: The major source of energy for electricity production in Germany is renewable energy[26], while France is dominated by nuclear energy with natural gas having a small share[27].

Nevertheless, it is believed that natural gas will have an important role in the transition stage to a low-carbon fueled society. Future energy outlook reports see most countries increasing the amount of natural gas while reducing other fossil fuels in their energy mix, thus indicating further increase in the global demand for natural gas.[28] We also see the tendency of natural gas being the preferred alternative energy source when a primary source fails in some way: When hydropower had a bad year in 2017 due to weather problems, natural gas demand increased in Europe. China is as mentioned trying to get rid of their smog filled skies and are changing from coal-fired to gas-fired generation. China alone stood for 30 % increase in global demand for natural gas in 2017.[25]

2.3.3 UK and US Demand

The residential and power sectors consume the most natural gas in the UK. The industrial sector follows as third. The UK is the third biggest consumer of natural gas in Europe but cannot meet their demand through their own production. They are therefore dependent on importing almost half of their demand and about 44 % of the import is supplied by Norway and Russia through pipelines. They are connected to continental Europe through the Interconnector pipeline.[24]

The demand composition in the US is somewhat different with the residential sector coming third after the power and industrial sector. Natural gas demand for 2017 fell with 8 % in the power sector, which comes from the fact that natural gas prices increased, and the demand was therefore squeezed by renewables and coal. The US is the biggest consumer of natural gas and used to have high level of import. However, because of the relatively recent shale gas revolution and the abundance of shale gas, they have become rather self-sufficient and the import levels have fallen. The small amount they do import comes through pipelines from Canada.[24]

2.4 Supply

The US market is self-supplied while the European market is dominated by a few suppliers. However, with current trends there will most likely be no dominant natural gas suppliers in the future. With growing demand, the production of natural gas has also increased with the years. The LNG[10] market has seen a major increase in demand since 2010, and accordingly more countries has entered the supply side to capture market shares. However, the growth in production has been slowing down with lower gas prices, increase in demand for and technological advances in renewable energy.

2.4.1 Storage

Storage is used to accommodate the varying demand throughout the year. Since demand varies with the weather while production is not flexible in that way, natural gas produced during summer is put in storage facilities to satisfy the demand during winter. This way, the seasonal pattern in the natural gas marked is accommodated. It is also used as supply safeguard in case of a black swan event[11]. Storage sys-

[10] Liquid Natural Gas
[11] A black swan event is a surprising, unforeseen event with significant impact.

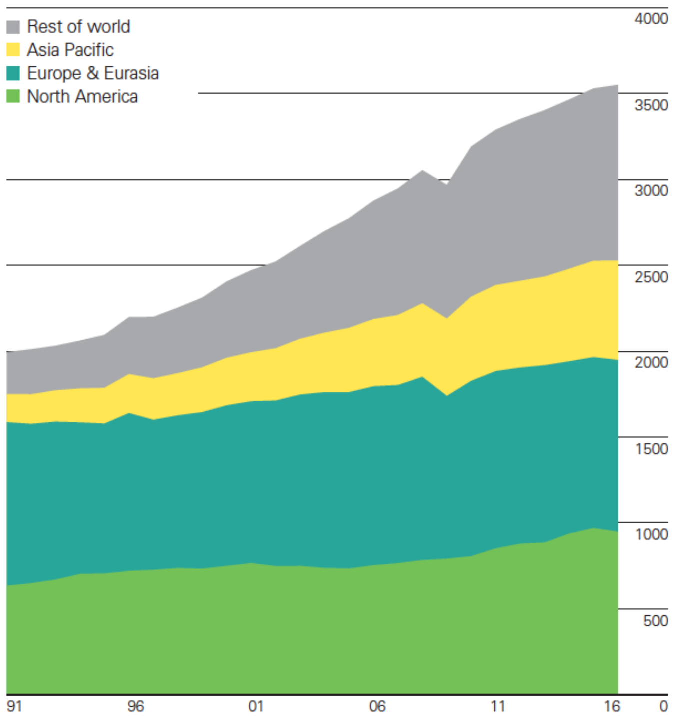


Figure 5: *Natural gas supply by region (in billion cubic meters).[24]*

tems are flexible in the way that they can react to shift in the market dynamics by switching between injection and withdrawal swiftly.

Storage is also used to speculate on prices. If natural gas is expected to be more valuable in the future, a producer can store the gas until the prices increase and it becomes profitable to sell.

2.4.2 Transportation

Proper infrastructure is essential to transport natural gas. The gas needs to be transported from production location or storage to the area of demand. The traditional way of doing this is through pipeline systems. However, pipelines have some bottlenecks in form of flow ceilings. This makes them less flexible to respond to increasing demand or supply shortage in short-term. Constructing pipeline systems is also time consuming, costly, and often restricted by geological factors. Therefore, not all markets and regions are possible to be reached by pipelines. LNG somewhat solves this problem. LNG makes it possible to reach demand points where pipelines are out of the picture through tankers or trucks. LNG has therefore introduced another dimension of flexibility and makes the global natural gas market more interconnected. It also makes the buyers less reliant on storage.

LNG has its own bottlenecks in form of availability of LNG vessels, capacity of liquefaction and regasification facilities, and freight fares. Constructing and maintaining LNG storage facilities is also costlier than developing underground storage facilities. Nonetheless, the increase in LNG trades appears to provide the possibility of lowering the volatility in the different markets. LNG tanks has the ability to be re-routed to markets that has problems with responding to increased demand and is experiencing peaking prices. Furthermore, the flexibility of LNG transport makes it possible for suppliers to exploit arbitrage opportunities and take advantage of the price differences between hubs. [29]

2.4.3 Shale Gas Revolution

Shale gas was for a long time deemed too hard and costly to produce. However, technological advancements in hydraulic fracturing and horizontal drilling has made it possible to produce shale gas at a profitable level, and has reduced gas prices considerably in the US market.[5] Further consideration about the shale gas revolution and the impact on the natural gas markets will be made in Section 3.4

2.4.4 UK and US supply

The US used to be a net importer of LNG, but because of the increase in their own supply they do not need to import the same levels anymore. Greater parts of the import facilities have therefore been re-constructed into export facilities and from 2016 to 2017 the US quadrupled their LNG export levels.[30] The US is already the world's largest producer of natural gas and will have the greatest increase in production levels the coming years. The US may not necessarily be the cheapest supplier when applying export costs (liquification, transportation, gasification) however, but they can work as a price ceiling against other exporters.

The UK have storage levels that are sub-par compared to their own consumption. History has shown that unexpectedly cold winters, supply shortage and black swan events creates price spikes on NBP because of their insufficient storage and high dependency on suppliers.

2.4.5 Natural Gas Contracts

Contracts used in the natural gas markets must consider the buyers need of flexibility and the suppliers need of assurance of returns on investments. The contracts are therefore a compromise between buyers and suppliers. Continental Europe mostly use long term “take or pay” contracts. In a take or pay contract, the buyer agrees to receive a certain minimal amount of gas annually or to receive some of the agreed amount and pay for the amount they did not need. The buyer also has some flexibility in the contract with the option of buying more gas than the agreed upon amount. The price of the gas delivered is priced after a formula that incorporates the price of substitutes. Thus, the buyers retain competitive prices. However, this has the effect of making the gas markets coupled with the most weighted substitutes. A consequence of this is for example the price dip in the gas marked during the 2014 oil crisis. Since the NBP is connected to continental Europe through the Interconnector the effects of energy substitute (oil) indexed prices also apply there.[11]

The US on the other hand is characterized as a gas-on-gas priced market i.e. gas competes with gas and price is determined by the interplay between supply and demand for gas. The US market have a large number of suppliers and an efficient infrastructure such that it is possible to buy a fixed amount of natural gas. Furthermore, with the shale gas revolution there has been an increase in short term LNG contracts in the US. These contracts have flexibility in the form of no restriction to destination and trade in lower volumes. Thus, the US contracts are free from prices indexed after energy substitutes and are generally more flexible.[29]

2.5 Law of One price

As mentioned in Section 2.4.2, LNG can be used to take advantage of price differences in different markets and make profit. That is, if it is profitable when adding all the costs related to bringing the gas to the other markets. This is called market arbitrage. The Law of One Price (LOP) relates to the effects of market arbitrage: If there are arbitrage possibilities, suppliers will try to take advantage of this and send their supplies to the market with higher prices. Since the supply increases in this market, the price will fall accordingly. The suppliers original market will have less supply and thereby prices will increase there. The opposite can also happen where the consumers move toward the market with lower prices. With increased demand the prices will increase, while the first market will see lower prices with lower demand. These cases assume the demand and supply stay constant in their respective cases. Hence, the prices in the two markets will converge towards one price for both cases.

The Law of One Price assumes that natural gas must be sold at different markets for the same price when expressed through a common currency. However, there are obvious costs related to moving the gas between markets. First, there are costs of physically moving the gas from one location to another, including transportation, insurance, and freight rates. Then there is the cost of the interest lost of not selling the gas today. Lastly, there is the cost concerning the risk of prices being lower when the gas arrives to the marked. A selling price will therefore accommodate all these costs. There exist arbitrage in the market when the price difference between markets is greater than the sum of the costs mentioned. The arbitrageur can buy a futures contract to eliminate the risk of price uncertainty since arbitrage is a riskless trade. However, some arbitrageurs may want to take the risk instead since it can be effort consuming and costly to buy a futures contract, because the contract wanted may not exist. The cost of the risk is then defined as a risk premium to the arbitrageur for taking the risk.[31]

It should be noted that the UK get most of their LNG from other countries than the US. There are also no significant direct trades the other way. Any observable price convergence between the two markets should therefore not be an effect of direct arbitrage. Nick and Tischler (2014) theorize that a price convergence could come from arbitrage through a third party.[32]

3 Literature Review

In the literature review, we will consider research topics of special interest to the thesis. The research provides the basis of which we hope to contribute with further insights. The literature has a focus on recent articles and research papers in order to make the thesis as up to date and *avant-garde* as possible. However, the interest for natural gas markets seems to have been of special interest in the 1990s, when the markets were deregulated. Even though the framework of Fama (1970) is from the 1970s, it will be considered in this thesis as it is essential for todays view on market efficiency. Further sections will discuss commodity market integration, commodity market financialization, shale gas revolution, and the effect those have on the natural gas markets.

3.1 Efficient Capital Market

One of the fundamental aspects of the capital market is that it should ideally have prices that give accurate signals for resource allocation. When this is the case, firms and individuals can make investment decisions on production and securities[12] ownership, respectively, by assuming that the security prices fully reflect all the available information of relevance to the market, at all times. This ideal situation forms the basis of the efficient market concept. However, that prices fully reflect all information is too general for empirical testing and further specification is needed.[33]

In 1970, Fama contributed to the understanding of efficient markets by specifying three information subsets[13]. The three information subsets entails the following forms of efficient market.

1. Weak form
2. Semi-strong form
3. Strong form

[12]Securities are tradeable financial instruments that have some type of monetary value.
[13]Two of the information subsets where already defined by Harry Roberts.

The weak form efficient market has an information subset of historical prices only. The semi-strong efficient market, however, includes information that is publicly available to all investors (e.g. earnings report, equity issue, etc.). In the last case of strong form efficient market, the information subset contain monopolistic information, which is held by certain individuals or groups.

3.1.1 Futures Market Efficiency and Cointegration

The expected future spot price is assumed to be the value of the futures contract price with delivery in that month. This is known as the unbiasedness hypothesis, and can be expressed as:

$$E_{t-j}\left(F_{t|t}\right) = F_{t-j|t} \tag{1}$$

where E_{t-j} is the expected value given the available information at time $t-j$, $F_{t|t}$ is the futures contract price at time t with delivery in month t, and $F_{t-j|t}$ is the futures contract price at time $t-j$ with delivery in month t.

The futures price should converge with the spot price at the time of delivery in order for the market to be efficient. In addition, we must assume that the futures price is a fair gamble given the information available. It is typical to test market efficiency by regressing the spot market price on the futures contract price with maturity in the spot month, i.e.

$$S_t = \alpha + \beta\left(F_{t-j|t}\right) + \epsilon_t \tag{2}$$

where S_t is the spot price in month t, α is an intercept, β is a slope, and ϵ_t is the error term.

In econometric terms, an efficient market requires the futures price to be an unbiased predictor of the future spot price. Thus, it can be performed a joint hypothesis test of $\alpha = 0$ and $\beta = 1$. The intercept, α, represents a constant difference between the prices, such as if there exists transportation costs or a risk premium. In the joint hypothesis it is thus assumed to be a futures contract with delivery at the same location, and with the same specifications with respect to e.g. quality, as the spot price. The slope, β, represents the relative change in price of spot price with respect to futures price. In order for the market to be efficient, a unit change in the futures price should be accompanied by a unit change in the spot price.[1]

3.1.2 Natural Gas Market Efficiency

Natural gas market efficiency is important for several reasons. de Roon et al.(2000) addressed this in their article on hedging pressure effects. If the futures price of a commodity in general is biased, then hedging and diversification will become more costly and less beneficial. The bias will also affect economic agents who do not take position in the futures market. The futures prices are used as predictors of the future spot price, and thus, it is often the basis for decisions on consumption, storage, processing, and hedging.

As the natural gas market has evolved from a highly regulated to a highly unregulated market, the question of market efficiency has gained interest since the 1990s[1]. During this time, natural gas has become a vital part of the US energy mixture and the US natural gas futures market has in its 28 years of existence proven to be one of the most volatile markets. Moreover, Ergen and Rizvanoghlu reported in their 2016 article that there are certain patterns in the natural gas futures volatility. Higher volatility has been witnessed on Mondays, during the winters, on the announcement days of natural gas and crude storage reports, and at times where storage and/or temperature diverges from seasonal means. They also invalidated the common belief that the volatility is increased by lower storage levels all year round. According to Ergen and Rizvanoghlu, it is in fact only valid during the winters, and the opposite is true during the summers.

There are several mechanisms that drive an efficient market. Speculative storage can be argued as one of them. Speculative storage agents may buy natural gas when the supply of natural gas is high[14], in order to bring it back to the market when the supply is low. The monetary incentive is quite obvious, yet the behavior also affects the market dynamics and thus the price movements. By supplying when the availability is low, and retracting when availability is high, they provide a counterbalance to supply and demand shortages. However, the storage capacity is fixed in the short run as expanding natural gas storage capacity is highly complex and capital intensive. Thus, the smoothing effect is limited and the effect will be negligible when the stocks from speculative storage run out.[34]

The empirical analyses of natural gas futures market efficiency provide mixed results. Walls (1995) concluded that the futures prices are cointegrated with the future spot prices and that the slope coefficients, β, can be regarded as unity in most cases. However, as the analysis was performed in 1995, there were only 44 monthly observations available, and the tests had a low power[15]. In an attempt to provide more rigorous results, Movassagh and Modjtahedi used the Stock-Watson procedure. This procedure enables to correct for the possible correlation between the futures prices and the error terms. The future spot prices were regressed on lagged futures prices of contracts with maturity between 3 and 12 months. The results showed that the futures prices and the spot prices where cointegrated, but that the futures prices under-predict the future spot prices[16]. Moreover, they found that the futures prices are only unbiased when the time to delivery is small. With increasing time to delivery the bias increase and becomes statistically significant at three months. The under-prediction was estimated to be almost 1%. With respect to market efficiency, the bias could be argued as a risk premium for the market participants. Mazighi (2003) found that neither Henry Hub nor NBP fulfill the efficiency hypothesis in their respective futures markets.

[14]High relative to demand

[15]Statistical power is the probability that the null hypothesis is rejected when the alternative hypothesis is true.

[16]The results where the same for most of the maturities used.

3.2 Commodity Market Integration

Economic theory dictates that integrated markets for identical commodities should have converging prices in the long run. The differences in price are related to transportation, quality, monopolies, barriers to trade, and many more. In the 20th century, the main causes of price difference in commodity markets were related to transportation costs and trade barriers. The liberalization seen in politics during the last century has driven the commodity markets to be more integrated. The reason to push for integrated markets is the belief that integration will contribute to higher global trade volumes. Given this understanding of what an integrated market is, the best way to measure the integration is to analyze the price difference for identical commodities in different markets.[35]

3.2.1 Natural Gas Market Integration

The liberalization politics has been especially pronounced in the European Union and in the US. Radical changes have been made through the European Gas Directives and the deregulations by FERC. The purpose of the gas directives are largely related to the efforts of creating an integrated European gas market. The first European Gas Directive was established in 1998 and facilitated competition by opening the gas markets within the EU. The second European Gas Directive came in 2003 and provided an unbundling of the gas operators. Thus, the transportation networks became independent of production and supply, which opens the gas networks to third parties. However, as things unfolded, the customers could still not freely choose their suppliers due to obstacles in the competition. In order to manage these obstacles, the third European Gas Directive was formed to adjust requirements for the networks and to inform regulators of their roles and responsibilities. This directive was to a great extent designed to provide transparency in the European natural gas markets. For the impact of these reforms, we would recommend reading Renou-Maissant (2012), who analyze the the Law of One Price between industrial natural gas prices of several European countries between 1991 and 2009.

Many researchers have explored the integration of natural gas markets. Most have been in specific regions, such as within Europe or the US. The literature on US natural gas market integration is comprehensive (e.g. Walls (1995), de Vany and Walls (1993)), whereas the European natural gas market has been covered to a lesser extent (e.g. Asche et al. (2001), Renou-Maissant (2012)). There are also research on whether markets are integrated globally (e.g. Siliverstovs et al. (2005), Li et al. (2014)). Walls (1995) found the US markets to be largely integrated. de Vany and Walls (1993) explored the effects of the late 1980s legislative developments in the US on the integration of the US natural gas prices. The results showed that almost none of the prices were integrated in 1987, but that the new policies caused more than 65 % to become integrated by 1991. Asche et al. (2001) determined the integration between the French, German, and Belgian markets. The supply to the French market is mainly covered by Norway, Russia, and the Netherlands. The export prices were found to be integrated and the Law of One Price holds. Furthermore, the French, German, and Belgian markets are highly integrated. As noted by Renou-Maissant, the new legislation in Europe is young, and the opening up of the European natural gas market is an evolving process, which is still actively taking place.

Siliverstovs et al. (2005) evaluated the integration between the US, Europe and Japan in the period 1990-2004. All three of the markets proved to be integrated internally. They also concluded with the US market being neither integrated with the European nor the Japanese. The reason is attributed to the low levels of arbitrage opportunities. Furthermore, the US market seem to be more competitive, and the price is set by market dynamics. The integration between the Japanese and the European market is attributed to their strong link to the Brent crude oil price. Li et al. (2014) evaluated the US, European and Asian markets in the period 1997-2011. In accordance with Siliverstovs et al., the markets in Japan, Korea, Taiwan and the UK proved to be integrated. Also, none of the markets are integrated with the US market, and thus, the global natural gas market is not fully integrated. They conclude with the US market being isolated due to the extensive pipeline network, which can match supplied natural gas with demand all over the North American continent.

The typical approach to determine market integration is the Johansen method which will be discussed in Section 5.3.

3.3 Commodity Market Financialization

The commodity market displayed historically low prices in the last month of 1998. The decade that followed (i.e. 1998-2008) has become known as the commodities boom, which is a part of the commodities super cycle. During the five years of 2003-2008 alone, the food commodities increased by 75%[17][3]. In the same period, the capital flow from institutional investors grew from $15 to $200 billion. Contributing factors to the higher prices were Asian demand, depreciation of the USD, and low interest rates.[4] The commodity boom era ended when the global economic growth declined. This is a familiar trait experienced from earlier commodity cycles, where the demand pressure diminishes when the economy slows down.[3]

Institutional investors have utilized commodities as an alternative asset, due to low correlation with other financial assets, and a comovement with inflation. However, the interest in commodities among investors can make the commodity markets more integrated with other markets such as stocks and bonds. This tendency is known as commodity market financialization. Researchers, such as Babalos and Balcilar (2017), has posed the question of whether this boom was caused by supply and demand factors or if it was due to excessive speculation by investors. There is a possibility that the volatility the commodities market has experienced is a result of an investment flow from institutional investors[18]. The topic has been of great interest due to the fundamental role this fact plays in efficient capital management and policy making. Adams and Gluck (2015) are some of several researches who have investigated this topic. They found that the behavior and dependence between stocks and commodities have been altered due to such investment flows. In particular, they found that the decline in commodity prices during the financial crisis

[17]in real price

[18]Institutional investors are pension funds, mutual funds, hedge funds, etc.

was triggered by frightened investors who sold both stocks and commodities. Furthermore, they conclude that the comovement of stocks and commodities is a result of commodities having become an investment style.[37] Erten and Ocampo (2013) claimes that investors used the booming commodities prices to hedge potential risks in their investment portfolio. Correlation between the return on commodity futures, stocks, and bonds have changed throughout the commodities boom. The correlation in the 90s where close to zero, but the various asset classes became more integrated and correlation increased until it peaked during the financial crisis. The correlation also increases with the volatility in the market, as measured by the VIX[19].[4] Adams and Gluck (2015) showed that the effect of the institutional investments on the correlation of the returns on commodities and stocks came into play somewhere around September 2008.

3.3.1 Natural Gas Market Financialization

We have already established in Section 2.1 and Section 2.2 that the natural gas markets in the US and the UK underwent large deragulation in the 90s. The natural gas futures markets have since then proved to be highly volatile. During the commodities boom the trading volumes of Henry Hub futures grew with a compound annual rate of 13.5% (from 1998 to 2012). The nearby-month[20] futures contract trades at 60 to 100 thousand contracts a day, and the second nearby-month futures trade at 20 to 60 thousand contracts a day.[6] Zhang et al. (2017) researched the comovement and the volatility spillover of the crude oil and natural gas markets with the stock market in the period between 1999 and 2015. They found that the markets comove in turbulent periods with high volatilty, and that the stock markets contaminates the crude oil and natural gas markets when the market panic. The natural gas market seem to be financialized even in the period post financial crisis. However, the stock market spillover effects only affect the Henry Hub prices, whereas the NBP prices are linked to Brent crude oil prices.[38]

[19] VIX is the ticker of the CBOE Volatility Index, and is interpreted as the investors anticipation of volatility.

[20] Nearby-month refers to the earliest maturing futures contract.

3.4 Effects of Shale Gas Revolution

The US shale gas industry has been booming since 2005. The US production of natural gas by source can be seen in Figure 6. There are vast shale gas reserves in the US and horizontal multilateral drilling along with fracking has enabled the profitable extraction of such unconventional gas reservoirs.[5] This development has resulted in discussions about the future of the energy industry around the world. The global energy market is highly interdependent. There are also several other countries that are in possession of shale gas reserves that haven't been tapped into as of yet. Some

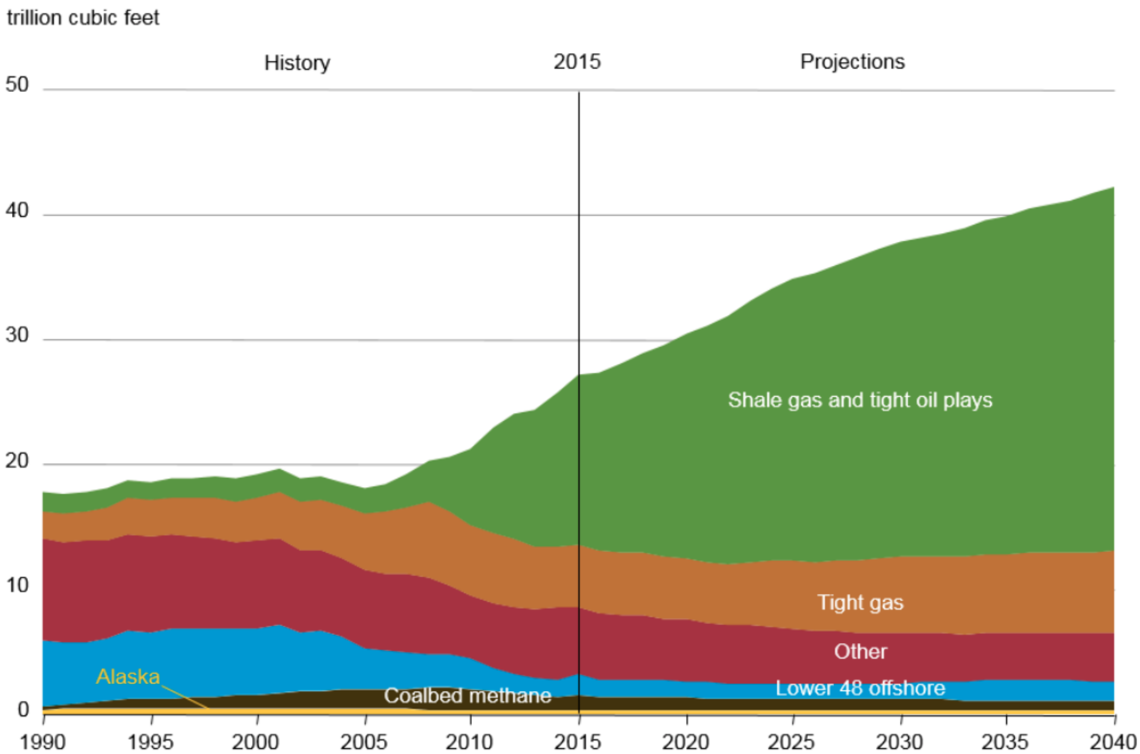


Figure 6: *US natural gas production by different sources.[39]*

of these countries are Argentina, China, South Africa, UK, and Germany. The global impact of shale gas production can highly affect both producing and consuming countries. The potential of shale gas production is dependent on technological advancement, and is therefore difficult to estimate. Optimistic estimates presented by Gracceva and Zeniewski (2013) predict that shale gas will account for almost 25 % of the total gas production in the world by 2030. However, there are also concerns posed by various governments. In a report from the European Commission, it was stated that the environmental impact from shale gas production was greater than from conventional natural gas production. The low oil prices beginning in 2014 has been attributed to fracking and horizontal drilling. OPEC and Russia did not manage to keep the prices neither inflated nor stable due to this disruptive technology.[41]

3.4.1 Shale Gas Revolution on Natural Gas Markets

The commodity market financialization along with increased arbitrage opportunities, and now also the shale gas revolution, is likely to have affected the natural gas market relationships in recent years. Researchers have tried to put the pieces together (e.g. Geng et al. (2016), Wakamatsu and Aruga (2013), Aruga (2016)), and there exists possible answers to some of the effects brought by the shale gas revolution.

The effects of the shale gase revolution on the US and UK markets were investigated by Geng et al. (2016), who applied the Markov regime-switching model to the price spread of oil and gas prices in the period 1998-2015. They found that Henry Hub prices switched from a slightly upward-regime to a sharply downward-regime, whereas the NBP prices switched from a sharply upward-regime to an alternating regime between a sharply downward and slightly upward. The Henry Hub prices seem to be decoupled from the WTI oil prices and the NBP seem to still have a long-term link to the Brent oil prices. Another result in the analysis of Geng et al. was that the seasonal attributes of the Henry Hub prices have vanished. Wakamatsu and Aruga (2013) investigated the effects of the shale gas revolution on the influence between the Japanese and the US natural gas market. They concluded with a one-sided influence from the US market on the Japanese before 2005, which then vanished in the aftermath of the shale gas revolution. It is obvious that the effects of the shale gas revolution must be taken into account by decision- and policy makers in the natural gas industry. Aruga (2016) analyzed the relationship between the US, Japanese and European markets before and after the shale gas revolution. The researcher also located a breakpoint in August 2006 with the Bai-Perron test. The US market showed a relation to the other markets before the break point, which then subsequently vanished. Thus, it seems that the US was the only market affected by the shale gas revolution and that the international market has not yet been affected. These findings are in line with the research discussed in Section 3.2.1 and 3.3.1.

4 Data

The data samples were found and exported using the financial database Datastream provided by Thomsen Reuters. The data samples used for the US market is the Henry Hub prices from the New York Mercantile Exchange. The UK market is represented through the National Balancing Point (NBP) prices from the Intercontinental Exchange. Continuous futures contracts for 1 to 8 months were chosen. A continuous futures contract is several futures contracts spliced together to represent their history. It often involves data adjustments to remove time gaps and create a smooth time series. It is therefore important to remember that continuous futures contracts are only a representation of the history. The spot prices exported were the daily closing prices, while futures prices were monthly.

4.1 Data Management

The best way to do the comparison would be to compare the spot price to futures price at the date of contract delivery. However, finding the exact delivery date would be difficult. We have therefore done a simplification: Since we are looking at long term effects and want to compare spot and futures prices, we converted the daily spot prices into average monthly spot prices. Removing heteroscedasticity is essential for certain cointegration tests and therefore the time series were applied a log transformation. Apart from reducing heteroscedasticity, the log transformation also normalizes the data and reduce any skewness.

The interval of historical data available varied for the different spot and futures datasets. The shortest dataset interval covered prices from February 1997 through March 2018. We found 1997 sufficient as lower limit for our analysis as it includes the commodity boom and shale gas revolution and therefore chose February 1997 to March 2018 as the interval for all datasets used in the analysis. No observations in this period was omitted from the datasets to preserve the information in the data.

The different markets use different units to denominate gas price. The US market uses USD per MMBtu while the UK market uses pence per therm. For better comparability when evaluating tests, the UK market data was converted into USD per MMBtu using the Natural Gas converter provided by Statoil[45]. A single conversion factor was used for the whole period.

The optimal way to convert the prices would be to use historical conversion factors. Since the relationship between USD and GBP changes with time, there could be important changes that may make us draw wrong conclusion if we do not take them into account. However, this would require meticulous work that may not provide any additional information to the analysis and therefore we chose to use a single conversion factor. We have instead included a brief evaluation of the historical relationship between these two currencies during the period of the datasets.

Figure 7: *GBP vs USD historical conversion rate.[46]*

In the period from February 1997 to March 2018, there have been a variation in the conversion rate of about 30 % around the average. The variation is significant but it seems to be quite stable with random walk around the mean.

4.2 Price Movements

The prices trace each other's movements relatively well until they start to diverge in 2009. However, we note that domestic historical incidents that affected one market had little to no effect on the other market. This could be an indication of the markets not being as integrated as they may seem.

Looking at the futures contract we see that the contracts trace the spot prices relatively well. We also see that contracts with longer maturity reacts less to price spikes in the spot price than contracts with lower maturity. This is consistent with the Samuelson effect: Contracts with longer time to maturity exhibit lower price volatility than those with shorter time to maturity.[47]

4.3 Summary Statistics

In order to get familiar with the dataset it is usually beneficial to perform some summary statistics. Typical test statistics such as mean and standard deviation is presented in Table 1, along with some other characteristics of the data.

					Percentiles			
	Variable	**Mean**	**Std.Dev**	**Min**	**5%**	**50%**	**95%**	**Max**
Henry Hub	Spot	4,40	2,22	1,72	1,98	3,81	8,58	13,42
	1M	4,47	2,27	1,70	2,08	3,88	8,92	14,04
	2M	4,57	2,32	1,73	2,13	3,95	8,86	14,10
	3M	4,66	2,36	1,77	2,16	4,08	8,94	14,24
	4M	4,70	2,35	1,80	2,21	4,11	9,07	14,11
	5M	4,74	2,37	1,83	2,22	4,13	9,28	13,85
	6M	4,77	2,36	1,87	2,21	4,13	9,59	13,69
	7M	4,80	2,37	1,92	2,22	4,13	10,04	13,89
	8M	4,82	2,38	1,96	2,18	4,13	9,97	13,82
NBP	Spot	4,99	2,63	1,23	1,34	4,70	9,40	11,95
	1M	5,08	2,65	1,22	1,36	4,79	9,42	11,84
	2M	5,18	2,72	1,22	1,35	4,87	9,61	12,79
	3M	5,24	2,71	1,22	1,43	5,03	9,65	12,98
	4M	5,30	2,72	1,23	1,46	5,24	9,63	13,19
	5M	5,34	2,73	1,23	1,49	5,29	9,59	13,24
	6M	5,39	2,74	1,28	1,49	5,50	9,67	13,04
	7M	5,41	2,75	1,15	1,50	5,50	9,56	12,79
	8M	5,45	2,74	1,31	1,55	5,54	9,57	12,80

Table 1: *Summary statistics of both trading hubs over the entire sample period.*

As can be seen from Table 1 the Henry Hub contracts show increasing upper percentiles until the 7M contract, while the lower percentile stays relatively consistent for the 4M, 5M, 6M, 7M contracts. The NBP contracts show different characteristics, with the upper percentile values varying between increasing and decreasing with increasing contract length. The lower percentiles however, show increasing values with increasing contract length. Furthermore, the mean increase with maturity for both markets. The contract prices are higher than their respective spot prices. This is an indication of the market being in contango on average, when the whole period is considered. However, the standard deviation is relatively large and is increasing with maturity. Therefore, it could be interesting to do a simple contango/backwardation analysis on separate periods of the data interval.

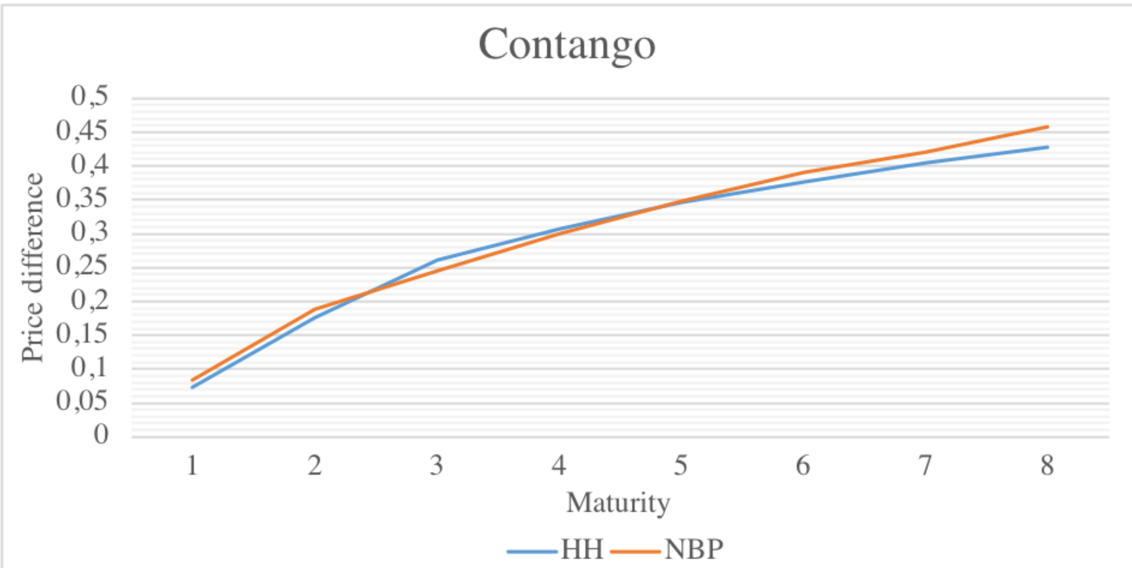
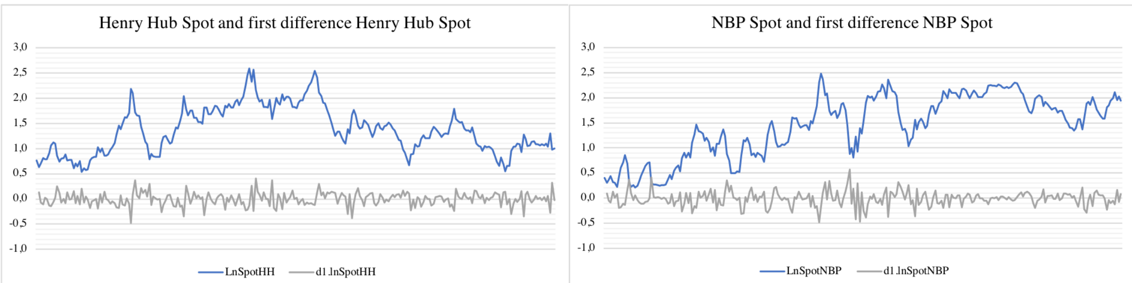


Figure 8: *The futures term structure indicate contango.*

Figure 8 shows plots of the average difference between the futures contract price and the spot price at both Henry Hub and NBP. As we have already established, the futures prices are on average greater than the spot price, and the graphs indicate that the futures markets are in contango, when considering the entire sample period. When the markets are in contango, the buyers are willing to pay a premium instead of buying on spot and pay for storage and cost of carry. This is normal characteristics of natural gas markets as storing natural gas can be rather expensive.

4.4 Visual Inspection of Stationarity

Stationarity and the order of integration is an important part of the procedure in this thesis, in order to determine the econometric approach. This will be made clear in the later parts of the thesis. An indication of the stationarity and the order of integration can be evaluated by assessing the time series graphs of the prices and the first or possibly second differences. The time series of the prices is difficult to assess, as there seems to be various trends from time to time. However, it is reasonable to claim that the first differences are stationary as they stay between -0.5 and 0.5 and appears to move randomly within that range for both NBP and Henry Hub spot prices. By this it seems likely that the time series are integrated of order one. Graphs of the remaining time series have been placed in Appendix A, yet they have been evaluated in a similar manner and yields the same conclusion. A more thorough explanation of stationarity and unit roots are given is Section 5.2, and a more rigorous analysis with Augmented Dickey-Fuller test is performed in Section 6.2. All series in Figure 9 are transformed to logarithmic values and the designation d1 represents the first difference.

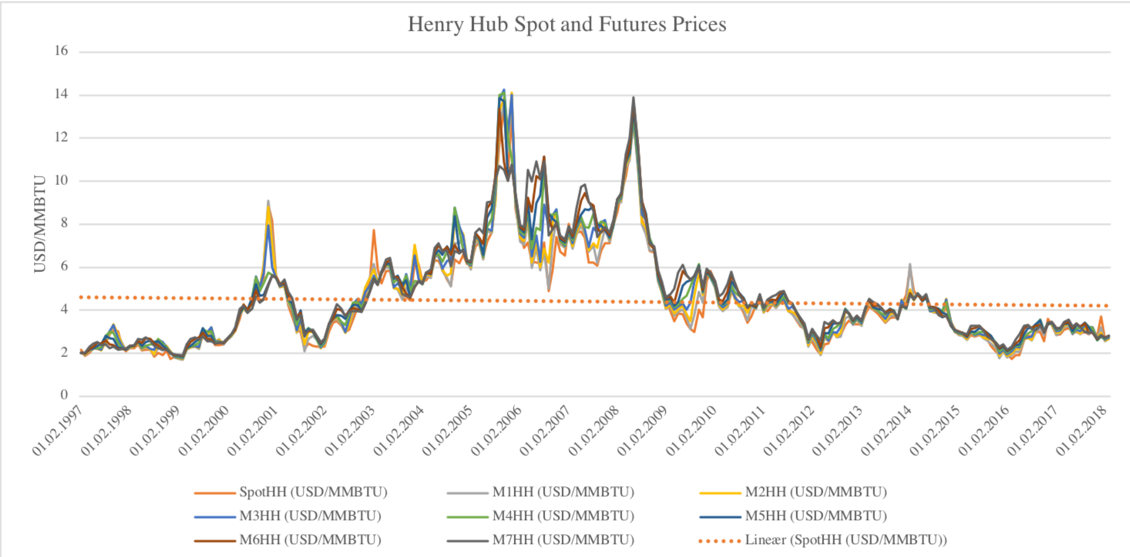


(a) *At Henry Hub.* **(b)** *At NBP*

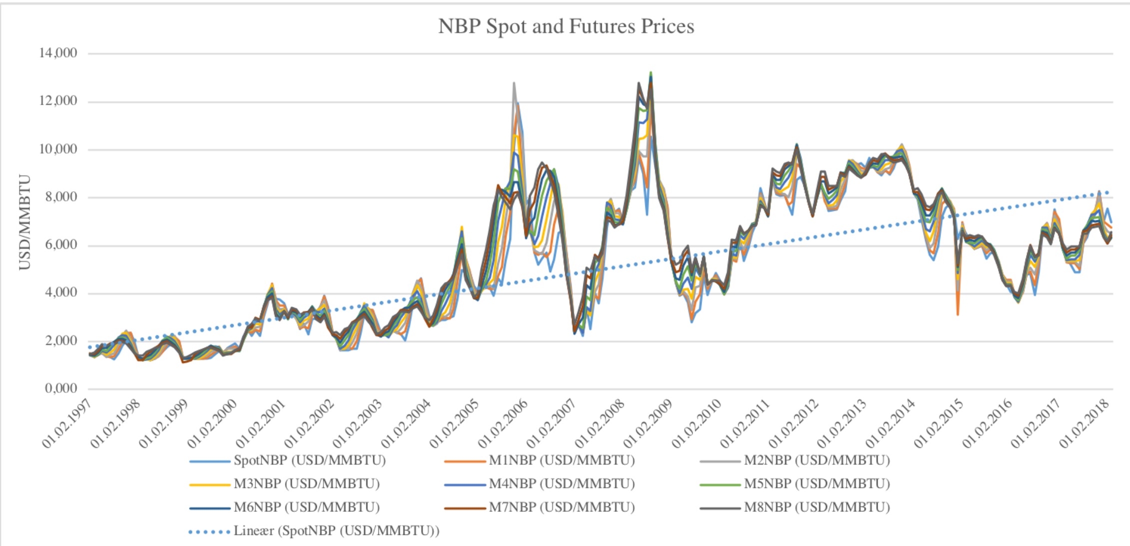
Figure 9: *Time series graphs of spot prices at level and at first differences on both HH and NBP.*

4.5 Trends and Seasonality

At this point it would be interesting to establish some tendencies in the data. By visual inspection of the graphs in Figure 10a and Figure 10b, and also by linear regression, it is evident that the NBP prices have a trend and that the Henry Hub prices doesn't. It is also obvious that the sample period and the sample length plays an important role in this simple investigation.



(a) *Henry Hub.*



(b) *NBP*

Figure 10: *Time series graphs of spot and futures prices on both HH and NBP.*

In the UK market there is a clear appearance of a trend with increasing prices. Whereas in the US market there was an increasing trend until 2009 (consistent with the UK market), but onward from there the prices took a dip and have stayed low since. This dip in prices makes the trend for the entire period appear somewhat neutral. The appearance of a trend gives us the reason to ask the question whether we are looking at trend stationary time series or time series that are random walk with drift. If the samples where to end in 2009 it is clear that both series would yield the same trend.

The above mentioned idea of splitting the samples in prior to 2009 and post 2009 proves to be interesting. As can be seen from Figure 11, it seems to have been a shift in the relationship between the two spot prices. The price of Henry Hub spot has been greater than the price of NBP spot in the majority of the time prior to 2009. Then, in the post 2009 sub-sample it seems as though this relationship has been inverted. The price of NBP spot has been, even more consistently, greater than the price of Henry Hub spot in the majority of the time post 2009.

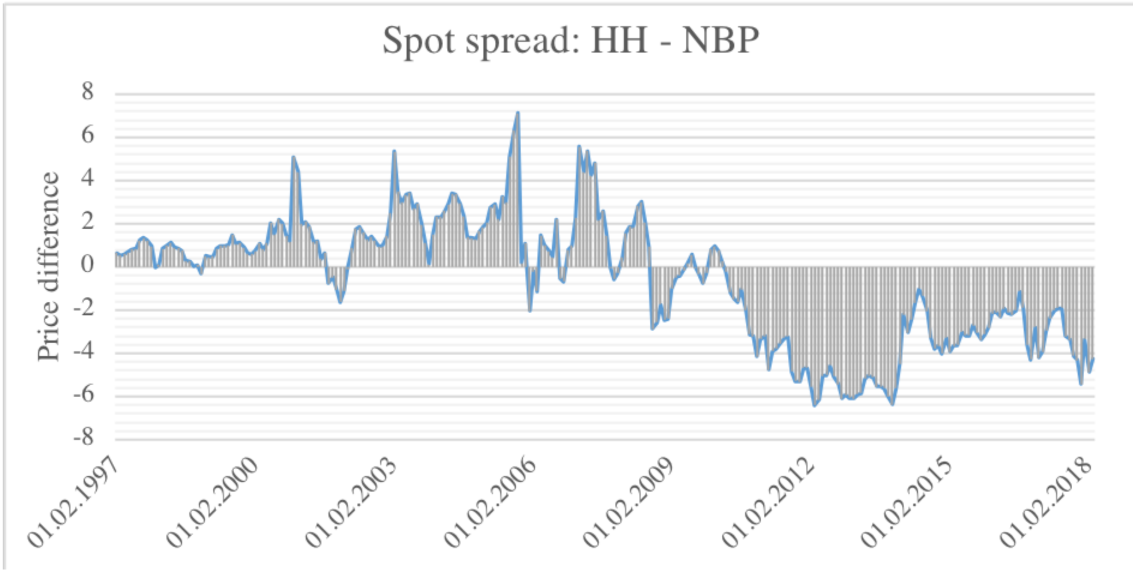


Figure 11: *Spot price spread between Henry Hub and NBP.*

There is also a seasonality pattern in the price movements. Recalling from Section 2.3.1, consumption patterns in natural gas markets are often driven by weather. From Figure 12 we see that prices are relatively high during the winter months and low during the summer months. This pattern is more apparent in the UK market than in the US market. The US having a much milder climate than the UK need less electricity for heating during the winter. This is further explained by energy consumption reports[48] that show that the UK have a much higher consumption (62 %) of natural gas used for residential heating than the US (15 %)[49]. However, the US market instead shows a peak during the summer in addition to the winter peak. This is explained by the fact that the US use more electricity during the summer because of the need for air conditioners[50].

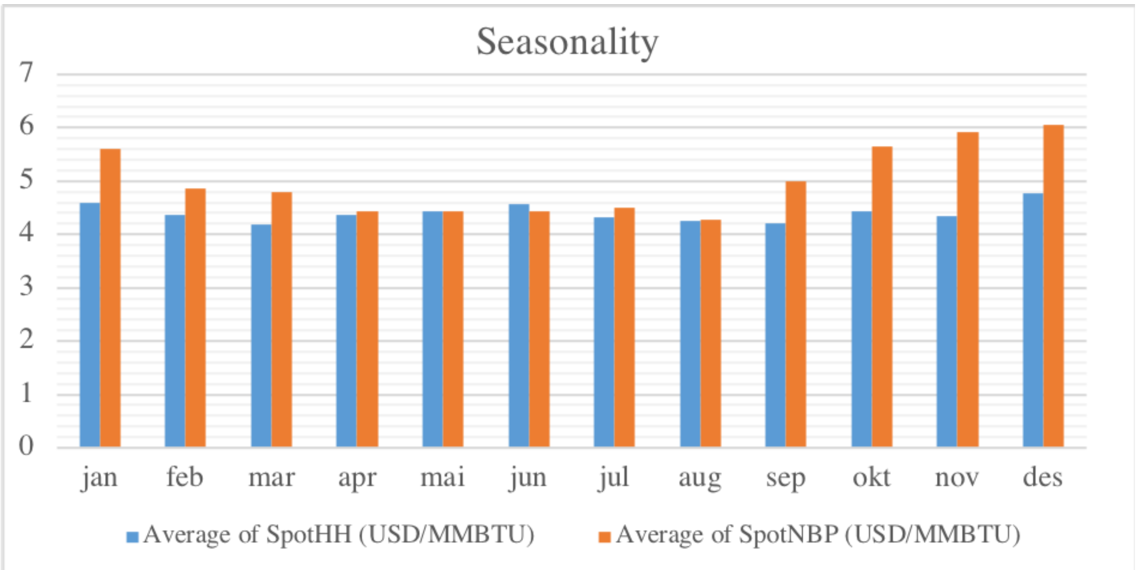


Figure 12: *Seasonal averages in spot prices at Henry Hub and NBP.*

5 Methodology

In this section we will explain the methodology used in the analyses performed later in the thesis. Special considerations will be made on the recommendations provided by researchers on the topics. To the best of ability, we will present pros and cons with the various alternatives, and give a sound reasoning of our selected approach. Furthermore, we will give an explanation to the selected approaches.

5.1 Optimal lag selection

In an autoregressive process with lag p, the model is represented by

$$y_t = a_1 y_{t-1} + a_2 y_{t-2} + \cdots + a_p y_{t-p} + \epsilon_t \tag{3}$$

where a_1, a_2, ..., a_p are parameters and ϵ_t is the random error term, which is normally distributed with 0 mean and σ^2 variance.[51]

In order to appropriately perform the tests in this thesis it is necessary to select the optimal lag for each bivariate and univariate case. The selection procedure is to create vector autoregressive models, VAR(p), for each lag, p, up until the maximum lag, which is set to 12 as the data is given in monthly observations. For each of the VAR models, an information criterion is calculated. The optimal lag is selected by minimizing the information criterion. The VAR models are not explicitly estimated, rather computer optimization determines the optimal lag.

There are several criteria developed for optimal lag selection. Unfortunately, the various criteria are not consistent with each others lag selection. Furthermore, there are none that are regarded as the correct one to use in general. Some of the most common criteria are AIC, SIC, BIC, FPE, HQIC and LR. As all the criteria contain penalty factors for fitting too many parameters[51] a practical means of choosing the optimal lag is to minimize the chance of under estimating the lag length. As shown by Liew's simulations in 2004 the AIC and FPE seems to outperform the others[21]. The simulations investigate the lag selection under various sample sizes. As a matter of fact, AIC and FPE yields the same lag selection for every single draw in all the simulations. However, all of the criteria show adequate precision for implementation in the thesis. Furthermore, AIC is a popular selection criteria in econometric research[52], which is why we decide to also use it.

The AIC was developed by Akaike in 1973. The criterion aims at estimating the goodness of an assumed model. By defining f_0 as the density of the true model, and f_1 is an estimate of this, one can use the Kullback–Leibler index to derive the AIC. We will not present the theoretical derivation as it would be a sidetrack to the thesis, but we will rather present the AIC as:

$$AIC = -2\log(\max L) + 2k \tag{4}$$

where k is the number of free parameters in the maximum likelihood estimator (MLE) of the vector of the parameters of the model under f_1. $\max L$ is the MLE of the assumed model. We can reason that the greater the log likelihood of the model, the nearer the assumed model is to its true distribution, and the smaller is AIC[54]. In practical terms, the model accuracy is optimal when the AIC is minimized.

5.2 Unit Root Test

When a stochastic process has a unit root, it means that unity, i.e. 1, is a root of the characteristic equation of the model. The process will be non-stationary if the process has a unit root. We perform unit root tests to avoid spurious regression and errant behavior. Also, the typical econometric models are based on the so-called Box-Jenkins methodology, which assumes stationarity[55].

There are several procedures for testing of unit root. Some of the most common are Dickey-Fuller tests, KPSS test, Phillips-Perron test, Ng-Perron test and ADF-GLS test. Just as for optimal lag selection, there is no method generally better than

[21] In the paper written by Liew, the criterias considered are: AIC, SIC, HQIC, FPE and BIC

the others, and the choice of unit root test is to some extent subjective judgment[55]. The selection can be made based on Arltová and Fedorová[22] who conducted simulation studies in 2016 to make an objective judgment of unit root test selection based on sample size. Arltová and Fedorová finds that it is appropriate to use ADF as a means of unit root testing, and the method performs especially well with a large time series length. Our dataset[23] is considered large with the scales defined by Arltová and Fedorová, and we will therefore use the ADF methodology to test for unit root.

Time series of economic data are typically not stationary. However, they will be difference stationary after some number of differentiation, d. This is known as the model's order of integration, $I(d)$. The Augmentet Dickey-Fuller test is a type of unit root test with a general model expressed as

$$y_t = d_t + \phi_1 y_{t-1} + \sum_{i=1}^{p-1} \gamma_i \Delta y_{t-i} + \epsilon_t \tag{5}$$

where $d_t = \sum_{i=0}^{p} \beta_i t^i$. This model contains both a constant and a trend. However, it can be simplified to eliminate either the constant and the trend or just the trend[55]. In order to appropriately execute this test it is necessary to conduct an optimal lag selection, which again is performed with evaluating AIC (as discussed in section 5.1). The null hypothesis is that there exists a unit root and that the time series variable is non-stationary. The alternative hypothesis will then claim that the variable is stationary. In order to use the Johansen test (elaborated in Section 5.3) the time series variable need to be integrated of order 1, i.e. an $I(1)$-process. This means that the variable in normal form is non-stationary, but that the first difference of the variable is stationary. The unit root tests are performed on univariate series. We include the constant in our test, but without trend.

[22] The study made by Arltová and Fedorová is suitable for samples of 25 to 500 values.

[23] Our dataset contains 254 observations, which is greater than the second largest time series length in Arltová and Fedorová's simulations.

5.3 Test of Cointegration

The concept of cointegration was developed by Robert Engle in 1981 and a test of cointegration was developed by Engle and Granger in 1987[56]. Non-stationary time series may have a linear combination, which itself is stationary[57]. The definition of cointegration given by Engle and Granger is as follows. If we have a k-dimensional time series with an order of integration d, then the time series process has cointegration vector α (where α is a $k \times 1$ vector) if αX_t has an order of integration $\delta < d$ [56].

Several tests have been developed in order to test for cointegration. Some of these tests are the Engle-Granger test, Johansen test, Phillips-Ouliaris test, multicointegration test, and Stock-Watson test. Reimers conducted an empirical comparison of several[24] multivariate cointegration tests in 1992[57]. Reimers find that Phillips-Ouliaris test is the weakest procedure for bivariate models. Bilgili (1998) states that Monte Carlo simulations show evidence of Johansen test performing better than single equation methods as well as multivariate methods. Bilgili also finds that Engle-Granger test has a problem of generating inconclusive results. With these findings in mind we decide to use the Johansen test of cointegration.

Having performed the ADF-test it is possible to use the Johansen test of cointegration if the results of the ADF-test yields an $I(1)$ process. The Johansen method is a maximum likelihood estimation of cointegration vectors. In our bivariate analyses the null hypothesis states that there are no cointegrating equations between the variables. The number of cointegrating equations are known as cointegration rank. The alternative hypothesis is that there exists one cointegrating equation. In case of multivariate analysis the test will also check if there are more than one cointegrating equations, i.e. higher cointegration ranks. Our cointegration tests look at bivariate combinations of Henry Hub spot with both Henry Hub and NBP futures, NBP spot with both Henry Hub and NBP futures, as well as Henry Hub spot with NBP spot. We specify our model to have a constant but no trend, as we assume the difference

[24] Reimers compare the Johansen test, Phillips-Ouliaris test, Stock-Watson test, and cointegration rank based on order selection criteria.

between the pairs should be constant for the co-movement.

5.4 Test of Cointegration with a Structural Break

The cointegration relationship may change over time and some time series may be cointegrated only in certain time intervals. Thus, it is interesting to look for structural breaks in the cointegration relationship. There are several methods developed for this purpose, some of which are from Banerjee, Lumsdaine-Stock-Bates, Chu, Gregory-Hansen, Hansen, Kramer, Ploberger-Alt, Perron, Perron-Vogelsang, Quintos-Phillips, and Zivot-Andrews[59].

The Gregory-Hansen test (1996) of cointegration with a structural break is based on residuals. The null hypothesis is that there is no cointegration. The test has three possible models:

1. Level shift,
2. Level shift with trend, and
3. Regime shift.

The regime shift has a shift in level and/or possibly a change in the slope coefficients[60]. The test is based on the procedures of finding a structural break in the cointegration relationship from Perron, and Zivot and Andrews. This is the reason for why we choose to perform the Gregory-Hansen test, as apposed to either that of Perron or Zivot and Andrews. In our analysis we use the third option of regime shift. The model used by Gregory and Hansen uses a dummy variable for the unknown break:

$$\phi_{t\tau} = \begin{cases} 0 & \text{if } t \leq n\tau \\ 1 & \text{if } t > n\tau \end{cases} \tag{6}$$

where τ is the relative timing of the break. The model then becomes:

$$y_{1t} = \mu_1 + \mu_2\phi_{t\tau} + \beta_1 t + \beta_2 t\phi_{t\tau} + \alpha_1^T y_{2t} + \alpha_2^T y_{2t}\phi_{t\tau} + e_t, \quad t = 1, ..., n \tag{7}$$

where μ_1, α_1, and β_1 corresponds to intercept, slope, and trend before the break, and similarly μ_2, α_2, and β_2 corresponds to after the regime shift. In our analysis we use bivariate combinations, as previously mentioned.

6 Results and Discussion

The results and discussion section will contain the findings of the analyses performed as well as a discussion around the interpretation. The discussion will also be directed towards similarities and differences from the literature. Statistical significance level will be 5 % as a general rule, but some deviation from this preference can be made were appropriate. As mentioned in Section 4, the time series are transformed into logarithms. We will not specify this in all occasions, and when we are referring to e.g. Henry Hub prices we are in fact referring to the logarithm of the Henry Hub prices. The significance levels will be designated by asterisks such as *** (1 %), ** (5 %), and * (10 %) along with the test statistic in tables.

The econometric approach will be to first find the optimal lags for all combinations of the time series variables that will be used in the analysis. We then proceed with testing the variables for unit-root, which determines whether the process is stationary. Furthermore, we conduct a structural break test of the cointegration relationship between Henry Hub and NBP spot price. The market integration is further investigated with the Johansen test of cointegration. We then move on to consider the futures market efficiency by using the Johansen test and check if the Law of One price and unbiasedness hypothesis holds. Lastly, we consider possible changes of the seasonality in the respective hubs.

6.1 Optimal Lag Selection

The optimal lags are selected for all combinations of variables that will be used in tests that require lag specification. The results will later present a structural break in the cointegrating relationship, and thus, the optimal lag selection will be made for the entire period, and the period prior to the breakpoint as well as post.

6.1.1 Univariate Models

The optimal lag selection for univariate cases will be needed for the ADF-test, which will be conducted later on. We will test the variables both in level and in first difference in the ADF-test to see if the variables are I(1)-processes. Thus, we will need the optimal lag for the variables in level and in first difference. The models estimated in order to calculate AIC in this section are autoregressive (AR(p)) with an unknown lag, p, which we will find.

		Optimal Lag		
Variable	**M**	**Total**	**Prior**	**Post**
Level Henry Hub	0	1	1	1
	1	2	1	2
	2	2	1	2
	3	2	1	2
	4	3	1	4
	5	6	6	4
	6	12	7	1
	7	3	1	12
	8	12	9	12

		Optimal Lag		
Variable	**M**	**Total**	**Prior**	**Post**
First difference Henry Hub	0	0	0	0
	1	1	1	1
	2	1	0	1
	3	1	1	1
	4	0	0	3
	5	7	5	0
	6	11	6	0
	7	0	0	11
	8	11	8	11

Table 2: *Lag selection for univariate models of Henry Hub data.*

		Optimal Lag		
Variable	**M**	**Total**	**Prior**	**Post**
Level NBP	0	12	12	2
	1	12	9	2
	2	12	11	1
	3	12	11	1
	4	12	11	4
	5	12	11	4
	6	12	11	12
	7	12	11	12
	8	3	2	12

		Optimal Lag		
Variable	**M**	**Total**	**Prior**	**Post**
First difference NBP	0	12	12	0
	1	12	12	1
	2	11	10	0
	3	11	10	0
	4	11	10	0
	5	11	10	0
	6	11	10	0
	7	11	10	0
	8	1	1	0

Table 3: *Lag selection of univariate models of NBP data.*

Table 2 and Table 3 show the lags of all prices both spot and futures at Henry Hub and NBP, respectively. In the total period we observe that the NBP data yield higher optimal lag than the Henry Hub data. In the prior period, the lags are generally somewhat lower than for the respective variables in the total period and the NBP variables still require more lags than Henry Hub. In the post period, the Henry Hub data has a higher amount of lags than the prior period, whereas the NBP data has a significantly lower number of lags. The lags in the NBP data is the lowest in the post period, and it is also lower than the Henry Hub lags in the same period. A high amount of lags lowers the test power and there are means available to account for this, however, further consideration of lags will not be made.

6.1.2 Bivariate Models

The bivariate cases are used in the Johansen test of cointegration, as well as the Gregory-Hansen test of cointegration with an unknown structural break. These tests are only dependent on the variables in level. The models estimated in order to calculate AIC in this section are vector autoregressive (VAR(p)) with an unknown lag, p, which we will find.

The tables can be seen in Appendix B, Table 20 and Table 21. In the bivariate cases we will look at spot price against futures prices on each hub, and the spot price at one hub against the futures prices at the other hub in all of the periods. All combinations of variables show the same trend of having the most lags in the total period, and the least lags in the post period. Combinations of spot and futures prices at the respective hubs seem to yield the most lags, compared to the combinations of the spot price on one hub against the futures prices of the other hub.

6.2 ADF-Test

The Augmented Dickey-Fuller test is used only for the univariate cases. We test the time series in level and in first difference to check if they are I(1)-processes. The lags previously determined are used when specifying the tests. By visual inspection of the graphs in Appendix A it seems that the series are I(1)-processes. However, we will test this formally with the ADF-test. The null hypothesis of the test is that the time series have a unit root. This also implies that the time series are non-stationary.

6.2.1 Prices in Level

The prices in level are tested for unit root. As for most economic data we are assuming that the tests will yield unit root and thus state the processes to be non-stationary. Table 4 shows the test statistics for all of the prices with corresponding interpolated Dickey-Fuller critical values at 1 %, 5 %, and 10 % level of significance. The table also contain the MacKinnon approximate p-value for Z(t), which provides a basis of evaluating the hypothesis.

The MacKinnon approximate p-values for Henry Hub and NBP are ranging from 0.11 to 0.43 and 0.13 to 0.30, respectively. All of the null hypotheses are accepted, and the time series are non-stationary in level, as had been expected.

Similar tables for the prior and post periods can be found in Appendix C. In the prior period all of the series had unit root, and are thus non-stationary. However, in the post period there are several of the series that rejects the null hypothesis at 10 %, 5 %, and even 1 % significance level. As stationarity would require alternative methods of testing for cointegration relations, we will test if the level of significance is stronger in the differenced variables in order to disregard stationarity. The amount of work to tailor the analyses to each case is out of the scope of the thesis. It can be mentioned that ARDL bounds test of cointegration could be used, when testing for cointegration among variables with different order of integration.

Level Variable	**M**	**Lags**	**MacKinnon Appr. p-value for Z(t)**	**Test Statistic**	**Interpolated Dickey-Fuller Critical Value**		
					1 %	**5 %**	**10 %**
Henry Hub	0	1	0,1085	-2,529	-3,460	-2,880	-2,570
	1	2	0,1270	-2,454	-3,460	-2,880	-2,570
	2	2	0,1396	-2,408	-3,460	-2,880	-2,570
	3	2	0,1662	-2,318	-3,461	-2,880	-2,570
	4	3	0,1653	-2,321	-3,461	-2,880	-2,570
	5	6	0,3669	-1,828	-3,463	-2,881	-2,571
	6	12	0,3813	-1,798	-3,465	-2,881	-2,571
	7	3	0,2632	-2,054	-3,462	-2,880	-2,570
	8	12	0,4279	-1,706	-3,466	-2,881	-2,571
NBP	0	12	0,1266	-2,456	-3,463	-2,881	-2,571
	1	12	0,1531	-2,361	-3,463	-2,881	-2,571
	2	12	0,1371	-2,417	-3,464	-2,881	-2,571
	3	12	0,1473	-2,381	-3,464	-2,881	-2,571
	4	12	0,1466	-2,383	-3,464	-2,881	-2,571
	5	12	0,1520	-2,365	-3,465	-2,881	-2,571
	6	12	0,1520	-2,364	-3,465	-2,881	-2,571
	7	12	0,1266	-2,456	-3,465	-2,881	-2,571
	8	3	0,2951	-1,981	-3,463	-2,881	-2,571

Table 4: *ADF-test of the prices at both Henry Hub and NBP for the total period. All prices are in level.*

6.2.2 Prices in First Difference

We then go on to test the prices in first difference for unit root. We will now expect the tests to reject the null hypotheses of no unit root, which then will mean that the data are stationary. With the prices in level being non-stationary, we can then conclude with the time series being integrated of order 1, i.e. I(1)-processes. Table 5 shows the test statistics with corresponding critical values and MacKinnon approximate p-value for Z(t), as previously.

The results from the tests of the total period can be seen in Table 5. The MacKinnon approximate p-values for Henry Hub and NBP are ranging from 0 to 0,0002 and 0 to 0,0031, respectively. All of the null hypotheses are rejected, and the time series are stationary in first difference. In addition, we notice that all of the time series are significant at 1 % significance level, which indicates a strong evidence.

First difference Variable	M	Lags	MacKinnon Appr. p-value for Z(t)	Test Statistic	Interpolated Dickey-Fuller Critical Value 1 %	5 %	10 %
Henry Hub	0	0	0,0000	-15,747***	-3,460	-2,880	-2,570
	1	1	0,0000	-11,3***	-3,460	-2,880	-2,570
	2	1	0,0000	-11,498***	-3,460	-2,880	-2,570
	3	1	0,0000	-10,933***	-3,461	-2,880	-2,570
	4	0	0,0000	-16,297***	-3,461	-2,880	-2,570
	5	7	0,0000	-7,059***	-3,463	-2,881	-2,571
	6	11	0,0001	-4,604***	-3,465	-2,881	-2,571
	7	0	0,0000	-14,82***	-3,462	-2,880	-2,570
	8	11	0,0002	-4,519***	-3,466	-2,881	-2,571
NBP	0	12	0,0014	-4,007***	-3,463	-2,881	-2,571
	1	12	0,0019	-3,913***	-3,464	-2,881	-2,571
	2	11	0,0013	-4,013***	-3,464	-2,881	-2,571
	3	11	0,0017	-3,945***	-3,464	-2,881	-2,571
	4	11	0,0016	-3,958***	-3,464	-2,881	-2,571
	5	11	0,0019	-3,916***	-3,465	-2,881	-2,571
	6	11	0,0025	-3,847***	-3,465	-2,881	-2,571
	7	11	0,0031	-3,783***	-3,465	-2,881	-2,571
	8	1	0,0000	-8,601***	-3,462	-2,880	-2,570

Table 5: *ADF-test of the prices at both Henry Hub and NBP for the total period. All prices are in first difference.*

Similar tables for the prior and post periods can be found in Appendix C. In the period prior to the breakpoint, all of the Henry Hub data are significant at 1 %, but the NBP data is less significant and the 1 month futures contract shows a p-value of as much as 8 %. We will consider the 10 % significance level as sufficient evidence in this case. However, it is possible that this series could be more accurately described as an I(2)-process. In the period post breakpoint, all series are significant at 1 %, except for the 8 months Henry Hub futures contract which is significant at 5 %. Thus, with a few possible exceptions we can conclude that the time series data are integrated of order 1. This means that the series can be used in our tests of cointegration, without violating of the assumptions of the tests.

6.3 Market Integration

In this thesis the US and UK markets are considered integrated if there exist a cointegration relations between the Henry Hub and NBP spot prices. The interpretation of cointegration will then be that the prices in the two markets tend to co-move and converge in the long run. The Henry Hub spot price will be considered representative for the US market, and the NBP spot price for the UK market. However, we are not only interested in whether or not they are integrated, but rather if there has occurred any change in the integration during the period February 1997 - March 2018. Therefore, we will conduct a Gregory-Hansen test of cointegration with an unknown breakpoint for Henry Hub against NBP spot prices. Furthermore, we will separate the data into a period prior to the breakpoint and post breakpoint.

				Asymptotic critical value		
	Test statistic	**Breakpoint**	**Date**	**1 %**	**5 %**	**10 %**
Zt	-5,19**	141	October 2008	-5,47	-4,95	-4,68
Za	-49,09**	141	October 2008	-57,17	-47,04	-41,85

Table 6: *Gregory-Hansen test for structural break in a cointegration relationship between the Henry Hub and NBP spot prices.*

The null hypothesis in the Gregory-Hansen test is that there is no regime shift in the cointegration relationship. Given the $Z(t)$ or $Z(a)$ statistic along with the respective critical values in Table 6, we can conclude with there being a statistically significant breakpoint in the cointegration relationship between Henry Hub and NBP spot prices. The structural break is found to be in October 2008. The breakpoint seem to be neatly represented in the spot spread, which can be seen in Figure 13. Recalling from Section 3.3 and 3.4.1 we can compare this to the breakpoint found by Adams and Gluck (2015) and Aruga (2016). The findings of Adams and Gluck were related to commodity market financialization in general and not natural gas markets specifically. The breakpoint they found was in September 2008 and was concluded to be the point in time where the effects of the investments from institutions affected the correlation of the returns on commodities and stocks. With regards to the two natural gas markets, the literature shows that Henry Hub prices are affected by the

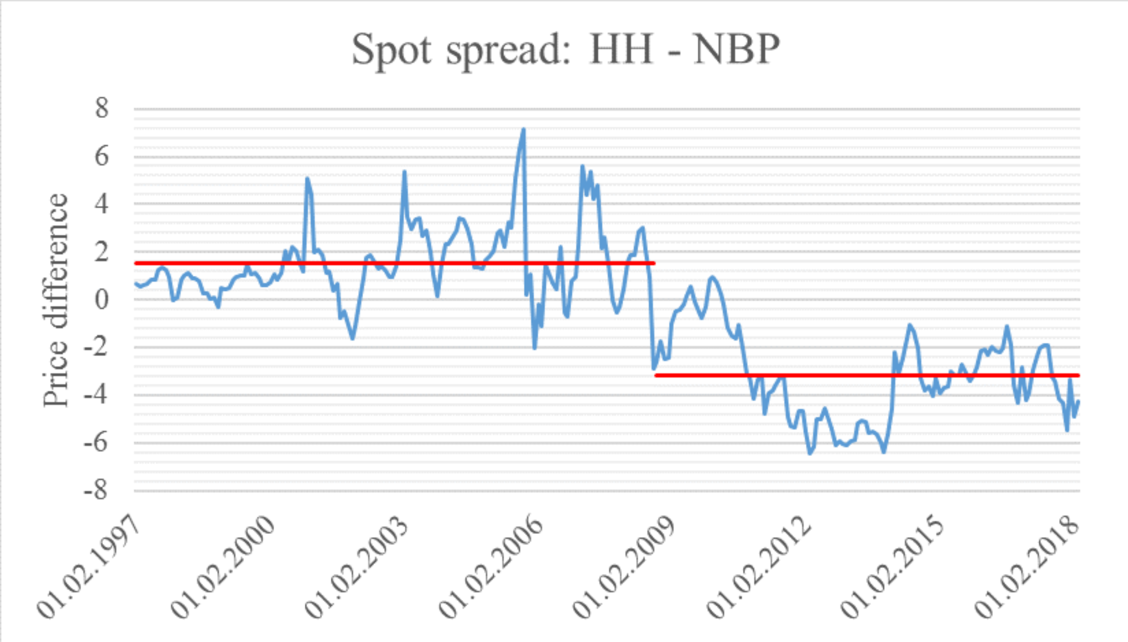


Figure 13: *Spot price spread between Henry Hub and NBP. The red lines indicate the average spot spread in each sub-period.*

stock markets, but that NBP prices are not.[38] In that sense, commodity market financialization could affect the cointegration relationship between the two markets. Increased investment flow from the institutional investors would further correlated the Henry Hub prices with the stock and bond markets. However, a question which remains to be answered is if increasing levels of investment flow could initiate a decoupling of NBP and Brent prices.

The second breakpoint we would like to compare from the literature is that of Aruga (2016), which is related to the shale gas revolution. The breakpoint he located is related to the natural gas production data in the US. This means it is an indication of the point in which the natural gas production from shale gas started to make a statistically significant impact on the total US natural gas production. As such, it is not indicative of when the effects from the shale gas revolution occurred. The breakpoint was located in August 2006. As prices are affected by market dynamics (i.e. both supply and demand) and that supply is affected by the supply chain, it is not necessary that the effects from the increased production would be significant straight off. Thus, it is possible that the breakpoint located in this thesis, October 2008, is related to the onset of the effects from the increase in shale gas revolution from August 2006.

Period	**Rank**	**Parms**	**Trace Statistic**	**Critical Value**	
				5 %	**1 %**
Total	0	46	9,285***	15,41	20,04
	1	49	1,2929	3,76	6,65
Prior	0	10	29,4182	15,41	20,04
	1	13	2,1135***	3,76	6,65
Post	0	6	16,811***	15,41	20,04
	1	9	4,4718	3,76	6,65

Table 7: *Johansen test of cointegration on Henry Hub spot vs NBP spot for all periods.*

The Johansen test of cointegration was conducted for the total period as well as the periods prior and post structural break. The null hypothesis of the test is that there exists a higher cointegration rank. In a bivariate case, this can be rank 1 at the most. The statistical findings can be seen in Table 7. When considering the total period, there is not a significant cointegration relation between the Henry Hub and NBP spot prices. Looking further, the period prior to the breakpoint was cointegrated and the period post was not. Thus, it has not only gone from one cointegration relation to another, but the cointegration has disappeared. Prior to the breakpoint, the natural gas markets were booming along with the commodity markets in general. In addition to this, the Henry Hub prices were linked to the WTI prices, and the NBP prices were linked to the Brent prices. Assuming we can state that WTI and Brent were highly integrated, then this would also suggest that Henry Hub and NBP were integrated. However, after the financial crisis, the Henry Hub natural gas prices decoupled from the WTI prices, and the NBP prices remained linked to the Brent prices.

Furthermore, the change in cointegration relation is consistent with the result of Li et al. (2014). They mention two main factors that could be the reason for the change in the cointegration relation: 1. With the shale gas revolution the US has increased their own supplies to the level where they are not dependent on import trades with the rest of the world. Furthermore, they have not had proper

LNG infrastructure to export their abundant supplies to hold a connection with the other markets, segregating themselves from the global trade. 2. As we have already mentioned the Henry Hub prices have decoupled from oil prices and developed a gas-on-gas price competition, while NBP stays linked through oil indexed contracts.

			95 % Confidence Interval (β)	
Period	α	β	**Lower**	**Upper**
Total	-2,440288	0,6729895	-0,1739225	1,519901
Prior	-0,3890879	-0,9745582	-1,157872	-0,791244
Post	-1,924315	0,4055163	-0,2293244	1,040357

Table 8: *LOP for Henry Hub vs NBP spot prices in all periods.*

The Law of One Price is tested by creating a vector error correction model (VECM) and evaluating the confidence interval of the slope coefficient, β. In order to fulfill the requirements for the LOP, the slope coefficient must be equal to -1 (i.e. $\beta = (1, -1)$). The VECM is misspecified when the underlying variables are not cointegrated. Furthermore, it is not of interest to test the LOP when we know that the variables are not cointegrated. As the period prior to the structural break is the only period which is cointegrated in this instance, we will only consider the VECM of this period. As can be seen from Table 8, the 95 % CI contains -1, and it is a statistically significant evidence of fulfilling the Law of One Price.

6.4 Futures Market Efficiency

With respect to futures market efficiency we will test the futures market for Henry Hub contracts and NBP contracts both separately and across the markets. The futures price will be tested against the spot price and we will look for evidence of cointegration, the Law of One Price and unbiasedness hypothesis. This analysis will be conducted for the total period and the sub-periods prior to- and post structural break in October 2008. The futures markets are not expected to be efficient across the two markets, but we will conduct the analyses as it is an easy extension to the futures market efficiency on each of the markets. The test of cointegration will be conducted as previously, with the Johansen test. The tests for LOP and unbiasedness are conducted by constraining coefficients in the resulting vector error correction models of the cointegrated time series variables.

6.4.1 Total Period Efficiency

The first step in the procedure is to conduct the Johansen test of cointegration. We are testing for a cointegration relation between the spot price and the futures price without an intercept and a trend. By evaluating the trace statistics and comparing this to the critical values we can conclude with regards to the variables being cointegrated or not. The results of the cointegration test can be seen in Table 9.

Henry Hub spot price is cointegrated with the Henry Hub futures prices for all maturities, 1 month through 8 months. The statistical significance provide a strong evidence of cointegration as all of the variables are cointegrated with a significance level of less than 1 %. Thus, we can conclude with the data indicating a cointegrated market for futures contracts in the US market in the period February 1997 to March 2018. Relating this to the literature on futures market efficiency on the Henry Hub contracts we know that Walls (1995) found the contracts to be cointegrated in the period June 1990 to January 1994, and Movassagh and Modjtahedi (2005) also found the contracts to be cointegrated in the period 1990 to 2003.

Cointegration test results on the NBP futures market also provides strong evi-

Variable	M	Rank	Parms	Trace Statistic	Critical Value 5 %	1 %
Henry Hub Spot	1	0	4	99,0879	12,53	16,31
		1	7	0.4039***	3,84	6,51
	2	0	44	38,3363	12,53	16,31
		1	47	0.0897***	3,84	6,51
	3	0	44	49,0107	12,53	16,31
		1	47	0.0599***	3,84	6,51
	4	0	44	53,311	12,53	16,31
		1	47	0.0363***	3,84	6,51
	5	0	36	56,4647	12,53	16,31
		1	39	0.0543***	3,84	6,51
	6	0	32	60,7072	12,53	16,31
		1	35	0.0340***	3,84	6,51
	7	0	36	65,9864	12,53	16,31
		1	39	0.0565***	3,84	6,51
	8	0	36	60,8491	12,53	16,31
		1	39	0.0374***	3,84	6,51
NBP Spot	1	0	44	28,4249	12,53	16,31
		1	47	0.0108***	3,84	6,51
	2	0	44	19,2199	12,53	16,31
		1	47	0.0262***	3,84	6,51
	3	0	44	22,2448	12,53	16,31
		1	47	0.0262***	3,84	6,51
	4	0	40	41,9516	12,53	16,31
		1	43	0.0753***	3,84	6,51
	5	0	40	37,0331	12,53	16,31
		1	43	0.2194***	3,84	6,51
	6	0	40	55,1755	12,53	16,31
		1	43	0.2902***	3,84	6,51
	7	0	40	58,2032	12,53	16,31
		1	43	0.3260***	3,84	6,51
	8	0	40	48,4806	12,53	16,31
		1	43	0.3445***	3,84	6,51

Table 9: *Johansen test of cointegration in the respective futures markets for the total period.*

dence of cointegration. All of the NBP futures contract prices are cointegrated with the NBP spot price at a 1 % significance level. The results of the cointegration tests are as expected, since the graphical representation of the prices clearly show that the futures prices and the spot price have co-movement. Thus, we will continue the analysis of LOP and unbiasedness hypothesis on the cointegrated variables found on the Henry Hub and NBP futures market.

				95 % Confidence Interval (β)	
Variable	**M**	α	β	**Lower**	**Upper**
Henry Hub Spot	1	0,0168052	-1,000486	-1,021751	-0,9792222
	2	0,003913	-0,9742663	-0,9965994	-0,9519332
	3	0,008658	-0,9637316	-0,9934568	-0,9340064
	4	0,0087488	-0,9543831	-0,9938154	-0,9149508
	5	0,0017705	-0,9447417	-0,9977056	-0,8917779
	6	0,0240051	-0,9515474	-1,007992	-0,8951029
	7	-0,0017685	-0,9300715	-0,9861523	-0,8739908
	8	-0,0199644	-0,9153476	-0,9710639	-0,8596313
NBP Spot	1	0,0125476	-0,9978632	-1,012162	-0,9835647
	2	0,0366785	-0,996629	-1,021409	-0,9718487
	3	0,0500342	-0,9982332	-1,026734	-0,9697319
	4	0,0675433	-0,996938	-1,027603	-0,9662728
	5	0,0764462	-0,9940521	-1,029197	-0,9589072
	6	0,0781642	-0,9902742	-1,033143	-0,9474058
	7	0,0552718	-0,9731359	-1,013401	-0,9328708
	8	0,0818584	-0,9813793	-1,031811	-0,930948

Table 10: *LOP for Henry Hub and NBP spot price against their respective futures contract prices in the total period.*

In order to fulfill the requirements of the Law of One Price, the confidence interval of β must contain the value -1 for the vector error correction model, with an unconstrained intercept coefficient, α. From Table 10 the results of the models on both futures market can be seen. The confidence intervals provide evidence of the LOP in Henry Hub futures contracts with maturity 1 and 6 months, but not in the rest of the contracts. Considering the lower bound of the confidence interval, it is noticeable that most of the contracts reach as far as -0.99 and are thus close to fulfilling the LOP. The results are somewhat unexpected as the efficiency should be greater in the contracts with shorter maturity as the trading volumes increase with decreasing maturity. Yet, several researchers have reported that the market was inefficient and biased in that period (e.g. Mazighi (2003), Movassagh and Modjtahedi (2005)).

As for NBP futures market, the test-results in Table 10 seem to fulfill the LOP in all futures contracts. This is evidence of efficiency in the NBP futures market, however, we cannot yet claim that the market is efficient.

				95 % Confidence Interval (β)	
Variable	**M**	α	β	**Lower**	**Upper**
Henry Hub Spot	1	0	-0,989293	-0,9958719	-0,9827142
	2	0	-0,9715506	-0,9776707	-0,9654305
	3	0	-0,9578121	-0,9658627	-0,9497616
	4	0	-0,9482586	-0,9588035	-0,9377137
	5	0	-0,9422371	-0,9564577	-0,9280166
	6	0	-0,9354821	-0,9504533	-0,920511
	7	0	-0,9305121	-0,9452663	-0,9157578
	8	0	-0,9260396	-0,9405413	-0,911538
NBP Spot	1	0	-0,9893116	-0,9946817	-0,9839415
	2	0	-0,977954	-0,987349	-0,968559
	3	0	-0,9705386	-0,9815313	-0,959546
	4	0	-0,9638247	-0,9753533	-0,952296
	5	0	-0,9578039	-0,9705829	-0,9450249
	6	0	-0,9520383	-0,9672011	-0,9368756
	7	0	-0,9474445	-0,9609988	-0,9338902
	8	0	-0,9424256	-0,9593756	-0,9254756

Table 11: *Unbiasedness hypothesis for Henry Hub and NBP spot prices against their respective futures contract prices in the total period.*

The unbiasedness hypothesis requires the futures price to be an unbiased predictor of the future spot price. In the models presented, this requires an intercept coefficient, α, of zero, and a slope coefficient, β, of -1. By imposing the constraint $\alpha = 0$, we will utilize the confidence interval for β to answer the hypothesis. Recalling that LOP has the constraint $\alpha = 0$, the unbiasedness hypothesis is a stricter test, which cannot be satisfied without the LOP being satisfied. As the Henry Hub futures contracts 1 and 6 months, and all NBP contracts fulfill the LOP, those er the ones we will test the unbiasedness hypothesis on. The results are presented in Table 11. All of the variables seem to be statistically significant in rejecting the null hypothesis of unbiased predictor of the future spot price. As a result none of the futures contracts fulfill the unbiasedness hypothesis. Furthermore, we can now conclude with none of the futures contract markets being efficient when considering the total period of February 1997 to March 2018.

6.4.2 Prior Period Efficiency

Now that we have established the lack of efficiency in the futures markets during the February 1997 - March 2018 period as a whole, we will look closer on the futures market efficiency in the period prior to the breakpoint, i.e. February 1997 - October 2008. This incorporates the commodity boom era, and the very beginning of the shale gas revolution. As for the total period, we start of by considering the cointegration relations in the variables. The results of the Johansen test of cointegration can be seen in Table 12.

In the Henry Hub futures market it is evident that all of the futures contracts with maturity 1 month through 8 months rejects the null hypothesis at rank 1, meaning that the cointegrating rank 1 is the statistically significant rank. Thus, all of the futures contracts are cointegrated with the spot price. Related to the total period, we now know that the Henry Hub futures contracts were cointegrated with the spot price in both the total period seen as a whole, and in the period prior to the breakpoint. In the NBP futures market the futures contracts were cointegrated with the spot price at a significance level of 1 % as well. As we use 5 % as enough evidence of a cointegrating relation, all of the futures contracts are cointegrated with their respective spot price. We will now further proceed with a test of LOP for the cointegrated variables.

The Henry Hub futures contracts were all cointegrated, but only contract maturity of 1 month fulfill the LOP. We would have expected several of the short horizon contracts to fulfill the LOP, and the market seems to show signs of inefficiency. Movassagh and Modjtahedi (2005) found that maturities 1 through 3 were unbiased, however, our results indicate that maturities 2 and 3 does not even fulfill the LOP. All of the NBP futures contracts were cointegrated as well. In these contracts, there were none displaying evidence of the LOP. Compared to the period as a whole, it is evident that only the 1 month contract fulfills the LOP in both the total and the prior period. The NBP contracts shows an absence of LOP in the prior period, even though all contracts fulfill the LOP in the total period.

Variable	M	Rank	Parms	Trace Statistic	Critical Value 5 %	Critical Value 1 %
Henry Hub Spot	1	0	0	259,9079	12,53	16,31
		1	3	0.0283***	3,84	6,51
	2	0	44	38,3403	12,53	16,31
		1	47	1.8024***	3,84	6,51
	3	0	44	50,0758	12,53	16,31
		1	47	1.7494***	3,84	6,51
	4	0	44	50,6682	12,53	16,31
		1	47	1.7869***	3,84	6,51
	5	0	44	41,2572	12,53	16,31
		1	47	1.2937***	3,84	6,51
	6	0	32	49,9997	12,53	16,31
		1	35	1.5697***	3,84	6,51
	7	0	36	42,8845	12,53	16,31
		1	39	1.4128***	3,84	6,51
	8	0	44	46,3335	12,53	16,31
		1	47	2.3876***	3,84	6,51
NBP Spot	1	0	44	33,1009	12,53	16,31
		1	47	1,4168***	3,84	6,51
	2	0	44	24,6166	12,53	16,31
		1	47	1.1267***	3,84	6,51
	3	0	44	24,0358	12,53	16,31
		1	47	1.0110***	3,84	6,51
	4	0	40	40,2305	12,53	16,31
		1	43	1.1290***	3,84	6,51
	5	0	40	35,0658	12,53	16,31
		1	43	1.6286***	3,84	6,51
	6	0	40	54,876	12,53	16,31
		1	43	2.2935***	3,84	6,51
	7	0	40	55,5419	12,53	16,31
		1	43	2.1283***	3,84	6,51
	8	0	40	35,2801	12,53	16,31
		1	43	1.7607***	3,84	6,51

Table 12: *Johansen test of cointegration in the respective futures markets for the period prior to the breakpoint.*

In order to fulfill the unbiasedness hypothesis, the LOP needs to be fulfilled as well, as previously described. Thus, we will only look at the Henry Hub 1 month contract that satisfied the test of LOP. The unbiasedness hypothesis was tested as for the total period. Table 14 indicates that the 1 month contract does not fulfill the unbiasedness hypothesis. Even though all of the contracts were cointegrated and 1

Variable	M	α	β	95 % Confidence Interval (β)	
				Lower	Upper
Henry Hub Spot	1	0,0392272	-1,008333	-1,032634	-0,9840333
	2	0,0249191	-0,9833414	-0,9990354	-0,9676475
	3	0,0183648	-0,9650646	-0,9891127	-0,9410165
	4	0,0039763	-0,9490859	-0,983662	-0,9145098
	5	-0,0007995	-0,9414983	-0,9882061	-0,8947905
	6	-0,0315891	-0,9269531	-0,9903507	-0,8635555
	7	-0,022984	-0,9149316	-0,9669719	-0,8628913
	8	-0,0255836	-0,9183885	-0,9850411	-0,851736
NBP Spot	1	-0,0086965	-0,9746745	-0,9843493	-0,9649998
	2	0,0040212	-0,952075	-0,9699642	-0,9341857
	3	0,0163562	-0,94568	-0,9672122	-0,9241479
	4	0,0233019	-0,9368601	-0,9646246	-0,9090956
	5	0,0184064	-0,9224597	-0,9543288	-0,8905907
	6	0,0289487	-0,9136223	-0,9501544	-0,8770902
	7	-0,0195411	-0,8837356	-0,9180069	-0,8494643
	8	0,0029056	-0,8840922	-0,932343	-0,8358413

Table 13: *LOP for Henry Hub and NBP spot price against their respective futures contract prices in the total period prior to the breakpoint.*

Variable	M	α	β	95 % Confidence Interval (β)	
				Lower	Upper
Henry Hub Spot	1	0	-0,9868005	-0,9951476	-0,9784534
	2	0	-0,9657306	-0,9707515	-0,9607097
	3	0	-0,9510104	-0,9575173	-0,9445035
	4	0	-0,9432146	-0,9520916	-0,9343376
	5	0	-0,9346824	-0,9495528	-0,919812
	6	0	-0,9310878	-0,9516091	-0,9105665
	7	0	-0,9235543	-0,941113	-0,9059956
	8	0	-0,9181172	-0,9404034	-0,8958309
NBP Spot	1	0	-0,9766762	-0,9806538	-0,9726986
	2	0	-0,9544114	-0,9618927	-0,9469302
	3	0	-0,9426605	-0,9514837	-0,9338373
	4	0	-0,931674	-0,9430106	-0,9203374
	5	0	-0,9219463	-0,9349446	-0,9089479
	6	0	-0,9112064	-0,9261549	-0,8962579
	7	0	-0,9063483	-0,9214571	-0,8912395
	8	0	-0,8959161	-0,9161761	-0,875656

Table 14: *Unbiasedness hypothesis for Henry Hub and NBP spot prices against their respective futures contract prices in the period prior to the breakpoint.*

contract fulfilled the LOP, both markets seem to be inefficient. As a result, it is clear that the futures markets, both at Henry Hub and NBP, were inefficient in the period prior to the breakpoint, and in the period as a whole. Relating this to the results found by Movassagh and Modjtahedi (2005) on the Henry Hub market, our results are in accordance with most futures contracts being biased predictors of the future spot price. Also, Mazighi (2003) found that both Henry Hub and NBP were inefficient, which we would agree upon.

6.4.3 Post Period Efficiency

The last period of interest in this thesis is the period post breakpoint, i.e. October 2008 - March 2018. From the former analyses we know that the markets were inefficient in the prior period and in the period as a whole. We will now conduct the same analyses on the most recent period, which include the post-financial crisis period and the period of rapid shale gas production growth in the US. As this period is of more recent times, the literature is scarce and there are few related results.

The Johansen test of cointegration for the period post breakpoint provided the results in Table 15. In this period all of the Henry Hub futures contracts had a cointegrating rank of 1 with the spot price. Thus, all of the contracts are cointegrated with the spot price. The significance level is 1 % in all of the cases. As a result, we now know that the Henry Hub futures contracts were cointegrated for the total period, and the periods prior to and post breakpoint in October 2008. The cointegration relationships on the NBP data show similar results. All of the contracts are cointegrated with the spot price, with a cointegration rank of 1 and a significance level of 1 %. The fact that the futures prices co-move is obvious, and the results of cointegrated variables validate the econometric approach. We will now consider the LOP for the period post breakpoint.

With cointegration of all futures contracts with the respective spot prices, we can evaluate the LOP for all of the contracts. The results from the tests can be seen in Table 16. The confidence intervals for β lead to the conclusion that the futures contracts on Henry Hub with maturity 1 through 5, and 7 months contracts fulfill the LOP. Compared to the prior period where only contract maturity 1 month fulfilled the LOP, this is a great improvement of the futures market efficiency. With the two sub-periods we use in this thesis it would then seem that the futures market has become more efficient throughout the period February 1997 - March 2018. It is possible that this is related to the commodity market financialization, which has increased trading volumes and thus possibly also the exploitation of arbitrage opportunities. The futures market on NBP shows a similar trend. All of the fu-

Variable	M	Rank	Parms	Trace Statistic	Critical Value 5 %	Critical Value 1 %
Henry Hub Spot	1	0	4	55,5065	12,53	16,31
		1	7	2.3120***	3,84	6,51
	2	0	4	113,5635	12,53	16,31
		1	7	2.0605***	3,84	6,51
	3	0	4	51,0585	12,53	16,31
		1	7	2.3140***	3,84	6,51
	4	0	4	43,9382	12,53	16,31
		1	7	2.2996***	3,84	6,51
	5	0	4	35,9156	12,53	16,31
		1	7	2.2369***	3,84	6,51
	6	0	0	26,7997	12,53	16,31
		1	3	2.2530***	3,84	6,51
	7	0	0	26,046	12,53	16,31
		1	3	2.3687***	3,84	6,51
	8	0	36	35,501	12,53	16,31
		1	39	5.0023***	3,84	6,51
NBP Spot	1	0	0	161,9838	12,53	16,31
		1	3	0.5077***	3,84	6,51
	2	0	0	73,7576	12,53	16,31
		1	3	0.5049***	3,84	6,51
	3	0	24	24,8192	12,53	16,31
		1	27	0.4258***	3,84	6,51
	4	0	24	24,1783	12,53	16,31
		1	27	0.4254***	3,84	6,51
	5	0	24	20,3074	12,53	16,31
		1	27	0.4266***	3,84	6,51
	6	0	16	35,4236	12,53	16,31
		1	19	0.4946***	3,84	6,51
	7	0	16	29,3018	12,53	16,31
		1	19	0.4936***	3,84	6,51
	8	0	16	25,0981	12,53	16,31
		1	19	0.4016***	3,84	6,51

Table 15: *Johansen test of cointegration in the respective futures markets for the period post breakpoint.*

tures contracts 1 through 8 months fulfill the LOP. In the prior period there were no contracts that did so. As for Henry Hub contracts, the NBP futures trading volumes have increased over the years, and this could leave to greater efficiency in the futures market. However, as mentioned by Zhang et al. (2017), the NBP market has not experienced the same effects from the commodity market financialization as the Henry Hub market. Nevertheless, our results show that the futures market

				95 % Confidence Interval (β)	
Variable	**M**	α	β	**Lower**	**Upper**
Henry Hub Spot	1	-0,0016965	-0,9855728	-1,028835	-0,9423108
	2	0,04825	-1,01501	-1,096506	-0,9335145
	3	0,100594	-1,041845	-1,17382	-0,9098707
	4	0,0504698	-0,9691508	-1,129766	-0,8085357
	5	-0,0506711	-0,8747233	-1,01462	-0,7348269
	6	-0,1058444	-0,8236242	-0,9772836	-0,6699648
	7	-0,0178576	-0,8933004	-1,012928	-0,7736727
	8	-0,0936026	-0,8342591	-0,9290356	-0,7394825
NBP Spot	1	0,0749816	-1,034614	-1,081077	-0,9881517
	2	0,140046	-1,060819	-1,15317	-0,9684675
	3	0,2992077	-1,138978	-1,306096	-0,9718598
	4	0,0914781	-1,024432	-1,176157	-0,8727062
	5	0,1094176	-1,028612	-1,187388	-0,8698348
	6	0,2206449	-1,080742	-1,259574	-0,9019092
	7	0,2677764	-1,100117	-1,276276	-0,9239589
	8	0,3378815	-1,13247	-1,349539	-0,9154019

Table 16: *LOP for Henry Hub and NBP spot price against their respective futures contract prices in the period post breakpoint.*

cointegration and LOP fulfillment has greatly improved in the period October 2008 - March 2018.

Lastly, we conduct the unbiasedness hypothesis on the period post breakpoint. The results of the tests can be seen in Table 17. The only contracts who could possibly stand the scrutiny of the test are those that were found to fulfill the LOP. The 1 and 3 months futures contracts on NBP accepts the unbiasedness hypothesis. Our results are thus indicative of the NBP futures market being more efficient than the Henry Hub futures market. However, there are only two short-term contracts that are unbiased predictors of the future spot price. The futures markets are to a great extent still inefficient, both on Henry Hub and NBP.

				95 % Confidence Interval (β)	
Variable	**M**	α	β	**Lower**	**Upper**
Henry Hub Spot	1	0	-0,9899067	-0,9993534	-0,9804601
	2	0	-0,9768808	-0,9944135	-0,9593481
	3	0	-0,9589209	-0,986034	-0,9318079
	4	0	-0,9370363	-0,9699921	-0,9040805
	5	0	-0,9278418	-0,9560776	-0,899606
	6	0	-0,9173038	-0,9490376	-0,88557
	7	0	-0,9243686	-0,9498559	-0,8988813
	8	0	-0,9090988	-0,9307988	-0,8873987
NBP Spot	1	0	-0,9954357	-1,002613	-0,9882587
	2	0	-0,986537	-0,9994302	-0,9736437
	3	0	-0,9814552	-1,001655	-0,9612552
	4	0	-0,9755271	-0,9919089	-0,9591453
	5	0	-0,9708277	-0,9869389	-0,9547166
	6	0	-0,9670745	-0,9837459	-0,9504031
	7	0	-0,9625086	-0,9784437	-0,9465736
	8	0	-0,9585632	-0,9775215	-0,9396049

Table 17: *Unbiasedness hypothesis for Henry Hub and NBP spot prices against their respective futures contract prices in the period post breakpoint.*

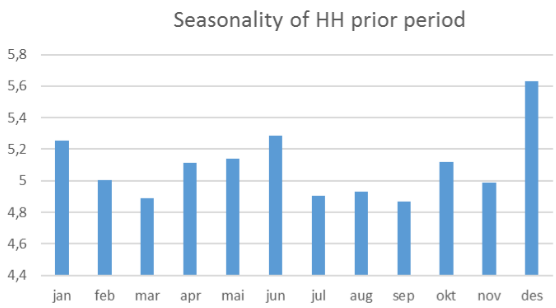
6.4.4 Efficiency Across Markets

As an extension of the analyses performed we would like to test the efficiency of the futures contracts in one market as predictors of the spot price in the other market. It is not expected that the markets will exhibit this efficiency, especially with the obtained results on the respective efficiencies. Even though we have established cointegration relation between Henry Hub and NBP spot, the futures contracts are not unbiased predictors of the future spot price. However, it is easily performed with the method at hand.

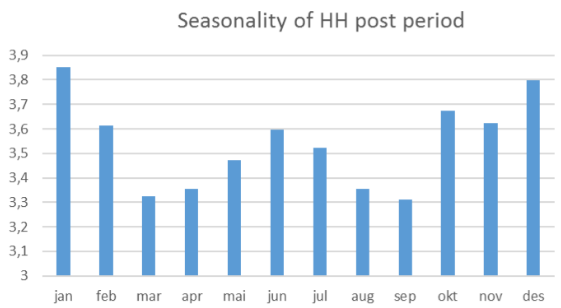
The results can be found in Appendix E for the total, prior, and post periods. The results are in line with the expectation that there should not be any statistically significant relation between the futures price of one market and the spot price of the other market. As the Johansen test of cointegration shows that only the Henry Hub spot and NBP 8 months futures contract show a sign of cointegration, we can conclude with there being no significant sort of efficiency across the markets. All the contracts that to not have a significant cointegration relation will neither fulfill the LOP nor accept the unbiasedness hypothesis.

6.5 Seasonality

Seasonality in Henry Hub for the total and the sub-periods are presented in Figure 14. As for the total period, the prior period show some signs of a seasonal pattern with a peak during the winter months and a smaller peak during the summer months. For the post period this pattern becomes even more visible, with a clear peak during June and December/January. We relate this to the effect of increased natural gas usage for power generation and residential use. With the lower prices in the post period natural gas has become the preferred energy source relative to substitutes.



(a) *Prior period*



(b) *Post period*

Figure 14: *Seasonality in Henry Hub spot prices prior to and post breakpoint.*

Our discovery is however contradicting to the result of Geng et al. (2016). They found indication of the seasonal pattern in Henry Hub disappearing. As mentioned in Section 2 the seasonal pattern in the natural gas markets comes from the changes in demand during winter and summer. Before the shale gas revolution, Henry Hub experienced the normal seasonal price pattern. However, after the revolution the US capacity reached levels that could satisfy the demand throughout the year. Without the infrastructure to export the excess natural gas, they had an excess of supplies and did not experience the usual seasonal price volatility.

The data used by Geng et al. (2016) were ranged between 1997-2016. We therefore took a look at the seasonality up to 2016 with our dataset, to compare the

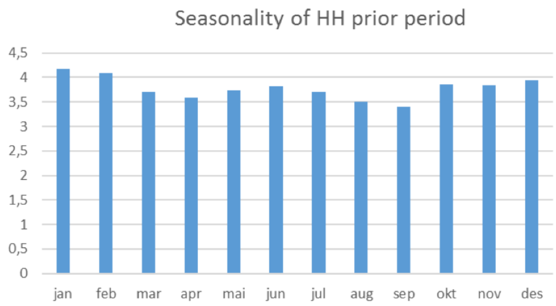
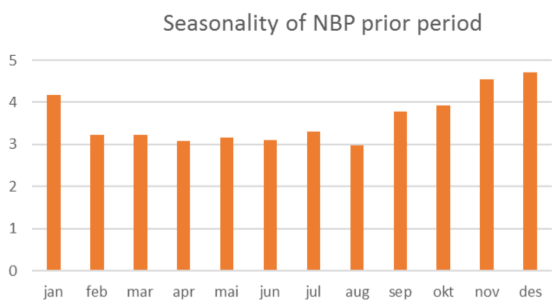
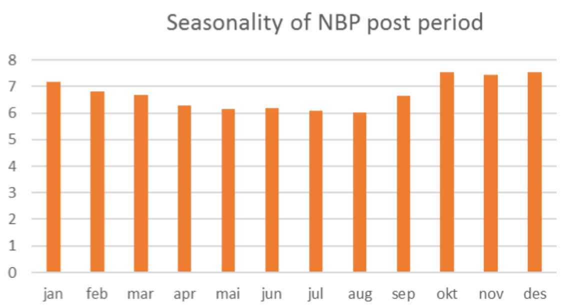


Figure 15: *Seasonality in Henry Hub spot prices between 1997 and 2016.*

effect of two extra years of data. The result is shown in Figure 15. The seasonal pattern for this period shows a much more smoothed out pattern and is more in line with the result of Geng et al. (2016). Thus, it is reasonable to say that something significant has happened the last two years to introduce seasonality back to Henry Hub. All though, we observe that the seasonality is very sensitive to the sample period length so further analysis into the change of seasonality could be interesting for future research. However, as mentioned in section 2.4, the US has been finishing their export facilities and has been increasing their export activity. We therefore argue that with reducing storage levels in the US and increased trade activity in the global marked the seasonal pattern can have returned to the US market.



(a) *Prior period*



(b) *Post period*

Figure 16: *Seasonality in NBP spot prices prior to and post breakpoint.*

Seasonality in NBP for the total and sub-periods are presented in Figure 16. We see that the seasonality is clearly visible for both periods. It even seems as though the seasonal pattern was more apparent in the prior period. This could come from the fact that the use of natural gas in the residential sector has decreased in relative importance in the latter period as mentioned in section 2.3.

7 Concluding Remarks

This thesis has analyzed the Henry Hub and NBP natural gas markets with respect to market integration and futures market efficiency in the period February 1997 - March 2018. The time series data was to a large extent found to be non-stationary processes with order of integration 1 (I(1)-processes) which is typical for economic data.

The data set contained a statistically significant structural break in the market integration relationship between Henry Hub and NBP spot prices in October 2008. This was found by using the Gregory-Hansen method for structural breaks in cointegration relations. Further testing with the Johansen test of cointegration revealed a cointegration relation between the markets satisfying the LOP in the period prior to the structural break that has later disappeared in the period post structural break. The shale gas revolution is likely to have made the Henry Hub prices less integrated with the global natural gas market and the commodity market financialization has lead to a decoupling of Henry Hub prices from the WTI crude oil prices, whereas the NBP is still linked to the Brent crude oil prices. The futures market efficiency has evolved for both Henry Hub and NBP futures, which may be related to increased futures trading volumes. Henry Hub prices were cointegrated both prior to and post October 2008, but the LOP holds in only the 1 month contract in the prior period and in 1-5, and 7 months contracts in the post period. The NBP futures contracts where also cointegrated with the spot price in the prior period and the post period. The LOP holds for none of the NBP futures contracts in the prior period, but for all in the post period. The only contracts that are unbiased predictors of the future spot price are the 1 and 3 months NBP futures contracts in the post period. However, with these results the markets are to a great extent inefficient. This could affect hedging and investment decisions, as decisions often are based on the assumption that the futures price is the expected future spot price.

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Appendices

The appendices section contain information and results which has been referred to in the thesis. Some results are quite comprehensive and space-consuming, which is why we have chosen to leave it in an appendix. The appendices are as follows:

A - Order of Integration

B - Optimal Lag Selection

C - ADF-Tests

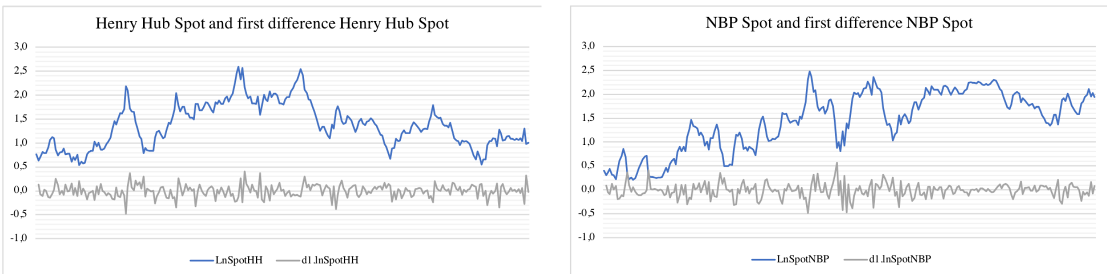
D - Gregory-Hansen Tests

E - Johansen Tests

F - Vector Error Correction Models

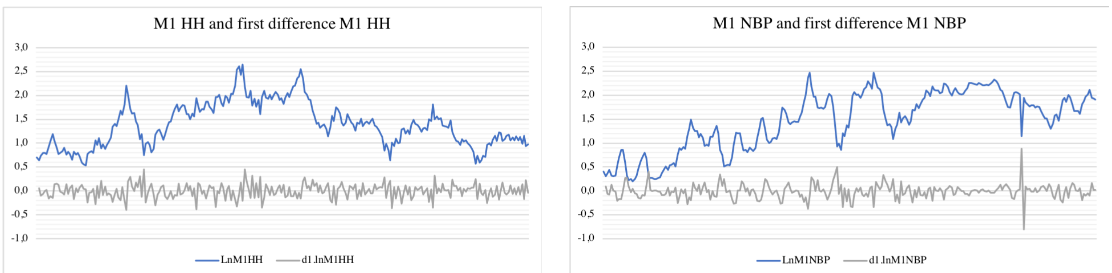
A Order of Integration

This section summarizes the findings of the visual inspection of stationarity for all futures contracts and spot prices. This simple analysis is not part of the econometric approach, but merely a way to get familiar with the data and improve intuition. It is obvious that the same conclusion can be taken on all of the cases as there is only subtle differences in the graphs. Prices at level are on blue, whereas prices at first difference are in gray. All time series seem to be integrated of order 1, i.e. I(1)-process.



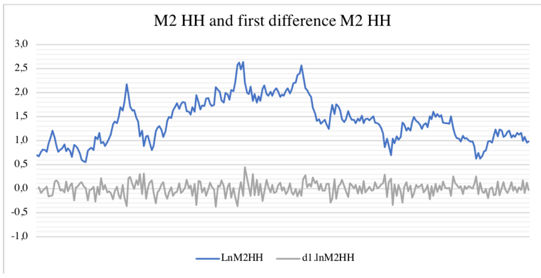
(a) *Henry Hub* **(b)** *NBP*

Figure 17: *Spot prices at level and at first difference.*

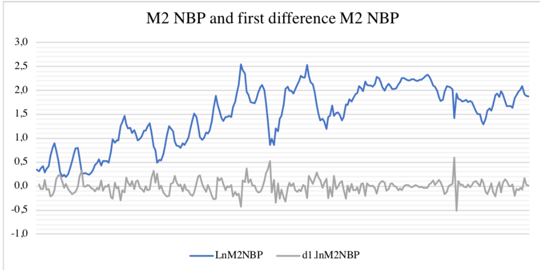


(a) *Henry Hub* **(b)** *NBP*

Figure 18: *1 Month futures contract prices at level and at first difference.*

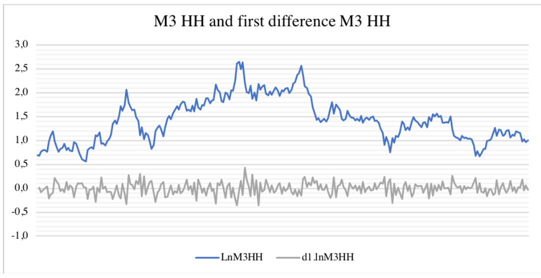


(a) *Henry Hub*

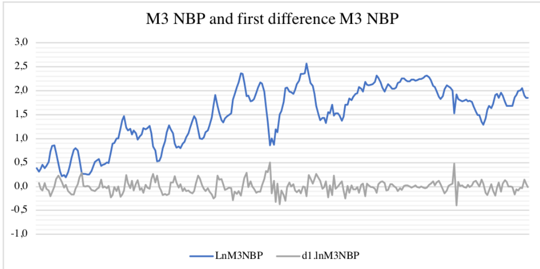


(b) *NBP*

Figure 19: *2 Month futures contract prices at level and at first difference.*

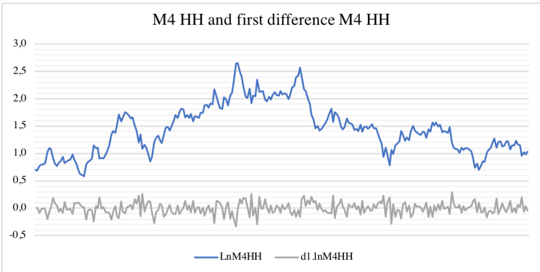


(a) *Henry Hub*

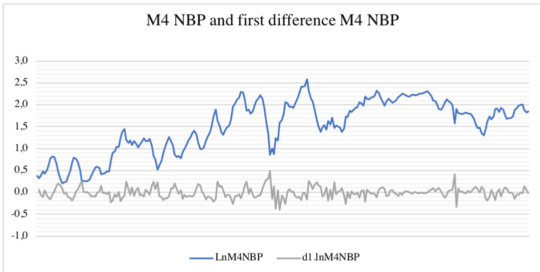


(b) *NBP*

Figure 20: *3 Month futures contract prices at level and at first difference.*

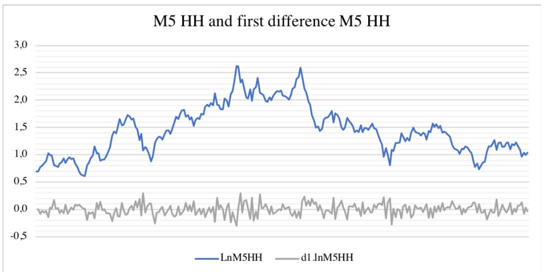


(a) *Henry Hub*

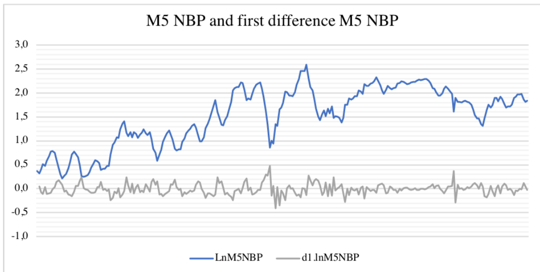


(b) *NBP*

Figure 21: *4 Month futures contract prices at level and at first difference.*

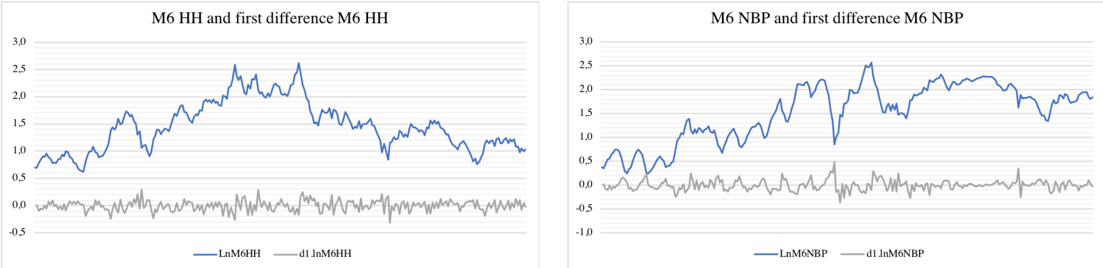


(a) *Henry Hub*



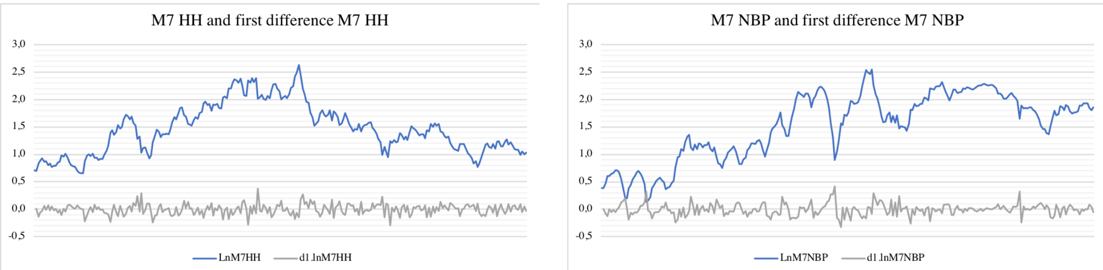
(b) *NBP*

Figure 22: *5 Month futures contract prices at level and at first difference.*



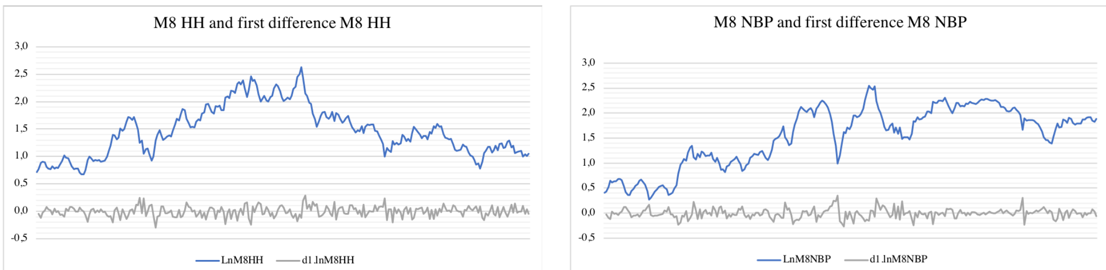
(a) *Henry Hub* (b) *NBP*

Figure 23: *6 Month futures contract prices at level and at first difference.*



(a) *Henry Hub* (b) *NBP*

Figure 24: *7 Month futures contract prices at level and at first difference.*



(a) *Henry Hub* (b) *NBP*

Figure 25: *8 Month futures contract prices at level and at first difference.*

B Optimal Lag Selection

This Appendix will contain all optimal lag selection used throughout the thesis. All selections are based on the minimal Akaike Information Criterion (AIC). Dashed lines simply means that the model does not exist (e.g. HH spot vs HH spot).

		Optimal Lag		
Variable	**M**	**Total**	**Prior**	**Post**
Level Henry Hub	0	1	1	1
	1	2	1	2
	2	2	1	2
	3	2	1	2
	4	3	1	4
	5	6	6	4
	6	12	7	1
	7	3	1	12
	8	12	9	12

		Optimal Lag		
Variable	**M**	**Total**	**Prior**	**Post**
First difference Henry Hub	0	0	0	0
	1	1	1	1
	2	1	0	1
	3	1	1	1
	4	0	0	3
	5	7	5	0
	6	11	6	0
	7	0	0	11
	8	11	8	11

Table 18: *Lag selection for univariate models of Henry Hub data.*

		Optimal Lag		
Variable	**M**	**Total**	**Prior**	**Post**
Level NBP	0	12	12	2
	1	12	9	2
	2	12	11	1
	3	12	11	1
	4	12	11	4
	5	12	11	4
	6	12	11	12
	7	12	11	12
	8	3	2	12

		Optimal Lag		
Variable	**M**	**Total**	**Prior**	**Post**
First difference NBP	0	12	12	0
	1	12	12	1
	2	11	10	0
	3	11	10	0
	4	11	10	0
	5	11	10	0
	6	11	10	0
	7	11	10	0
	8	1	1	0

Table 19: *Lag selection of univariate models of NBP data.*

Base Variable	Changing Variable	M	Optimal Lag Total	Prior	Post
Spot Henry Hub	Henry Hub	0	-	-	-
		1	2	2	2
		2	11	12	4
		3	11	12	4
		4	11	12	5
		5	9	10	8
		6	10	9	8
		7	11	12	10
		8	12	11	12
	NBP	0	12	3	1
		1	1	2	2
		2	12	9	1
		3	9	7	1
		4	10	7	1
		5	12	12	1
		6	12	11	1
		7	2	2	1
		8	2	2	1

Table 20: *Lag selection of bivariate models with Henry Hub as base variable.*

Base Variable	Changing Variable	M	Optimal Lag Total	Prior	Post
Spot NBP	Henry Hub	0	12	3	1
		1	12	4	2
		2	12	3	3
		3	10	3	4
		4	7	3	5
		5	6	6	3
		6	4	3	2
		7	4	4	1
		8	12	12	1
	NBP	0	-	-	-
		1	12	12	1
		2	12	9	3
		3	12	11	4
		4	12	11	7
		5	12	12	8
		6	12	11	12
		7	12	12	12
		8	12	12	12

Table 21: *Lag selection of bivariate models with NBP as base variable.*

C ADF-Tests

This Appendix contains all of the results from the ADF-tests. The ADF-test is conducted for all variables through all periods.

Level Variable	**M**	**Lags**	**MacKinnon Appr. p-value for Z(t)**	**Test Statistic**	**Interpolated Dickey-Fuller Critical Value** 1 %	5 %	10 %
Henry Hub	0	1	0,1085	-2,529	-3,460	-2,880	-2,570
	1	2	0,1270	-2,454	-3,460	-2,880	-2,570
	2	2	0,1396	-2,408	-3,460	-2,880	-2,570
	3	2	0,1662	-2,318	-3,461	-2,880	-2,570
	4	3	0,1653	-2,321	-3,461	-2,880	-2,570
	5	6	0,3669	-1,828	-3,463	-2,881	-2,571
	6	12	0,3813	-1,798	-3,465	-2,881	-2,571
	7	3	0,2632	-2,054	-3,462	-2,880	-2,570
	8	12	0,4279	-1,706	-3,466	-2,881	-2,571
NBP	0	12	0,1266	-2,456	-3,463	-2,881	-2,571
	1	12	0,1531	-2,361	-3,463	-2,881	-2,571
	2	12	0,1371	-2,417	-3,464	-2,881	-2,571
	3	12	0,1473	-2,381	-3,464	-2,881	-2,571
	4	12	0,1466	-2,383	-3,464	-2,881	-2,571
	5	12	0,1520	-2,365	-3,465	-2,881	-2,571
	6	12	0,1520	-2,364	-3,465	-2,881	-2,571
	7	12	0,1266	-2,456	-3,465	-2,881	-2,571
	8	3	0,2951	-1,981	-3,463	-2,881	-2,571

Table 22: *Testing for unit root in level variables for the total period.*

First difference Variable	M	Lags	MacKinnon Appr. p-value for Z(t)	Test Statistic	Interpolated Dickey-Fuller Critical Value 1 %	5 %	10 %
Henry Hub	0	0	0,0000	-15,747***	-3,460	-2,880	-2,570
	1	1	0,0000	-11,3***	-3,460	-2,880	-2,570
	2	1	0,0000	-11,498***	-3,460	-2,880	-2,570
	3	1	0,0000	-10,933***	-3,461	-2,880	-2,570
	4	0	0,0000	-16,297***	-3,461	-2,880	-2,570
	5	7	0,0000	-7,059***	-3,463	-2,881	-2,571
	6	11	0,0001	-4,604***	-3,465	-2,881	-2,571
	7	0	0,0000	-14,82***	-3,462	-2,880	-2,570
	8	11	0,0002	-4,519***	-3,466	-2,881	-2,571
NBP	0	12	0,0014	-4,007***	-3,463	-2,881	-2,571
	1	12	0,0019	-3,913***	-3,464	-2,881	-2,571
	2	11	0,0013	-4,013***	-3,464	-2,881	-2,571
	3	11	0,0017	-3,945***	-3,464	-2,881	-2,571
	4	11	0,0016	-3,958***	-3,464	-2,881	-2,571
	5	11	0,0019	-3,916***	-3,465	-2,881	-2,571
	6	11	0,0025	-3,847***	-3,465	-2,881	-2,571
	7	11	0,0031	-3,783***	-3,465	-2,881	-2,571
	8	1	0,0000	-8,601***	-3,462	-2,880	-2,570

Table 23: *Testing for unit root in first difference variables for the total period.*

Level Variable	M	Lags	MacKinnon Appr. p-value for Z(t)	Test Statistic	Interpolated Dickey-Fuller Critical Value 1 %	5 %	10 %
Henry Hub	0	1	0,3793	-1,802	-3,497	-2,887	-2,577
	1	1	0,4095	-1,742	-3,498	-2,888	-2,578
	2	1	0,5192	-1,529	-3,498	-2,888	-2,578
	3	1	0,6748	-1,197	-3,498	-2,888	-2,578
	4	1	0,6558	-1,241	-3,499	-2,888	-2,578
	5	6	0,8426	-0,716	-3,501	-2,888	-2,578
	6	7	0,7913	-0,890	-3,501	-2,888	-2,578
	7	1	0,6408	-1,275	-3,500	-2,888	-2,578
	8	9	0,7471	-1,017	-3,503	-2,889	-2,579
NBP	0	12	0,6733	-1,201	-3,501	-2,888	-2,578
	1	9	0,9203	-0,336	-3,500	-2,888	-2,578
	2	11	0,8006	-0,861	-3,501	-2,888	-2,578
	3	11	0,8276	-0,771	-3,502	-2,888	-2,578
	4	11	0,7853	-0,908	-3,502	-2,888	-2,578
	5	11	0,8032	-0,852	-3,502	-2,888	-2,578
	6	11	0,7636	-0,971	-3,503	-2,889	-2,579
	7	11	0,7699	-0,953	-3,503	-2,889	-2,579
	8	2	0,5470	-1,473	-3,500	-2,888	-2,578

Table 24: *Testing for unit root in level variables for the period prior to the breakpoint.*

First Difference Variable	M	Lags	MacKinnon Appr. p-value for Z(t)	Test Statistic	Interpolated Dickey-Fuller Critical Value		
					1 %	5 %	10 %
Henry Hub	0	0	0,0000	-11,577***	-3,497	-2,887	-2,577
	1	1	0,0000	-8,296***	-3,498	-2,888	-2,578
	2	0	0,0000	-12,39***	-3,498	-2,888	-2,578
	3	1	0,0000	-8,066***	-3,499	-2,888	-2,578
	4	0	0,0000	-11,409***	-3,499	-2,888	-2,578
	5	5	0,0000	-5,581***	-3,501	-2,888	-2,578
	6	6	0,0000	-5,574***	-3,501	-2,888	-2,578
	7	0	0,0000	-10,773***	-3,500	-2,888	-2,578
	8	8	0,0000	-4,823***	-3,503	-2,889	-2,579
NBP	0	12	0,0629	-2,768*	-3,501	-2,888	-2,578
	1	12	0,0820	-2,656*	-3,502	-2,888	-2,578
	2	10	0,0254	-3,116**	-3,501	-2,888	-2,578
	3	10	0,0367	-2,981**	-3,502	-2,888	-2,578
	4	10	0,0355	-2,994**	-3,502	-2,888	-2,578
	5	10	0,0554	-2,82*	-3,502	-2,888	-2,578
	6	10	0,0176	-3,244**	-3,503	-2,889	-2,579
	7	10	0,0138	-3,324**	-3,503	-2,889	-2,579
	8	1	0,0000	-6,259***	-3,500	-2,888	-2,578

Table 25: *Testing for unit root in first difference variables for the period prior to the breakpoint.*

Level Variable	M	Lags	MacKinnon Appr. p-value for Z(t)	Test Statistic	Interpolated Dickey-Fuller Critical Value 1 %	5 %	10 %
Henry Hub	0	1	0,0227	-3,155**	-3,505	-2,889	-2,579
	1	2	0,0294	-3,063**	-3,505	-2,889	-2,579
	2	2	0,0031	-3,78***	-3,505	-2,889	-2,579
	3	2	0,0015	-3,975***	-3,505	-2,889	-2,579
	4	4	0,0085	-3,48***	-3,505	-2,889	-2,579
	5	4	0,0195	-3,209**	-3,505	-2,889	-2,579
	6	1	0,1306	-2,441	-3,505	-2,889	-2,579
	7	12	0,1788	-2,279	-3,505	-2,889	-2,579
	8	12	0,3861	-1,789	-3,505	-2,889	-2,579
NBP	0	2	0,0807	-2,663*	-3,505	-2,889	-2,579
	1	2	0,1536	-2,359	-3,505	-2,889	-2,579
	2	1	0,1478	-2,379	-3,505	-2,889	-2,579
	3	1	0,1577	-2,345	-3,505	-2,889	-2,579
	4	4	0,0411	-2,938**	-3,505	-2,889	-2,579
	5	4	0,0452	-2,901**	-3,505	-2,889	-2,579
	6	12	0,0293	-3,065**	-3,505	-2,889	-2,579
	7	12	0,0180	3,235**	-3,505	-2,889	-2,579
	8	12	0,0246	-3,127**	-3,505	-2,889	-2,579

Table 26: *Testing for unit root in level variables for the period post breakpoint.*

First Difference Variable	M	Lags	MacKinnon Appr. p-value for Z(t)	Test Statistic	Interpolated Dickey-Fuller Critical Value 1 %	5 %	10 %
Henry Hub	0	0	0,0000	-10,753***	-3,505	-2,889	-2,579
	1	1	0,0000	-7,817***	-3,505	-2,889	-2,579
	2	1	0,0000	-8,015***	-3,505	-2,889	-2,579
	3	1	0,0000	-7,635***	-3,505	-2,889	-2,579
	4	3	0,0000	-4,961***	-3,505	-2,889	-2,579
	5	0	0,0000	-11,548***	-3,505	-2,889	-2,579
	6	0	0,0000	-10,809***	-3,505	-2,889	-2,579
	7	11	0,0062	-3,575***	-3,505	-2,889	-2,579
	8	11	0,0101	-3,425**	-3,505	-2,889	-2,579
NBP	0	0	0,0000	-9,954***	-3,505	-2,889	-2,579
	1	1	0,0000	-8,638***	-3,505	-2,889	-2,579
	2	0	0,0000	-11,489***	-3,505	-2,889	-2,579
	3	0	0,0000	-10,757***	-3,505	-2,889	-2,579
	4	0	0,0000	-10,256***	-3,505	-2,889	-2,579
	5	0	0,0000	-9,988***	-3,505	-2,889	-2,579
	6	0	0,0000	-9,776***	-3,505	-2,889	-2,579
	7	0	0,0000	-9,704***	-3,505	-2,889	-2,579
	8	0	0,0000	-9,81***	-3,505	-2,889	-2,579

Table 27: *Testing for unit root in first difference variables for the period post breakpoint.*

D Gregory-Hansen Tests

This Appendix contain the results from the Gregory-Hansen test for structural break in a cointegration relationship.

	Test statistic	Breakpoint	Date	Asymptotic critical value		
				1 %	**5 %**	**10 %**
Zt	-5,19**	141	October 2008	-5,47	-4,95	-4,68
Za	-49,09**	141	October 2008	-57,17	-47,04	-41,85

Table 28: *Gregory-Hansen test for structural break in a cointegration relationship between the Henry Hub and NBP spot prices.*

E Johansen Tests

This Appendix contain all results of the Johansen test of cointegration. Such results have been conducted both with respect to market integration and futures market efficiency.

				Critical Value	
Period	**Rank**	**Parms**	**Trace Statistic**	**5 %**	**1 %**
Total	0	46	9,285***	15,41	20,04
	1	49	1,2929	3,76	6,65
Prior	0	10	29,4182	15,41	20,04
	1	13	2,1135***	3,76	6,65
Post	0	6	16,811***	15,41	20,04
	1	9	4,4718	3,76	6,65

Table 29: *Johansen test of cointegration on Henry Hub spot vs NBP spot for all periods.*

Variable	M	Rank	Parms	Trace Statistic	Critical Value 5 %	1 %
Henry Hub Spot	1	0	4	99,0879	12,53	16,31
		1	7	0.4039***	3,84	6,51
	2	0	44	38,3363	12,53	16,31
		1	47	0.0897***	3,84	6,51
	3	0	44	49,0107	12,53	16,31
		1	47	0.0599***	3,84	6,51
	4	0	44	53,311	12,53	16,31
		1	47	0.0363***	3,84	6,51
	5	0	36	56,4647	12,53	16,31
		1	39	0.0543***	3,84	6,51
	6	0	32	60,7072	12,53	16,31
		1	35	0.0340***	3,84	6,51
	7	0	36	65,9864	12,53	16,31
		1	39	0.0565***	3,84	6,51
	8	0	36	60,8491	12,53	16,31
		1	39	0.0374***	3,84	6,51
NBP Spot	1	0	44	28,4249	12,53	16,31
		1	47	0.0108***	3,84	6,51
	2	0	44	19,2199	12,53	16,31
		1	47	0.0262***	3,84	6,51
	3	0	44	22,2448	12,53	16,31
		1	47	0.0262***	3,84	6,51
	4	0	40	41,9516	12,53	16,31
		1	43	0.0753***	3,84	6,51
	5	0	40	37,0331	12,53	16,31
		1	43	0.2194***	3,84	6,51
	6	0	40	55,1755	12,53	16,31
		1	43	0.2902***	3,84	6,51
	7	0	40	58,2032	12,53	16,31
		1	43	0.3260***	3,84	6,51
	8	0	40	48,4806	12,53	16,31
		1	43	0.3445***	3,84	6,51

Table 30: *Johansen test of cointegration in the respective futures markets for the total period.*

Variable	M	Rank	Parms	Trace Statistic	Critical Value	
					5 %	1 %
Henry Hub Spot	1	0	0	259,9079	12,53	16,31
		1	3	0.0283***	3,84	6,51
	2	0	44	38,3403	12,53	16,31
		1	47	1.8024***	3,84	6,51
	3	0	44	50,0758	12,53	16,31
		1	47	1.7494***	3,84	6,51
	4	0	44	50,6682	12,53	16,31
		1	47	1.7869***	3,84	6,51
	5	0	44	41,2572	12,53	16,31
		1	47	1.2937***	3,84	6,51
	6	0	32	49,9997	12,53	16,31
		1	35	1.5697***	3,84	6,51
	7	0	36	42,8845	12,53	16,31
		1	39	1.4128***	3,84	6,51
	8	0	44	46,3335	12,53	16,31
		1	47	2.3876***	3,84	6,51
NBP Spot	1	0	44	33,1009	12,53	16,31
		1	47	1,4168***	3,84	6,51
	2	0	44	24,6166	12,53	16,31
		1	47	1.1267***	3,84	6,51
	3	0	44	24,0358	12,53	16,31
		1	47	1.0110***	3,84	6,51
	4	0	40	40,2305	12,53	16,31
		1	43	1.1290***	3,84	6,51
	5	0	40	35,0658	12,53	16,31
		1	43	1.6286***	3,84	6,51
	6	0	40	54,876	12,53	16,31
		1	43	2.2935***	3,84	6,51
	7	0	40	55,5419	12,53	16,31
		1	43	2.1283***	3,84	6,51
	8	0	40	35,2801	12,53	16,31
		1	43	1.7607***	3,84	6,51

Table 31: *Johansen test of cointegration in the respective futures markets for the period prior to the breakpoint.*

Variable	M	Rank	Parms	Trace Statistic	Critical Value 5 %	1 %
Henry Hub Spot	1	0	4	55,5065	12,53	16,31
		1	7	2.3120***	3,84	6,51
	2	0	4	113,5635	12,53	16,31
		1	7	2.0605***	3,84	6,51
	3	0	4	51,0585	12,53	16,31
		1	7	2.3140***	3,84	6,51
	4	0	4	43,9382	12,53	16,31
		1	7	2.2996***	3,84	6,51
	5	0	4	35,9156	12,53	16,31
		1	7	2.2369***	3,84	6,51
	6	0	0	26,7997	12,53	16,31
		1	3	2.2530***	3,84	6,51
	7	0	0	26,046	12,53	16,31
		1	3	2.3687***	3,84	6,51
	8	0	36	35,501	12,53	16,31
		1	39	5.0023***	3,84	6,51
NBP Spot	1	0	0	161,9838	12,53	16,31
		1	3	0.5077***	3,84	6,51
	2	0	0	73,7576	12,53	16,31
		1	3	0.5049***	3,84	6,51
	3	0	24	24,8192	12,53	16,31
		1	27	0.4258***	3,84	6,51
	4	0	24	24,1783	12,53	16,31
		1	27	0.4254***	3,84	6,51
	5	0	24	20,3074	12,53	16,31
		1	27	0.4266***	3,84	6,51
	6	0	16	35,4236	12,53	16,31
		1	19	0.4946***	3,84	6,51
	7	0	16	29,3018	12,53	16,31
		1	19	0.4936***	3,84	6,51
	8	0	16	25,0981	12,53	16,31
		1	19	0.4016***	3,84	6,51

Table 32: *Johansen test of cointegration in the respective futures markets for the period post breakpoint.*

Base Variable	Changing Variable	M	Rank	Parms	Trace Statistic	Critical Value 5 %	1 %
Henry Hub Spot	NBP	1	0	2	14.9561***	15,41	20,04
			1	5	7,0825	3,76	6,65
		2	0	46	8.2668***	15,41	20,04
			1	49	1,9794	3,76	6,65
		3	0	34	12.3631***	15,41	20,04
			1	37	3,3898	3,76	6,65
		4	0	38	10.7218***	15,41	20,04
			1	41	4,1698	3,76	6,65
		5	0	46	8.3766***	15,41	20,04
			1	49	2,9538	3,76	6,65
		6	0	46	8.0947***	15,41	20,04
			1	49	2,8237	3,76	6,65
		7	0	6	17.9393***	15,41	20,04
			1	9	7,2131	3,76	6,65
		8	0	6	17.8883***	15,41	20,04
			1	9	6,04	3,76	6,65
NBP Spot	Henry Hub	1	0	46	9.1625***	15,41	20,04
			1	49	0,9955	3,76	6,65
		2	0	46	10.5909***	15,41	20,04
			1	49	0,5704	3,76	6,65
		3	0	38	7.3870***	15,41	20,04
			1	41	1,0145	3,76	6,65
		4	0	26	6.7089***	15,41	20,04
			1	29	2,4748	3,76	6,65
		5	0	22	6.9079***	15,41	20,04
			1	25	1,971	3,76	6,65
		6	0	14	8.9328***	15,41	20,04
			1	17	2,5289	3,76	6,65
		7	0	14	7.1649***	15,41	20,04
			1	17	2,4201	3,76	6,65
		8	0	46	8.4033***	15,41	20,04
			1	49	1,7703	3,76	6,65

Table 33: *Johansen test of cointegration on the spot price of one market against the futures price of the other market for the total period.*

Base Variable	Changing Variable	M	Rank	Parms	Trace Statistic	Critical Value 5 %	1 %
Henry Hub Spot	NBP	1	0	6	14.9415***	15,41	20,04
			1	9	6,2722	3,76	6,65
		2	0	34	11.2075***	15,41	20,04
			1	37	3,8721	3,76	6,65
		3	0	26	13.5696***	15,41	20,04
			1	29	4,718	3,76	6,65
		4	0	26	15.9144***	15,41	20,04
			1	29	5,2456	3,76	6,65
		5	0	46	8.3766***	15,41	20,04
			1	49	2,9538	3,76	6,65
		6	0	42	11.0223***	15,41	20,04
			1	45	4,4923	3,76	6,65
		7	0	6	17.9393***	15,41	20,04
			1	9	7,2131	3,76	6,65
		8	0	6	17.8883***	15,41	20,04
			1	9	6,04	3,76	6,65
NBP Spot	Henry Hub	1	0	14	13.4868***	15,41	20,04
			1	17	4,9543	3,76	6,65
		2	0	10	15.2000***	15,41	20,04
			1	13	4,8704	3,76	6,65
		3	0	10	13.4932***	15,41	20,04
			1	13	3,9573	3,76	6,65
		4	0	10	13.1978***	15,41	20,04
			1	13	3,9547	3,76	6,65
		5	0	22	6.9079***	15,41	20,04
			1	25	1,971	3,76	6,65
		6	0	10	10.1653***	15,41	20,04
			1	13	3,1065	3,76	6,65
		7	0	14	7.1649***	15,41	20,04
			1	17	2,4201	3,76	6,65
		8	0	46	8.4033***	15,41	20,04
			1	49	1,7703	3,76	6,65

Table 34: *Johansen test of cointegration on the spot price of one market against the futures price of the other market for the period prior to the breakpoint.*

Base Variable	Changing Variable	M	Rank	Parms	Trace Statistic	Critical Value 5 %	Critical Value 1 %
Henry Hub Spot	NBP	1	0	6	14.9415***	15,41	20,04
			1	9	6,2722	3,76	6,65
		2	0	2	16.9432***	15,41	20,04
			1	5	7,1564	3,76	6,65
		3	0	2	17.1235***	15,41	20,04
			1	5	7,2017	3,76	6,65
		4	0	2	18.1960***	15,41	20,04
			1	5	7,0194	3,76	6,65
		5	0	2	18.4485***	15,41	20,04
			1	5	7,6862	3,76	6,65
		6	0	2	20,2015	15,41	20,04
			1	5	7,3468	3,76	6,65
		7	0	2	20,4382	15,41	20,04
			1	5	6,7682	3,76	6,65
		8	0	2	22,303	15,41	20,04
			1	5	6.4067***	3,76	6,65
NBP Spot	Henry Hub	1	0	6	13.0167***	15,41	20,04
			1	9	5,0747	3,76	6,65
		2	0	10	15.2000***	15,41	20,04
			1	13	4,8704	3,76	6,65
		3	0	14	12.0283***	15,41	20,04
			1	17	2,892	3,76	6,65
		4	0	18	9.5291***	15,41	20,04
			1	21	2,1569	3,76	6,65
		5	0	10	11.4847***	15,41	20,04
			1	13	3,0999	3,76	6,65
		6	0	6	10.6720***	15,41	20,04
			1	9	3,7887	3,76	6,65
		7	0	2	12.9475***	15,41	20,04
			1	5	6,2397	3,76	6,65
		8	0	2	14.4493***	15,41	20,04
			1	5	5,6865	3,76	6,65

Table 35: *Johansen test of cointegration on the spot price of one market against the futures price of the other market for the period post breakpoint.*

F Vector Error Correction Models

This Appendix contain the results related to the Law of One Price (LOP) and the unbiasedness hypothesis.

F.1 Law of One Price

			95 % Confidence Interval (β)	
Period	α	β	**Lower**	**Upper**
Total	-2,440288	0,6729895	-0,1739225	1,519901
Prior	-0,3890879	-0,9745582	-1,157872	-0,791244
Post	-1,924315	0,4055163	-0,2293244	1,040357

Table 36: *LOP for Henry Hub vs NBP spot prices in all periods.*

				95 % Confidence Interval (β)	
Variable	**M**	α	β	**Lower**	**Upper**
Henry Hub Spot	1	0,0168052	-1,000486	-1,021751	-0,9792222
	2	0,003913	-0,9742663	-0,9965994	-0,9519332
	3	0,008658	-0,9637316	-0,9934568	-0,9340064
	4	0,0087488	-0,9543831	-0,9938154	-0,9149508
	5	0,0017705	-0,9447417	-0,9977056	-0,8917779
	6	0,0240051	-0,9515474	-1,007992	-0,8951029
	7	-0,0017685	-0,9300715	-0,9861523	-0,8739908
	8	-0,0199644	-0,9153476	-0,9710639	-0,8596313
NBP Spot	1	0,0125476	-0,9978632	-1,012162	-0,9835647
	2	0,0366785	-0,996629	-1,021409	-0,9718487
	3	0,0500342	-0,9982332	-1,026734	-0,9697319
	4	0,0675433	-0,996938	-1,027603	-0,9662728
	5	0,0764462	-0,9940521	-1,029197	-0,9589072
	6	0,0781642	-0,9902742	-1,033143	-0,9474058
	7	0,0552718	-0,9731359	-1,013401	-0,9328708
	8	0,0818584	-0,9813793	-1,031811	-0,930948

Table 37: *LOP for Henry Hub and NBP spot price against their respective futures contract prices in the total period.*

Variable	M	α	β	**95 % Confidence Interval (β)**	
				Lower	**Upper**
Henry Hub Spot	1	0,0392272	-1,008333	-1,032634	-0,9840333
	2	0,0249191	-0,9833414	-0,9990354	-0,9676475
	3	0,0183648	-0,9650646	-0,9891127	-0,9410165
	4	0,0039763	-0,9490859	-0,983662	-0,9145098
	5	-0,0007995	-0,9414983	-0,9882061	-0,8947905
	6	-0,0315891	-0,9269531	-0,9903507	-0,8635555
	7	-0,022984	-0,9149316	-0,9669719	-0,8628913
	8	-0,0255836	-0,9183885	-0,9850411	-0,851736
NBP Spot	1	-0,0086965	-0,9746745	-0,9843493	-0,9649998
	2	0,0040212	-0,952075	-0,9699642	-0,9341857
	3	0,0163562	-0,94568	-0,9672122	-0,9241479
	4	0,0233019	-0,9368601	-0,9646246	-0,9090956
	5	0,0184064	-0,9224597	-0,9543288	-0,8905907
	6	0,0289487	-0,9136223	-0,9501544	-0,8770902
	7	-0,0195411	-0,8837356	-0,9180069	-0,8494643
	8	0,0029056	-0,8840922	-0,932343	-0,8358413

Table 38: *LOP for Henry Hub and NBP spot price against their respective futures contract prices in the total period prior to the breakpoint.*

Variable	M	α	β	**95 % Confidence Interval (β)**	
				Lower	**Upper**
Henry Hub Spot	1	-0,0016965	-0,9855728	-1,028835	-0,9423108
	2	0,04825	-1,01501	-1,096506	-0,9335145
	3	0,100594	-1,041845	-1,17382	-0,9098707
	4	0,0504698	-0,9691508	-1,129766	-0,8085357
	5	-0,0506711	-0,8747233	-1,01462	-0,7348269
	6	-0,1058444	-0,8236242	-0,9772836	-0,6699648
	7	-0,0178576	-0,8933004	-1,012928	-0,7736727
	8	-0,0936026	-0,8342591	-0,9290356	-0,7394825
NBP Spot	1	0,0749816	-1,034614	-1,081077	-0,9881517
	2	0,140046	-1,060819	-1,15317	-0,9684675
	3	0,2992077	-1,138978	-1,306096	-0,9718598
	4	0,0914781	-1,024432	-1,176157	-0,8727062
	5	0,1094176	-1,028612	-1,187388	-0,8698348
	6	0,2206449	-1,080742	-1,259574	-0,9019092
	7	0,2677764	-1,100117	-1,276276	-0,9239589
	8	0,3378815	-1,13247	-1,349539	-0,9154019

Table 39: *LOP for Henry Hub and NBP spot price against their respective futures contract prices in the period post breakpoint.*

F.2 Unbiasedness Hypothesis

			95 % Confidence Interval (β)	
Period	α	β	**Lower**	**Upper**
Total	0	-0,703044	-1,211135	-0,1949524
Prior	0	-1,264602	-1,391135	-1,13807
Post	0	-0,5995724	-0,7157282	-0,4834167

Table 40: *Unbiasedness hypothesis for Henry Hub vs NBP spot prices in all periods.*

				95 % Confidence Interval (β)	
Variable	**M**	α	β	**Lower**	**Upper**
Henry Hub Spot	1	0	-0,989293	-0,9958719	-0,9827142
	2	0	-0,9715506	-0,9776707	-0,9654305
	3	0	-0,9578121	-0,9658627	-0,9497616
	4	0	-0,9482586	-0,9588035	-0,9377137
	5	0	-0,9422371	-0,9564577	-0,9280166
	6	0	-0,9354821	-0,9504533	-0,920511
	7	0	-0,9305121	-0,9452663	-0,9157578
	8	0	-0,9260396	-0,9405413	-0,911538
NBP Spot	1	0	-0,9893116	-0,9946817	-0,9839415
	2	0	-0,977954	-0,987349	-0,968559
	3	0	-0,9705386	-0,9815313	-0,959546
	4	0	-0,9638247	-0,9753533	-0,952296
	5	0	-0,9578039	-0,9705829	-0,9450249
	6	0	-0,9520383	-0,9672011	-0,9368756
	7	0	-0,9474445	-0,9609988	-0,9338902
	8	0	-0,9424256	-0,9593756	-0,9254756

Table 41: *Unbiasedness hypothesis for Henry Hub and NBP spot prices against their respective futures contract prices in the total period.*

Variable	M	α	β	95 % Confidence Interval (β)	
				Lower	**Upper**
Henry Hub Spot	1	0	-0,9868005	-0,9951476	-0,9784534
	2	0	-0,9657306	-0,9707515	-0,9607097
	3	0	-0,9510104	-0,9575173	-0,9445035
	4	0	-0,9432146	-0,9520916	-0,9343376
	5	0	-0,9346824	-0,9495528	-0,919812
	6	0	-0,9310878	-0,9516091	-0,9105665
	7	0	-0,9235543	-0,941113	-0,9059956
	8	0	-0,9181172	-0,9404034	-0,8958309
NBP Spot	1	0	-0,9766762	-0,9806538	-0,9726986
	2	0	-0,9544114	-0,9618927	-0,9469302
	3	0	-0,9426605	-0,9514837	-0,9338373
	4	0	-0,931674	-0,9430106	-0,9203374
	5	0	-0,9219463	-0,9349446	-0,9089479
	6	0	-0,9112064	-0,9261549	-0,8962579
	7	0	-0,9063483	-0,9214571	-0,8912395
	8	0	-0,8959161	-0,9161761	-0,875656

Table 42: *Unbiasedness hypothesis for Henry Hub and NBP spot prices against their respective futures contract prices in the period prior to the breakpoint.*

Variable	M	α	β	95 % Confidence Interval (β)	
				Lower	**Upper**
Henry Hub Spot	1	0	-0,9899067	-0,9993534	-0,9804601
	2	0	-0,9768808	-0,9944135	-0,9593481
	3	0	-0,9589209	-0,986034	-0,9318079
	4	0	-0,9370363	-0,9699921	-0,9040805
	5	0	-0,9278418	-0,9560776	-0,899606
	6	0	-0,9173038	-0,9490376	-0,88557
	7	0	-0,9243686	-0,9498559	-0,8988813
	8	0	-0,9090988	-0,9307988	-0,8873987
NBP Spot	1	0	-0,9954357	-1,002613	-0,9882587
	2	0	-0,986537	-0,9994302	-0,9736437
	3	0	-0,9814552	-1,001655	-0,9612552
	4	0	-0,9755271	-0,9919089	-0,9591453
	5	0	-0,9708277	-0,9869389	-0,9547166
	6	0	-0,9670745	-0,9837459	-0,9504031
	7	0	-0,9625086	-0,9784437	-0,9465736
	8	0	-0,9585632	-0,9775215	-0,9396049

Table 43: *Unbiasedness hypothesis for Henry Hub and NBP spot prices against their respective futures contract prices in the period post breakpoint.*