University of
Stavanger

Efficiency in the Crude Oil Futures Market

– an Empirical Study after the Shale Oil Revolution

Student: Ragne Myrhol Lade

Universitetet i Stavanger

FACULTY OF SOCIAL SCIENCES,
UIS BUSINESS SCHOOL

MASTER'S THESIS

STUDY PROGRAM:	THESIS IS WRITTEN IN THE FOLLOWING SPECIALIZATION/SUBJECT:
Master i Økonomi og Administrasjon	Applied Finance IS THE ASSIGNMENT CONFIDENTIAL? (**NB**! Use the red form for confidential theses)

TITLE:

Efficiency in the Crude Oil Futures Market
- an Empirical Study after the Shale Oil Revolution

AUTHOR(S)		SUPERVISOR:
Student number: 222 933 ………………… …………………	Name: Ragne Myrhol Lade ……………………………………. …………………………………….	Bård Misund

ACKNOWLEDGE RECEIPT OF 2 BOUND COPIES OF THESIS

Stavanger, ……/…… 2016 Signature administration:……………………………

Abstract

This thesis has studied efficiency in the crude oil futures market for WTI and the Brent Blend for a period including the “shale oil revolution”. The main objective was to provide new information by investigating a period in time not much explored in already published articles. Furthermore, the thesis sought to close a gap of earlier empirical studies performed, by combining the two crude oil types and including up to 6 months maturities for futures contracts, while at the same time having a precise definition of an efficient market. The raw data applied was daily closing prices for spot and 1-, 2-, 3-, 4-, 5-, and 6- months (M) futures contracts from January 1986 to March 2016 for WTI and from October 2003 to March 2016 for the Brent Blend. The data was converted to monthly observations, and the Johansen cointegration analysis was performed while imposing the restrictions of the unbiasedness hypothesis, $\alpha = 0$ and $\beta = 1$. Tests were performed pairwise, both for the same blends and across blends. The cointegration analyses were further performed both for the total period and separately for the sub period (January 2012- March 2016), as the produced amounts of shale oil started its sharp incline in 2012. Finally, tests of weak exogeneity were performed.

For the total period, the market was concluded efficient for the cointegration pairs Brent spot/Brent 1M, WTI spot/WTI 1M, WTI spot/Brent 3M, WTI spot/Brent 4M, WTI spot/Brent 5M and WTI spot/Brent 6M. For the sub period, the market was concluded efficient for the pairs Brent spot/Brent 4M, WTI spot/WTI 2M, WTI spot/WTI 4M, WTI spot/WTI 5M, WTI spot/Brent 2M, WTI spot/Brent 3M and WTI spot/Brent 4M. In general, futures prices were found to have led spot prices for most of the cointegrated pairs. The hypothesis of the spot price leading the futures price was rejected for all cointegrated pairs. For the total period, the finding of efficient markets for the contract with the shortest maturity for WTI and Brent was similar to previous empirical findings. The amount of cointegrated pairs however implied a higher degree of cointegration than previously. There was found little cointegration and no market efficiency for the Brent spot/WTI futures- pairs, implying possible speculation opportunities. The assumption of “normal backwardation” did not seem applicable for the periods investigated, as most relationships showed signs of contango. Suggestions were made that a non-linear method or a method including a structural break might better model the crude oil futures market. Risk-varying premiums, convenience yields and investors with different investment horizons were among the factors discussed as possible explanations to why the unbiasedness hypothesis was rejected in most cases. Finally, the results implied that using crude oil futures as a risk management tool might not be efficient for all maturities.

Preface

This thesis concludes my Master’s Degree in Economics and Business Administration with specialization in Applied Finance at the University of Stavanger Business School. I want to thank my thesis supervisor, Bård Misund, for all the good advices during the writing process.

The thesis seeks to find some answers to the complicated crude oil price puzzle. I hope it is as interesting to read it as it was to write it.

I have to thank my husband for allowing me to be so preoccupied with my own thoughts and ideas for these last months. And also, a big thank you to our two little ones for sleeping through (most) nights, not fighting (too much) and for being so loveable (always).

Contents

Figures

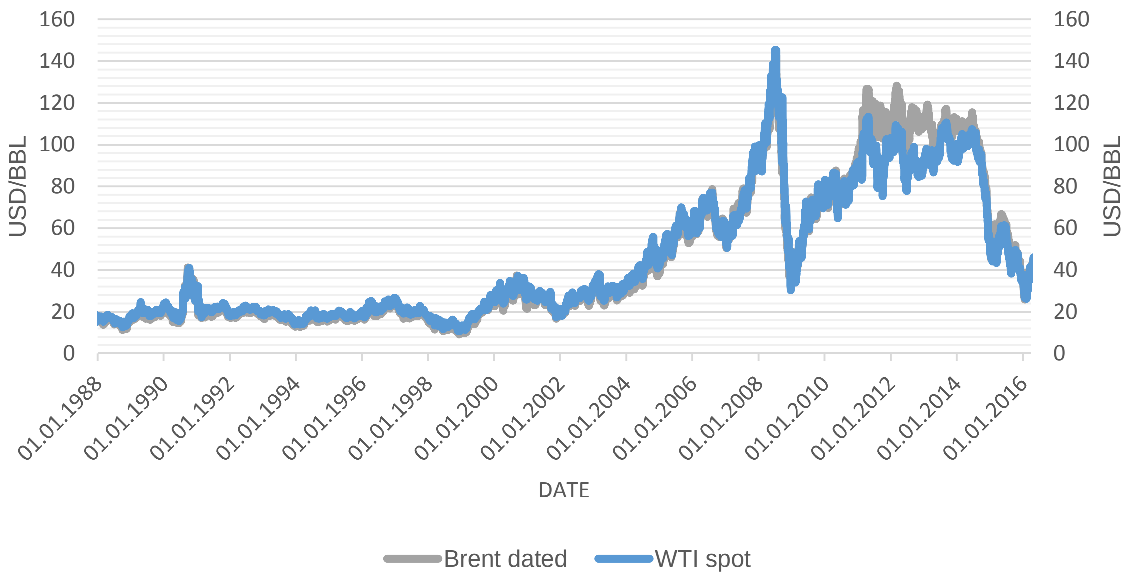
Tables

1 Introduction

1.1 Background

In 2014, the spot prices for the renowned crude oil benchmarks Brent Blend and the West Texas Intermediate (WTI) crude oil started a dramatic decline, as can be seen in Figure 1. From a comfortable price of $115.43 per barrel (bbl) on June 19 2014, the price for a bbl of dated Brent was as low as $25.91 on January 1 2016. The price development was similar for WTI.

Figure 1. Daily spot prices for WTI and Brent Blend in USD/bbl



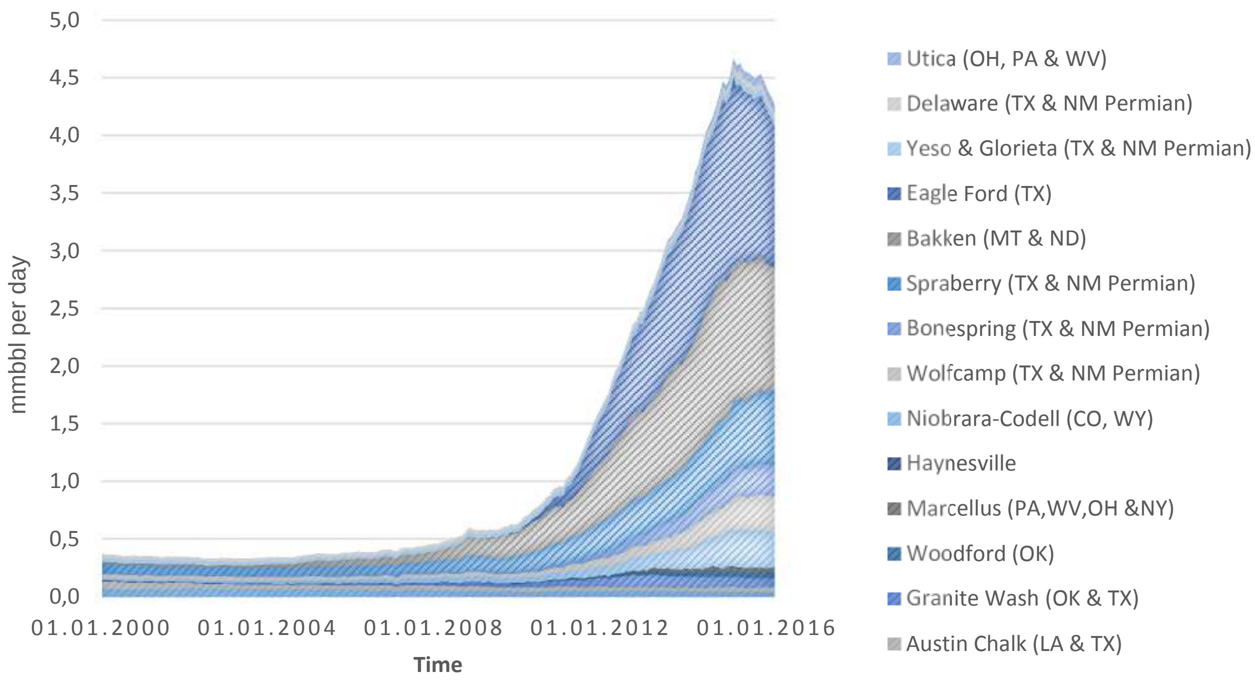
Source: Data for Brent (ICE) and WTI (NYMEX) was retrieved using *Datastream*

Although there historically has been several negative price shocks for crude oil, for instance following the credit crunch of 2008, this time it was different, as the drop in price was related to a significant increase in supply of oil in the market. Figure 2 shows the development in daily produced shale[1] oil in million barrels for selected U.S. fields as of March 2016 (U.S. Energy Information Administration, 2016a). New technology, for instance horizontal drilling and hydraulic fracturing, caused shale oil fields that were previously uneconomical to develop, to now be of great interest for oil extraction. One can imagine that the previously high oil prices had both motivated to search for more oil resources, as well as financed and reasoned for investments made in the development of the new technology. The result of these investments

[1] The oil type in this thesis referred to as "shale oil" is more correctly referred to as "tight oil" within the oil industry. Tight oil is a generic term for oil produced from low permeability geological formations composed of tight, sandstone, and carbonate (U.S. Energy Information Administration, 2016). However, as shale oil is the term more commonly used, that is also the notation used in this thesis.

is evident when reading Figure 2; a massive increase in shale oil produced. The graph shows the produced amount for some selected shale oil fields in the United States, measured in million barrels per day.

Figure 2. U.S. shale oil production for selected fields in million barrels per day.



Source: U.S. Energy Information Administration (2016a)

When looking at the development in shale oil produced according to Figure 2, it is natural to wonder if and how the “shale oil revolution” has affected the crude oil market dynamics. This curiosity prompted the research questions to be further explored in this thesis.

1.2 Statement of the problem and purpose of the study

This thesis will investigate the simple form market efficiency in the crude oil futures market. The purpose of the study is to provide new information, as it investigates a period of time that has not yet been thoroughly analyzed. Although crude oil market efficiency has been examined in a vast number of studies that will be further presented in the theory section, studies should be performed also including this last period, as the market dynamics might have been altered due to the increased amount of oil available. In addition, it is interesting to see as an isolated phenomenon whether the market was efficient during a period of such rapid change in volumes. This might provide new information regarding the efficiency of the market. Furthermore, the study considers both Brent Blend and WTI, while many previous studies have only studied the dynamics for one of the blends. In a study investigating the efficiency of different commodities, Kristoufek and Vosvrda (2014) found that WTI had a higher efficiency index than Brent. Cointegration analyses will therefore be performed for both crude oil types. In addition, the analyses will be run across crude oil types, e.g. Brent spot and WTI futures, as most studies performed has only analyzed the blends separately. It could for instance be interesting to investigate whether there is any price discovery findings across the two blends. Finally, several previous studies have been criticized for having imprecise definitions of market efficiency (Moosa & Al-Loughani, 1994). This study has a precise definition of how cointegration should be interpreted and the conditions that need to be fulfilled in order to conclude on whether the market has been efficient or not.

Summarizing, the thesis seeks to answer the following research questions:

- Was the crude oil futures market for Brent and WTI efficient during the price decline that started in 2014?
- Has the crude oil futures market for Brent and WTI been efficient considering the total period, when including the price decline of 2014/2015?

1.3 Why does crude oil market efficiency matter?

Inspecting the crude oil prices development in Figure 1, for instance the significant decline in 2008, it is evident that the prices can be quite volatile. Information regarding the oil market efficiency is therefore relevant for a variety of market participants. For both oil producers and oil consumers, futures can be an appropriate risk management tool in order to reduce the risk of the volatile prices (Hull, 2015). It can help increase predictability for the companies that are dependent on crude oil for their business. If the market is not efficient, the hedging function of the futures will be weakened, which will be useful information for those investors. Furthermore, disclosure of inefficiency in the crude oil market can shed a light on possible unrealized gains, and be of interest for both arbitrageurs and speculators. Finally, considering the importance of oil worldwide for a variety of different industries and economies, the oil market efficiency is of interest also on a more macroeconomic level. BP estimated in their Energy Outlook to 2035 that energy consumption will increase by 34% by 2035, and that fossil fuels will provide approximately 60% of this increase and account for almost 80% of the total energy supply in 2035 (BP, 2016). In other words, the question of crude oil market efficiency will continue to be of importance also in the future.

1.4 Procedure

This thesis will apply the Johansen cointegration analysis (Johansen, 1988, 1991; Johansen & Juselius, 1990) while imposing the restrictions of the joint hypothesis, $\alpha = 0$ and $\beta = 1$, for the crude oil types WTI and Brent Blend to answer the research questions mentioned in section 1.2. In order for the futures market to be considered efficient, the cointegration must be significant, and in addition, it is necessary that the joint hypothesis is not rejected for the cointegrated pair. This is similar to the conditions for futures market efficiency applied in the analyses of for instance Silvapulle and Moosa (1999) and Switzer and El-Khoury (2007). The raw data will be daily closing prices for spot and 1-, 2-, 3-, 4-, 5-, and 6- months futures contracts for the periods January 2 1986 to March 31 2016 for WTI (NYMEX) and October 1 2003 to March 31 2016 for Brent Blend (ICE). The analyses will be performed using monthly observations on a fixed date for futures prices and monthly averages of daily prices for the spot prices. The Augmented Dickey Fuller (1981) - test will be performed in advance to ensure that all the variables are integrated of the same order and consequently suitable for cointegration analysis. Finally, there will be performed a test of weak exogeneity to investigate whether spot prices have led the futures prices or if futures prices have led the spot prices.

1.5 Limitations of the thesis

There are some limitations to the methods applied in this thesis. Chen, Lee, and Zeng (2014) investigated the spot and futures relationship in the crude oil market, and concluded that a lack of incorporating structural breaks into the analysis will cause incorrect judgments regarding oil market efficiency, as they identified structural breaks that switches the oil market efficiency. This study does not include any statistical method that allows for structural breaks in the variables considered. In other words, it is assumed that the long-run relationship between the variables is unchanged for the period in mention. This assumption might not necessarily be correct. Further, the Johansen cointegration test models a linear relationship between the variables, while others, such as Silvapulle and Moosa (1999) and Wang and Wu (2013) have found that the relationship is non-linear.

However, as Johansen cointegration analysis has been widely used investigating the crude oil market efficiency historically, it is considered to be an appropriate choice of method, as it makes it possible to compare the result of the analysis to the previous works of others. Furthermore, although it is appealing to incorporate all relevant factors into the analysis, structural breaks will not be included, in order to limit the extent of the thesis.

1.6 Disposition

The thesis is structured as follows. In chapter two, relevant literature and previous empirical work performed is presented. Chapter three describes the methods applied. Chapter four is the data chapter, presenting the data gathering process as well as descriptive statistics of the variables. In chapter five, the results from the cointegration tests are presented. Finally, the results are discussed and conclusions drawn in chapter six.

2 Literature review

The following section will first present the definition of an efficient market according to the Fama theory framework, as well as critique against the market efficiency hypothesis. Then the application of the Fama framework to the commodity market will be described. Next follows a discussion of what cointegration implies regarding market efficiency, and a presentation of previous empirical work. Finally, there will be a brief summary of the literature review.

2.1 Definition of an efficient market and the different forms of market efficiency

A market can be described as "efficient" if the prices in the market always fully reflect all available information (Fama, 1970). Within the Fama framework, the conditions for market efficiency are defined as

i. no transaction costs for trading securities
ii. all information is free of cost available to all market participants and
iii. all market participants agree on the implications that the current available information has regarding the current price and distributions of future prices of the security

Fama (1970) commented that the assumptions hardly describe the real world markets, and that they should be seen as sufficient, but not necessary. He emphasized that as long as the market participants have taken into account all available information, transaction costs in themselves do not imply that the prices will not fully reflect all available information. Likewise, it might not be necessary that all market participants have all information; it might be satisfactory that a sufficient number of market participants have access to the available information. Similarly, disagreement between investors regarding how information should be interpreted in itself does not imply inefficiency, as long as there is not a situation where some investors consistently are able to make better judgments than the other investors in the market. According to Fama, transaction costs, restricted access to information and disagreement among investors regarding the implications of the information, are all factors that exist in real markets. They should not necessarily be seen as sources of inefficiencies in the markets, but rather potential sources of inefficiencies.

To further reflect on the rationale behind this definition of market efficiency, consider if it was possible to create a model that predicted the future price of a stock. If the model foresaw a price increase for the stock, all investors with access to the information from this model would rush to buy the stock. However, as those already holding the stock also had access to all information, nobody would want to sell, and the asymmetry between demand and supply of the stock would push the prices up. The new equilibrium price would be at a higher level, where those investors holding the stock would be willing to sell it. This higher price would compensate them for the gain they would have achieved by instead keep holding the stock and sell at the future point in time where the price would be higher, as predicted by the model. At this equilibrium price, no more new investors would be willing to buy the stock, because the potential future gain of buying the stock today and selling it at a later point would already be incorporated into the current higher price. Consequently, instead of a future price increase in the stock, due to the free information flow it became an immediate price increase, and the price of the stock reflects all current available information (Bodie, Marcus, & Kane, 2014).

According to Fama (1970), there are three different versions of the market efficiency hypothesis, depending on which information set forms the basis for the “all available information”- expression.

i. The market is *weak form efficient* if the current price reflects all information derived from historical prices only.
ii. The market is *semi-strong efficient* if the current price also incorporates other information that is obviously publically available. For the stock market, such information could be for instance announcements of annual earnings or stock splits. For crude oil prices, such information could be for instance announcements regarding new technology that make it possible to retrieve more oil from old oil fields.
iii. Finally, markets are *strong form efficient* if the prices in addition to public information reflect private information relevant for price formation, which only given investors or groups have monopolistic access to. This is a rather extreme version of market efficiency. In a strong form efficient market, in theory, there would be no need for insider information legislation. It does not appear to be a very realistic description of real life markets.

2.2 The market efficiency hypothesis and its controversies

Although the market efficiency hypothesis in the form as presented by Fama (1970) had been around for many years and from that perspective might be considered an established theory, Silvapulle and Moosa (1999) stated that the empirical evidence regarding the market efficiency hypothesis has not been unanimously positive. Malkiel (2003) summarized some of this critique. Several of the points he addressed, such as predicting future returns from initial dividend yield or the equity risk premium puzzle, are not directly applicable for the commodity market and will not be further elaborated here. The interested reader is encouraged to read the article for more information regarding the more stock-market related critique. Turning to some of the points more directly valid also for the commodity market, Malkiel (2003) described how a new movement of economists more concerned with psychological and behavioral elements of the stock-price determination process claimed that future stock prices actually are somewhat predictable. Even more controversially, some claimed that the predictable patterns allow investors to earn excess risk adjusted rates of return. Lo and Mackinlay (1999) for instance rejected the hypothesis of true random walk of stock prices, as they found both positive and negative serial correlations as well as the existence of "too many" moves in the same direction, implying the presence of a momentum effect in the short-run stock market prices. According to Malkiel (2003), research within behavioral finance has found such short-run momentum to be consistent with psychological feedback mechanisms. However, he rejected these findings as evidence of market inefficiencies. Although the hypothesis of a perfect random walk might be rejected on a statistical level, the economic gains from the lack of randomness are so small that it is not likely investors earn any excess returns from them. Further, these so-called bandwagon effects might sound reasonable, but research performed for instance by Fama (1998) suggests that underreaction and overreaction to information is approximately equally common, and that postevent continuation of abnormal returns is approximately equally common as postevent reversal of abnormal returns. Malkiel (2003) further noted that the key factor is whether the patterns are consistent over time, and that many predictable patterns seem to disappear once they have received attention through publications. Malkiel's final conclusion was that the stock markets are more efficient and less predictable than many of the critics claim, and that while some predictability might exist, that is not synonymous with enabling investors to earn significant extraordinary risk adjusted returns. The conclusion of Malkiel is similar to the moderating views of Fama (1970) regarding assumptions for market efficiency as presented in section 2.1, who commented that it is important to distinguish between necessary and sufficient assumptions for market efficiency. It appears to be reasonable perspectives, and this thesis assumes that they can be considered valid also for the commodity market. The framework of Fama (ibid.) regarding the market efficiency hypothesis will therefore form the theoretical basis of the thesis.

2.3 The market efficiency framework applied to commodity markets

Futures contracts can be defined as an agreement between two parties to buy or sell an asset for an agreed upon amount at a specific time in the future (Fabozzi, Fuss, & Kaiser, 2008; Hull, 2015). Futures are standardized, as they are usually traded on an exchange. The participants of futures markets can be divided into three broad groups; hedgers, speculators (traders) and arbitrageurs. While hedgers, such as for instance commodity producers, use futures contracts to reduce risk, speculators deliberately take on risk by betting on the prices in the market to either decline or increase. Finally, the arbitrageurs seek to generate riskless profits by entering two markets at the same time, trying to take advantage of time- or location-based price differences. Futures commodity contracts can be settled in two ways; either by physical delivery on the date of maturity, or by closing the position prior to the maturity date (Fabozzi et al., 2008). Physical delivery happens in approximately 2% of the cases.

Energy futures trading started with the establishment of the International Petroleum Exchange (IPE) [2] in London in 1980 (ibid.). WTI crude oil futures started trading on the New York Mercantile Exchange (NYMEX) in 1983. Already during the first year, daily futures contracts on average traded 6,000 contracts, and sometimes as high as 10,000 contracts (Gülen, 1998). Considering that one contract is equal to 1,000 barrels, the introduction of the WTI must be considered successful. The success of the WTI futures, as well as the ending of the official pricing by OPEC, initiated the introduction of the Brent Blend futures on IPE in 1988.

The Fama (1970) framework regarding market efficiency described in section 2.1 was developed for the stock market. Financial commodity markets differ from the stock markets as the underlying objects for instance requires storage or might be subject to decay. However, many of the mechanisms are assumed to be the same, and the theory has been applied to the crude oil market in a vast number of studies, such as in the work of Crowder and Hamed (1993), Silvapulle and Moosa (1999) and Switzer and El-Khoury (2007), to mention a few. For more details on work performed and conclusions from the studies, see descriptions in section 2.5 below. All of the mentioned studies are concerned with investigating the relationship between futures and spot prices. In order to explain why basis, or the difference between futures and

[2] IPE changed name to ICE Futures in 2005.

spot prices, might create an interesting starting point for market efficiency investigations in the crude oil market, one can derive an example similar to the one presented in section 2.1. Consider a commodity market where the assumptions mentioned in section 2.1 applies, meaning there is free information, no transaction costs and agreement on the implications of the information. Further, assume that there is a model that is able to predict the spot price of oil at a certain future point in time, *t*. For simplicity, assume that the date of maturity is equal to the date of delivery. Ignoring all other aspects such as risk free rate and inflation; if the future spot price is expected to increase, an investor should go long in futures with maturity at point *t*. At point *t*, the investor buys the crude oil in accordance with the futures contract price, and immediately sells it in the market for the higher spot price. As all information is available to all market participants, all investors see this opportunity, and wish to go long in futures. This increase in demand for futures pushes the price of futures up to the point where investors are indifferent to enter a long position in futures, because the gain is already incorporated into the price of the futures. Therefore, in an efficient market, the price of the futures includes all currently available information. The example will be vice versa if the future spot price is expected to decline. Consequently, investigations of basis might provide information regarding the efficiency of the market.

2.4 What cointegration implies regarding market efficiency

Cointegration analysis investigates whether there is a long-term relationship between time-series variables (Fabozzi, Focardi, Rachev, & Arshanapalli, 2014). For more details, see description of cointegration in section 3.1. Considering the example in section 2.3, cointegration analysis seems to be an appropriate method in order to investigate market efficiency, as it could reveal if there is an empirically significant relationship between the two prices. Interestingly, all though cointegration has been widely used for this purpose, there is a lack of consensus regarding whether a market where cointegration prevails should be interpreted as efficient or inefficient. Lai and Lai (1991) advocated that cointegration is one of the necessary conditions for market efficiency, as the market efficiency hypothesis suggests that the futures price on average is an unbiased predictor of the spot price. For investigating market efficiency, they referred to the linear model:

$$S_t = \alpha + \beta F_{t-1,t} + \varepsilon_t \tag{1}$$

where S_t is the spot price at time *t*, α and β are constant coefficients, $F_{t-1,t}$ is the price of futures contract at time *t-1* maturing at time *t*, and ε_t is the error term, or the part of the current spot price not explained by the other factors in the equation. According to Lai and Lai, cointegration between S_t and $F_{t-1,t}$ is only one of the necessary conditions for market efficiency, as the market efficiency hypothesis suggests that $F_{t-1,t}$ on average is an unbiased predictor of S_t. In addition, it is required that $\alpha = 0$ and $\beta = 1$, referred to as the unbiasedness hypothesis or the speculative efficiency hypothesis. This is also the view of for instance Chowdhury (1991), Silvapulle and Moosa (1999) and Switzer and El-Khoury (2007).

Others, such as Granger (1986) or Haikko and Rush (1989), claimed that cointegration would contradict the market efficiency assumption, as the price of one of the assets then may be used to predict the price of the other asset. Consistent with Fama's (1970) definition of weak form market efficiency, price changes from one period to the next should be unpredictable given today's current prices (Crowder & Hamed, 1993). Masih and Masih (2002) suggested that markets where cointegration prevails are inefficient only if investors can use the predictability to earn risk-adjusted excess returns. Predictability in itself, however, does not necessarily say anything about inefficiency. Dwyer and Wallace (1992) concluded that cointegration does not suggest neither market efficiency nor market inefficiency. Cointegration of asset prices is simply a function of the relevant model used. According to Maslyuk and Smyth (2009), that is also the view with which the opinion now lies.

This thesis will test whether spot and oil prices are cointegrated for the linear model shown in equation (1), while imposing the restrictions $\alpha=0$ and $\beta=1$. In other words, the unbiasedness hypothesis will be used. Cointegration will be interpreted as a sign of market efficiency, but in addition, it is necessary that $\alpha=0$ and $\beta=1$ to conclude that the market has been efficient. More specifically, the restriction $\beta'=(1,-1)'$ will be tested, while holding the constant equal to zero.

2.5 Existing empirical studies of market efficiency in the crude oil market

The following section summarizes a few of the many studies performed regarding crude oil market efficiency.

Silvapulle and Moosa (1999) used daily observations for the prices of spot, one month, three months and six months futures when performing Johansen cointegration analysis for the WTI crude oil market, for the period January 2 1985 to July 11 1996. They found that the spot price was only cointegrated with the one month contract. As a possible explanation as to why only the shortest maturity was cointegrated with the spot price, they referred to Moosa (1996). He concluded that it is the price of the contract one month ahead of time that forms the basis for speculation in the crude oil futures market, as uncertainties cause the speculators to have short time horizons for their decisions.

Based on monthly observations from NYMEX for the period March 1983 to September 1990, Crowder and Hamed (1993) performed Johansen cointegration analysis using the futures price 30 days prior to the last day of trading, and the cash price of the futures on the last day of trading as the future spot price. Restrictions were imposed on alpha and beta so that $\alpha=0$ and $\beta=1$. They found significant cointegration and also support for the joint hypothesis, and interpreted their result as supporting the simple efficiency hypothesis.

Jiang, Xie, and Zhou (2014) used nonparametric methods to estimate the Hurst indexes when testing the US WTI oil market efficiency from April 4, 1983 to October 2, 2012, based on daily closing prices for spot and futures. They found the market to be efficient when the period as a whole was considered. Dividing the period into subsections showed that inefficiency only occurred when there was turbulent events, such as the Gulf War.

Maslyuk and Smyth (2009) investigated the spot/futures- relationship using the Gregory Hansen test, which is a residual-based cointegration test that allows for one structural break. They tested for a bivariate relationship between spot and futures prices, both for the same grade of crude oil as well as different grades of crude oil, for instance cointegration between WTI spot and Brent Blend futures prices. The data was daily prices for Brent Blend and WTI for the period January 1991 to November 2008, for spot, one month and three months futures contracts. They found cointegration both for spot and futures prices of the same grade, as well as different grades. They further suggested that appropriate cointegration models should include a structural break, as they found statistically significant break points for the period tested.

Moosa and Al-Loughani (1994) criticized earlier studies for having imprecise definitions of market efficiency as well as applying inappropriate statistical methods and foregoing the necessary test of $\alpha=0$ and $\beta=1$, or the unbiasedness hypothesis, as defined in section 2.4. Based on monthly observations for the WTI spot, one month and three months futures prices for a sample period of January 1986 to July 1990, they performed an Engle-Granger cointegration analysis. The test statistics showed significant cointegration relationships for all variables. However, as the restrictions $\alpha=0$ and $\beta=1$ were rejected in all cases, Moosa and Al-Loughani concluded that the market was not efficient for the period investigated.

Switzer and El-Khoury (2007) criticized the work of Moosa and Al-Loughani (1994) by suggesting that they had drawn their conclusion based on a too short time period, that also included the highly volatile period due to the Iraqi war. Using daily closing prices for WTI spot and one month-futures for January 1986 to April 2005, Switzer and El-Khoury (2007) examined the futures efficiency focusing on the inclusion of periods with extreme conditional volatility, such as the Iraqi war. Based on results from the Johansen cointegration test, they found that the futures had been unbiased predictors of the future spot price, and that the spot and futures prices had been cointegrated. Consequently, the conclusion was that the market had been efficient.

2.6 Summary of the literature review

In this section follows a brief summary of some of the key points from the literature presented in section 2.1 to 2.5. Although the market efficiency hypothesis in the form presented by Fama (1970) is well-established, it also has its critics, as Malkiel (2003) summarized in his article. The points made that are most valid for commodity markets was suggested to be the findings of some predictability and momentum effects. Malkiel argued that the existence of some degree of predictability should not be interpreted as inefficiency because it is unlikely that the findings described has allowed the investors to earn significant extraordinary risk adjusted returns. This thesis assumes the same conclusion might be applicable for the commodity market, and therefore, the market efficiency hypothesis framework (Fama, 1970) will form the theoretical foundation for the thesis. Cointegration analysis of basis has been widely used to investigate efficiency in the crude oil futures market, but while some, such as for instance Lai and Lai (1991), considered cointegration to be a sign of efficiency, others, such as Hakkio and Rush (1989) perceived cointegration as a sign of inefficiency, as it also indicates predictability. Dwyer and Wallace (1992) concluded that cointegration in itself implies neither efficiency nor inefficiency, that is determined by the relevant model used. This seems to be a reasonable assumption. Further, Lai and Lai (1991) among others claimed that cointegration is only one of the necessary conditions in order to conclude that a market has been efficient. In addition, it is required that the joint hypothesis $\alpha=0$ and $\beta=1$ can not be rejected, meaning that the futures price has been an unbiased estimator of the spot price.

The results from various empirical studies differ. Silvapulle and Moosa (1999) found that only the one month contract was cointegrated with the spot price when investigating the one, three and six month futures of WTI. They did however not include the restrictions of the joint hypothesis. Moosa and Al-Loughani (1994) found cointegration, but not support for the joint hypothesis, when investigating the one month futures contract for WTI. Switzer and El-Khoury (2007) and Crowder and Hamed (1993) found both cointegration and support for the joint hypothesis for the WTI one month futures. Using a cointegration test that allowed for a structural break, Maslyuk and Smyth (2009) found cointegration both for the same oil types, and across oil types, for the one- and three- month contract for both WTI and Brent, and they also identified a structural break. Finally, considering turbulent periods, Jiang et al. (2014) used nonparametric methods and found efficiency for the total period, but inefficiency during periods with turbulent events.

Summarizing, most of the empirical work described above only included the shortest contracts and only WTI crude oil in the analyses. Silvapulle and Moosa (1999) included the one-, three- and six- months futures of WTI and Maslyuk and Smyth (2009) included both Brent and WTI, but none of them included the restriction of the joint hypothesis. This thesis seeks to mediate that gap by including all maturities from 1-6 months for futures of both crude oil types, and performing cointegration pairwise both for the same and across blends, while at the same time imposing the restrictions of the joint hypothesis. Hopefully, by combining all of these aspects, new information regarding the spot/futures- relationship will be revealed.

3 Methodology

In this part of the thesis, there will first be provided a definition and a general description of cointegration. Then follows a description of how the models were established. Third, the concepts of stationarity and non-stationarity will be explained, and the three different varieties of the Augmented Dickey-Fuller test will be presented. Next, the Johansen cointegration test is described, followed by a presentation of the test of weak exogeneity.

3.1 Cointegration

When two variables are cointegrated, the difference between the two variables is stationary, though the variables themselves are non-stationary (Hill, Lim, & Griffiths, 2012). Cointegration implies that the variables share similar stochastic characteristics, and since the difference between them is stationary, consequently, they never drift too far apart from each other. Though there might be great variations in the individual development of the variables, there seems to be some form of restrain that prevents them from moving too far apart from each other. As an informal comparison, there is a simple example circulating on different statistical forums online that compares cointegration between two variables to a drunk man walking his dog on a leash. Both of them wander around, sometimes the man is walking on the left side of the dog, while sometimes it is the other way around. Sometimes they walk close, other times the leash is tight because they wander off in separate directions. Nevertheless, although their separate routes are different, they end up in the same place, and they never walk too far apart from each other because of the restriction of the length of the leash.

Cointegration provides a method of investigating relationships between non-stationary data, as regression analysis can cause false significant results if applied to variables that do not have a constant mean or variance (Hill et al., 2012). However, if two variables are to form a long-run equilibrium relationship, as cointegration implies, it is a prerequisite that they are integrated of the same order (Quan, 1992). The order of integration of a variable is the minimum number of times the variable must be differenced in order for the variable to become stationary. A variable that is non-stationary in levels and stationary in first differences can be denoted as *I(1)*, meaning that it is integrated of order 1. This thesis will apply the Augmented Dickey Fuller (1979)- test to investigate the integration- characteristics of the variables.

3.2 Establishing the models

The models were established by following the principles of the Box-Jenkins (1976) approach, as described by Box, Jenkins, and Reinsel (2008), though adjusted to fit the characteristics of the hypotheses to be tested. First, the variables were investigated for stationarity characteristics, see section 4.5, to see if all variables were integrated of the same order and as such applicable for cointegration analysis. Second, VAR-models were estimated, using Akaike Information Criterion (AIC) as lag selection criterion. Finally, diagnostic tests were performed for the residuals of the estimated VAR- models in form of autocorrelation-, heteroskedasticity- and normality- tests to see whether they followed the assumptions of the model. The diagnostic tests used are described in section 3.2.1 below. If autocorrelation was detected, the number of lags was increased by one until autocorrelation was no longer present in the residuals. The rationale for this is based on the theory to be tested; the simple efficiency hypothesis claims that the current price reflects all information derived from historical prices. Consequently, autocorrelated residuals indicate that the model might not be properly fitted to capture the phenomenon.

3.2.1 Diagnostic tests for the residuals

Errors are serial correlated or autocorrelated if the value of the error term is dependent on previous values of itself (Hill et al., 2012). This means that correlation in time between present and past values of the variable has not been completely captured by the variables in the model. Autocorrelation can be removed by increasing the number of lags, or lagged variables, included in the model. This thesis will use the Breusch-Godfrey- test (Breusch, 1978; Godfrey, 1978) to check for autocorrelation. Rejection of the null hypothesis suggest that the residuals are autocorrelated.

Heteroskedasticity means that the observations have different variances (Hill et al., 2012). Using crude oil as an example, heteroskedasticity is present if for instance the variance of the low oil prices is lower than the variance of the high oil prices. This thesis will use ARCH-model (Engle, 1982), short for Auto-Regressive Conditional Heteroskedasticity, to check for heteroskedasticity. A rejection of the null hypothesis in the ARCH-test means that ARCH-effects exist in the data.

Variables are non-normal if the mean and variances are not normally distributed (Hill et al., 2012). Most tests, including the Johansen cointegration test, assumes a normal distribution. The Jarque-Bera (1980) test statistic allows for a combined test of skewness and kurtosis. If the null hypothesis is rejected, the data is non-normal.

For the total period, there was found no autocorrelation in the residuals when applying Akaike Information criterion (AIC) as a lag selection criterion, and AIC is therefore used for those variables. For the sub period however, the small sample size caused errors when trying to calculate lag selection according to AIC, as *R software* then suggested 13 lags for all time variables. Such a high number of lags would significantly reduce the power of the test. Therefore, an alternative approach was used to choose the amount of lags for those variables. First, unrestricted VAR models were estimated with lag amount of 2. Residual checks were performed regarding autocorrelation. For all those variables where the residuals were autocorrelated, lag order was increased by one. If the residuals of this VAR model also were autocorrelated, lag order was again increased by one, until autocorrelation no longer was present in the residuals of the unrestricted VAR model. The number of lags chosen can be seen in appendix A and B. This study uses the trace statistic only, as it has shown signs of robustness against non-normality (Yin-Wong & Lai, 1993) and against moderate residual ARCH-effects according to Rahbek, Hansen and Dennis (2002) as referred in Juselius (2006). The residuals of the models were tested for autocorrelation using Portmonteau test, non-normality using JB-test and heteroskedasticity using ARCH-test. As previously mentioned, there was no autocorrelation in the residuals of the final models, but there was non-normality and heteroskedasticity for several of the models. However, as the trace statistic has shown some robustness against heteroskedasticity and non-normality, the result did not affect the further development of the models. The results are however listed in Appendix E and F to show to the reader of the thesis the characteristics of the residuals of the models.

3.3 Tests for stationarity/non-stationarity

A time series, y_t, is stationary if it for all values and for all time periods has the characteristics specified as:

$$E(y_t) = \mu \quad (2)$$

$$var(y_t) = \sigma^2 \quad (3)$$

$$cov(y_t, y_{t+s}) = cov(y_t, y_{t-s}) = \gamma_s \quad (4)$$

where $E(y_t) = \mu$ means that the time series has a constant mean, $var(y_t) = \sigma^2$ means that the time series has a constant variance, and $cov(y_t,y_{t+s}) = cov\ (y_t,y_{t-s}) = \gamma_s$ means that the covariance between two values in the time series depends only on the length of time, s, separating the two values, and not the actual times at which the values are observed, t (Hill et al., 2012). If regression analysis is applied for non-stationary time series data, one can get apparently significant regression results, although the relationships in reality are spurious. It is therefore important to test for non-stationarity prior to choosing the method of analysis for the relationship between spot and futures prices for the crude oil market.

The most popular test for determining whether a series is stationary or non-stationary is the Dickey-Fuller (1979) test. Stochastic, or random, processes can include a constant term, include a time trend in addition to the constant term, or include neither a constant term nor a time trend. Consequently, there are three different varieties of the Dickey-Fuller test, presented below.

When the null hypothesis described in section 3.3.1, 3.3.2 and 3.3.3, $H_0: \gamma = 0$, is true, the distribution of the t-statistic changes, because the data then is stationary and has a variance that increases when the sample size increases. In order to mediate this problem, the t-statistic must be compared to special generated critical values. The t- statistic is then denoted τ instead of the usual t. As adding a constant term or a time trend term alters the distribution of the time series, the three tests below are compared to separate calculated critical values, τ_c. It is therefore important to make a correct judgment regarding the attributes of the time series data.

3.3.1 The Dickey- Fuller test with no constant and no trend

In order to demonstrate the Dickey-Fuller test with no constant and no trend, consider a simple, univariate AR(1) model specifying the value of variable y:

$$y_t = \rho y_{t-1} + v_t \quad (5)$$

where y_t is the value of y at time t, y_{t-1} is the value of y at time $t-1$, t is time, ρ is the parameter and the v_t are independent, random error terms with a zero mean and a constant variance σ^2_v (Dickey & Fuller, 1979). In order to make the formula above more intuitive, one can alter it by subtracting y_{t-1} from both sides (Hill et al., 2012):

$$y_t - y_{t-1} = \rho y_{t-1} - y_{t-1} + v_t \tag{6}$$

$$\Delta y_t = (\rho - 1)y_{t-1} + v_t \tag{7}$$

$$\Delta y_t = \gamma y_{t-1} + v_t \tag{8}$$

where $\gamma = \rho - 1$. A Dickey-Fuller test is a one-tailed test checking whether the data is stationary (H_1: $\gamma < 0$) or non-stationary (H_0: $\gamma = 0$), or, if instead using the original formula, checking whether the data is stationary (H_1: $\rho < 1$) or non-stationary (H_0: $\rho = 1$). In other words, as the null hypothesis is that the data is non-stationary, a lack of rejecting the null means that the data is non-stationary, while if the null is rejected, the data is stationary.

3.3.2 The Dickey- Fuller test with a constant but no trend

The Dickey-Fuller (1979) test for time series with a constant but no trend includes a constant term, α, in the above equation (9), transforming it to:

$$\Delta y_t = \alpha + \gamma y_{t-1} + v_t \tag{9}$$

The null and alternative hypothesis are the same as previously mentioned, H_0: $\gamma = 0$, H_1: $\gamma < 0$.

3.3.3 The Dickey- Fuller test with a constant and a trend

Finally, the Dickey-Fuller (1979) test for time series with a constant and a time trend includes both a constant term, α, and a time-trend term, λ_t:

$$\Delta y_t = \alpha + \gamma y_{t-1} + \lambda_t + v_t \tag{10}$$

The null and alternative hypothesis are the same as above, H_0: $\gamma = 0$, H_1: $\gamma < 0$.

3.3.4 The augmented Dickey- Fuller test

The extended version of the Dickey-Fuller test is referred to as the Augmented Dickey-Fuller(1981)- test (ADF-test). For the test of stationarity in this thesis, the ADF-test was used. Compared to the original Dickey-Fuller test, the ADF-test includes lagged first differences of the time series variable in order to correct any autocorrelation in the error term, giving the following test equations:

ADF-test: no constant, no trend

$$\Delta y_t = \gamma y_{t-1} + \sum_{s=1}^{m} a_s \, \Delta y_{t-s} + v_t \tag{11}$$

ADF- test: constant, no trend

$$\Delta y_t = \alpha + \gamma y_{t-1} + \sum_{s=1}^{m} a_s \, \Delta y_{t-s} + v_t \tag{12}$$

ADF-test: constant and trend

$$\Delta y_t = \alpha + \gamma y_{t-1} + \lambda_t + \sum_{s=1}^{m} a_s \, \Delta y_{t-s} + v_t \tag{13}$$

where $\Delta y_{t-1}=(y_{t-1} - y_{t-2})$, $\Delta y_{t-2}=(y_{t-2} - y_{t-3}),\ldots$, and α_s are the estimated lag coefficients. One should add as many lags as required to make the data no longer autocorrelated. Adding lags has its price. The more lags added, the more initial observations are lost, reducing the power of the test (Wooldridge, 2013). However, if one does not include sufficient lags, the risk of falsely rejecting H_0 increases, as the validity of the critical values depend on whether the dynamics are correct modeled. In other words, it is important to choose the numbers of layers included with caution.

3.4 The Johansen test of cointegration

As previously mentioned, if regression analysis is applied for non-stationary time series data, one can get apparently significant regression results, although the relationships in reality are spurious (Hill et al., 2012). Cointegration analysis is however an appropriate analysis method for time series data that are *I(1)*, as described in section 3.1. The well-established Engle-Granger test for cointegration has some weaknesses (Fabozzi et al., 2014). First, any variable may be utilized as the dependent variable. Engle and Granger showed that as the sample size approaches infinity, the cointegration test gives the same results regardless of which variable is chosen as the dependent variable. The question is how big the sample must be in order to avoid any errors from the choice of rank as dependent/independent variable. Another problem is that the errors used to test for cointegration are not the true errors, they are the estimates of the true errors. Consequently, if there are any mistakes in the estimate of the error term, this will be carried forward into the final regression equation of the test. Finally, the Engle-Granger test is not able to handle multivariate relationships. As these weaknesses are mediated in the Johansen model for cointegration (ibid.), this thesis applied the Johansen cointegration test for analysis of cointegration relationships in the crude oil market.

The Johansen test of cointegration (Johansen, 1988, 1991; Johansen & Juselius, 1990) enables tests of cointegration relationship for more than two variables. While the Engle-Granger cointegration analysis is an error-correction model, the Johansen cointegration test uses maximum likelihood as estimation strategy (Crowder & Hamed, 1993; Switzer & El-Khoury, 2007). Considering a general VAR model of order *k* written in the error correction form:

$$\Delta X_t = D_t + \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \mathit{\Delta} X_{t-i} + \varepsilon_t \tag{14}$$

where X_t is a $p\ x\ 1$ vector of $I(1)$ variables, ΔX_t is calculated as $X_t - X_{t-1}$, D is a deterministic term for constant or time trends, Π and Γ are matrixes of coefficients, ε_t is the error term at time t, and p is the number of dimensions. Π is a $p\ x\ p$ matrix, and has reduced rank if the variables in X_t are cointegrated. Π can further be decomposed into the two matrices α and β, which are $p\ x\ r$ matrices, so that $\alpha\beta' = \Pi$. While the columns in β show the r stationary or cointegrated linear combinations of X_t, α have corresponding columns presenting the corresponding error correction coefficients. These can be interpreted as the speed of the adjustment parameters. The hypotheses are specified as restrictions on Π, so it is the rank of Π that is of interest (Johansen, 1991). The rank of Π will be r if there are r cointegrating vectors, and as the maximum number of cointegrating vectors are $N-1$, r can range from zero to $N-1$ (Kocenda & Cerny, 2014). The Johansen test uses the ordered sample of estimated eigenvalues $\lambda_1 > \lambda 2 > \lambda 3 > \ldots > \lambda_N$ to produce two different test statistics, the maximum eigenvalue statistic and the trace statistic. The trace statistic formula is as follows:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{N} \ln(1 - \lambda_i) \tag{15}$$

and tests the hypothesis H_0: *rank Π is less or equal to r* against H_1: *rank Π is bigger than r*.

The maximum eigenvalue statistic is calculated as:

$$\lambda_{max}(r, r+1) = -Tln(1-\lambda_{r+1}) \tag{16}$$

and tests the hypothesis H_0: *rank Π is less or equal to r* against H_1: *rank Π is equal to r+1*.

The test statistics has an asymptotical distribution and is compared against specifically calculated critical chi square values, as it does not follow the chi square distribution perfectly. If the statistic calculated is above the critical value, the null hypothesis is rejected.

As referred in Juselius (2006), Rahbek, Hansen and Dennis (2002) found the cointegration rank tests to be robust against moderate residual ARCH- effects. Further, Yin-Wong and Lai (1993) found signs of robustness against non-normality for the trace statistics. In most cases, the trace- and the max eigenvalue- statistic will lead to the same conclusion. The residuals for several of the models used in this thesis show signs of both ARCH- and non-normality effects. Consequently, conclusions in this thesis will be based on the trace test statistic, and the max eigenvalue statistic will not be calculated nor commented further.

As described in section 2.4, this thesis defines the crude oil market as efficient if there is significant cointegration while at the same time the unbiasedness hypothesis, $\alpha = 0$ and $\beta = 1$, cannot be rejected. Therefore, the cointegration tests will be run with the intercepts set to "none", or zero, while at the same time testing whether $\beta' = (1,-1)'$. It is required that all of these conditions are met in order for the market to be defined as efficient.

3.5 Weak exogeneity

In the theory section, the linear relationship to be investigated was expressed as:

$$S_t = a + bF_{t-1,t} + \varepsilon_t \tag{1}$$

The equation above defines spot price as the dependent variable and the futures price as the independent variable. This is not necessarily the case; for instance, Silvapulle and Moosa (1999) found the spot/futures- relationship in the crude oil market to be bidirectional. If there is uncertainty regarding the causality of the variables, it can be convenient to use a Vector Auto Regression (VAR), which treats each variable symmetrically (Enders, 2010). In a VAR, equations are specified for each variable. Consequently, variables are not defined as dependent or independent, they are just defined as variables. If the intercept is excluded, a simple one-lag VAR model for the spot-futures relationship described above can be:

$$S_t = a_{11}S_{t-1} + a_{12}F_{t-1} + \varepsilon_{st} \tag{17}$$

$$F_t = a_{21}S_{t-1} + a_{22}F_{t-1} + \varepsilon_{Ft} \tag{18}$$

where S_t is the spot price, F_t is the futures price, a are coefficients and ε_t are the error terms, at time t. Rephrasing this into a Vector Error Correction Model (VECM) that is normalized with respect to S_t, we get the following equations:

$$\Delta S_t = \alpha_{S_t}(S_{t-1} - \beta F_{t-1}) + \varepsilon_{S_t} \tag{19}$$

$$\Delta F_t = \alpha_{F_t}(S_{t-1} - \beta F_{t-1}) + \varepsilon_{F_t} \tag{20}$$

where:

$$\alpha_{S_t} = -\frac{a_{12}a_{21}}{1 - a_{22}}\,, \qquad \beta = \frac{1 - \alpha_{22}}{a_{21}}, \qquad \alpha_{F_t} = a_{21}$$

By transforming it to a VECM, it is now possible to see how changes in one of the variables affect the value of the other variable. The alphas are referred to as speed of adjustment coefficients. In other words, the size of the alpha determines how fast the variable responds to the deviation from the long-run equilibrium relationship in the previous period. This is the "error correction"- part of the model. It is not possible for both alphas to be zero, this would mean that the change in the variables was only a result of the error terms, and by definition, it would no longer be a VECM. However, by using two separate calculations, each time restricting one of the alphas to be zero, it is possible to get implications regarding the relationship between the two variables. Two tests will therefore be performed for all models; first a test where
H_0: $\alpha_{St} = 0$, which means that the futures prices has led the spot prices, and second a test where H_0: $\alpha_{Ft} = 0$, meaning that the spot prices has led the futures prices.

This concludes the presentation of the different methods applied in this thesis. Next follows a presentation of the data that is to be investigated.

4 Data

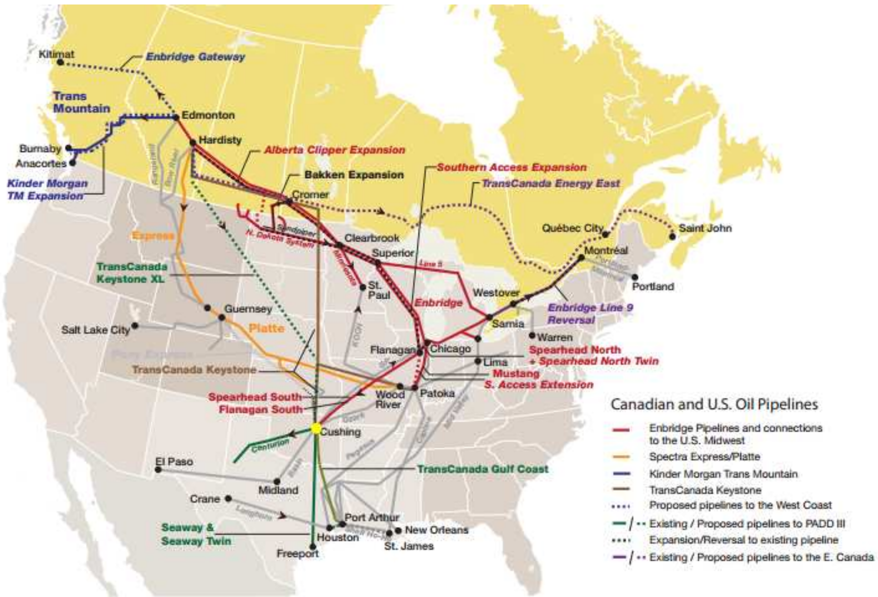
In the data section, first background information for the WTI crude oil and the Brent Blend will be presented. Then, the data frame period, data gathering process as well as data transformations and considerations will be described. Next follows descriptive statistics of the variables included in the analysis, before a presentation of the stationarity/non-stationarity characteristics of the variables, in the form of the results from the ADF-tests. Finally, a simplified analysis of contango/backwardation is presented.

4.1 Description of the crude oils included in the analyses

4.1.1 WTI crude oil

The West Texas Intermediate crude oil, referred to as WTI, is a light sweet North American oil, with delivery point at Cushing, Oklahoma (Clark, 2014). As can be seen in Figure 3, the transshipment point of Cushing is centrally located, connecting the pipelines of the Gulf Coast oilfields with consumers across most of the North American continent. The central location and pipeline distribution network has led to the importance of the WTI as an important benchmark within the oil industry.

Figure 3. The U.S. and Canadian oil pipeline system

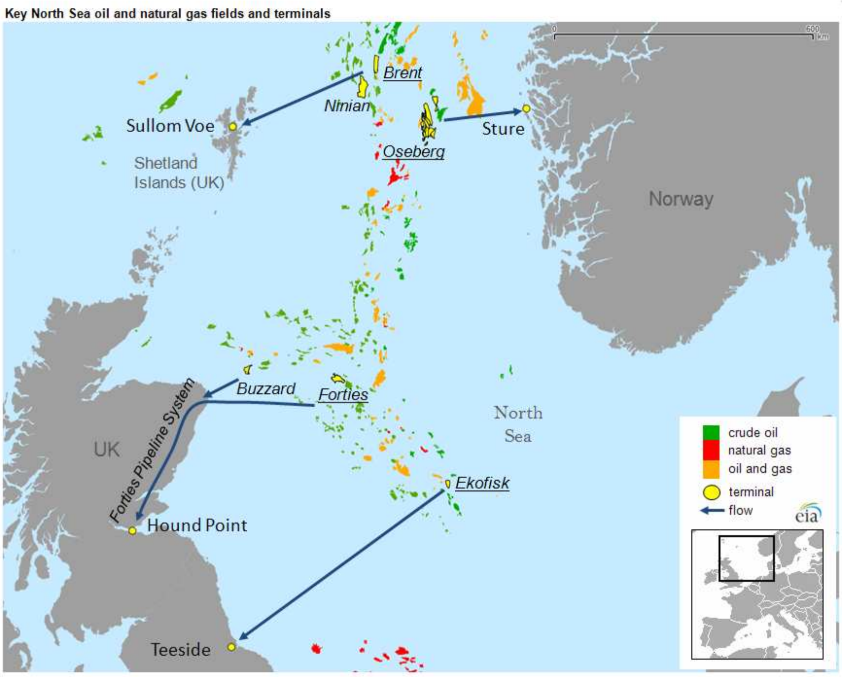


Note: Figure 3 shows the existing and proposed Canadian and U.S. oil pipelines as of 2015. Cushing, Oklahoma is marked with a yellow marker. *Source:* Canadian Association of Petroleum Producers (2015).

4.1.2 Brent Blend crude oil

Brent is a light sweet European crude oil, with qualities quite similar to the that of the WTI (Clark, 2014). Compared to WTI which is land based, Brent is retrieved via platforms in the North Sea. The crude oil generally just referred to as Brent today, is more accurately the Brent Blend, which is a blend of crude oils from the four North Sea oilfields Brent, Forties, Oseberg and Ekofisk. The Brent Blend was constructed to keep the benchmark viable, as the Brent field has declined from a peak production of approximately 400,000 bbls per day in the mid-1980s, to practically zero today. All of the four crude oils have different landing points, as shown in Figure 4. Pipelines connect Brent to the Sullom Voe shipping terminal at Shetland Islands, Forties to the Hound Point terminal in the UK, Oseberg to the Sture terminal in Norway and Ekofisk to the Teesside terminal in the UK.

Figure 4. Location and landing points for the four oil fields included in the Brent Blend



Source: U.S. Energy Information Administration (2013a)

4.2 Description of time frame of the data

Daily historical spot and futures closing prices for WTI (NYMEX) and Brent (ICE) were downloaded using the financial database *Datastream* on April 29 2016. For futures contracts, the durations chosen were 1 month, 2 months, 3 months, 4 months, 5 months and 6 months, which in this thesis often will be referred to using the abbreviations 1M, 2M, 3M, 4M, 5M and 6M. There were differences in how much historical data that was available for the different spot and futures contracts, as *Datastream* does not have all historical data for all contracts.

The data downloaded for the WTI spot and futures contracts was for the period 02.01.1986 until 31.03.2016. For Brent, data for spot and the 1M futures contract ranged from 02.01.1989 until 31.03.2016, while the history for the rest of the futures contracts was from 01.10.2003 to 31.03.2016. For simplicity considering comparison, for Brent this thesis has applied futures data from 01.10.2003 for all maturities. After lagging the futures prices, only those lines with prices for all six maturities were included in the analyses. Consequently, the time frame for the lagged prices was April 2004 to March 2016 for Brent and July 1986 to March 2016 for WTI, as described in section 4.4.

4.3 Data transformations and considerations

Spot prices were obtained as daily closing prices. For the Brent Blend, dated Brent was used as a spot price, as this is the underlying object of the futures considered. Dated Brent is however not “as spot” as the WTI, since it takes on average 17 days before it is ready for delivery (Caumon & Bower, 2004). The futures prices were downloaded as continuous time series for each duration type, with switch over to the next month on the first day of the new month trading. All variables were log-transformed prior to the analysis in order to make them more streamlined and adequate for analysis. It was decided not to do any more transformations of the data, such as for instance winsorizing or removal of outliers, in order to preserve as much information in the data as possible. The rationale for this is that what is first perceived as outliers or extreme values might actually be a display of the characteristics of market efficiency/inefficiency.

For the “total period”, data was used for as long periods as data for both spot and futures of the blends was available, which was January 1986 to March 2016 for WTI and October 2003 to March 2016 for Brent Blend, as described in section 4.2. The “sub period”, which was the period where the prices declined, was defined as of January 2012 throughout March 2016. The starting point of 2012 was chosen as this was the point in time where the produced amount of shale oil started to significantly increase, as can be seen in Figure 2.

Consistent with the theories described in section 2.3, the current price of futures was to be compared to the spot price at maturity. In order to do this in a more practical manner, the data were converted into monthly observations. Samuelson (1965), as referred in Black and Tonks (2000), found that the prices of futures have varying volatility, with increasing volatility when approaching the maturity date. This is also referred to as the Samuelson effect. Consequently, calculations of average monthly prices for futures can include a lot of noise, decreasing the quality of the estimate. Instead, a fixed date every month was chosen as the monthly observation for the future contracts. The date was set approximately one week ahead of the last day of trading.

For WTI, the last day of trading is three business days prior to the 25th calendar date of the month prior to the contract month. If that date is not a business day, it is the first business day prior to that (U.S. Energy Information Administration, 2016b). For WTI, the 15th every month was chosen as the observation date, as this was approximately one week ahead of the last day of trading. If the 15th was not a business day, the next business day following the 15th was chosen as the observation date.

For Brent, the last day of trading for the one month futures contract up to and including the February 2016 contract was the 15th calendar date in the month prior to the delivery month, if this date was a business day (The ICE, 2016). If this was not a business day, then the last day of trading was the first business day prior to the 15th calendar date in the month prior to delivery. As of, and including, the March 2016 contract, the last day of trading was the last business day of the second month preceding the delivery month. As an example, if January 31 2016 was a business day, this would be the last day of trading for the March 2016 one month futures contract. For this thesis, up until and including February 2016 delivery contracts, the 5th every month was chosen as observation date. If the 5th was not a business day, the next following business day would be the observation date. For the contracts with delivery in March 2016, the 20th two months prior to the contract date was chosen as the observation date for the one month futures, the 20th three months prior to the delivery month for the three month futures, and so on. If the 20th was not a business day, the first business day following the 20th was chosen as the observation date.

Ideally, if one were to follow the theories exactly as described in section 2.4, the futures price should be compared to the spot price on the exact date of delivery. However, determining the exact day for delivery is challenging. Therefore, as an estimate for the spot price upon delivery, the average spot price for the delivery month has been chosen as the monthly observation value for spot prices.

There are disadvantages regarding the described methods chosen to obtain the monthly observation values. For the futures observations, there is a risk that the chosen date is very different from all other dates, also referred to as a statistical outlier, and that if we had chosen the prior or subsequent date, the conclusions from the analysis would have been different. For the spot prices, extreme values might bias the calculated average. However, for the purpose of this thesis, the benefits of this convenient way of handling the data is considered to outweigh the potential negative consequences mentioned.

4.4 Descriptive statistics

Table 1 shows descriptive statistics for what will hereafter be referred to as the “total period”. For Brent, this is from April 2004 to March 2016. For WTI, it is from July 1986 to March 2016. Table 2 shows descriptive statistics for what will hereafter be referred to as the “sub period”, which is the period where the prices declined after the shale oil revolution, which is January 2012 to March 2016, for both blends.

Table 1. Descriptive statistics of variables for the total period

Variable	Mean	Std.dev.	Min.	5% perc	Median	95% perc	Max.
Brent spot	4.3099	0.3687	3.4377	3.6470	4.3205	4.7779	4.8911
Brent 1M	4.3155	0.3682	3.3279	3.6225	4.3303	4.7656	4.9549
Brent 2M	4.3204	0.3625	3.3690	3.6272	4.3364	4.7642	4.9605
Brent 3M	4.3242	0.3606	3.3628	3.6139	4.3445	4.7624	4.9654
Brent 4M	4.3239	0.3654	3.3354	3.5712	4.3527	4.7597	4.9694
Brent 5M	4.3217	0.3726	3.3109	3.5537	4.3577	4.7571	4.9723
Brent 6M	4.3182	0.3811	3.2880	3.4689	4.3602	4.7544	4.9756
WTI spot	3.5349	0.6702	2.4289	2.7017	3.3387	4.6264	4.8970
WTI 1M	3.5312	0.6711	2.4467	2.6788	3.3503	4.6091	4.9326
WTI 2M	3.5288	0.6766	2.4432	2.6873	3.3411	4.6075	4.9371
WTI 3M	3.5248	0.6823	2.4319	2.6961	3.3073	4.6091	4.9404
WTI 4M	3.5195	0.6867	2.4406	2.6933	3.2817	4.6055	4.9435
WTI 5M	3.5153	0.6893	2.4406	2.7082	3.2699	4.6061	4.9460
WTI 6M	3.5114	0.6906	2.4406	2.7100	3.2554	4.6026	4.9477

Note: All numbers in log numbers. The spot prices are monthly averages. The futures prices are monthly observations on a fixed date. Brent numbers are ICE-numbers and WTI-numbers are from NYMEX, all data retrieved using *Datastream*.

Table 2. Descriptive statistics of variables for the sub period

Variable	Mean	Std.dev.	Minimum	5% perc.	Median	95% perc.	Maximum
Brent spot	4.4269	0.3996	3.4377	3.5795	4.6723	4.7848	4.8305
Brent 1M	4.4606	0.3731	3.3279	3.6622	4.6617	4.7811	4.8187
Brent 2M	4.4888	0.3303	3.6058	3.8162	4.6617	4.7746	4.8117
Brent 3M	4.5111	0.2930	3.8304	3.9013	4.6604	4.7715	4.8066
Brent 4M	4.5284	0.2695	3.9142	3.9324	4.6613	4.7682	4.8018
Brent 5M	4.5433	0.2498	3.9281	3.9535	4.6574	4.7641	4.7965
Brent 6M	4.5577	0.2314	3.9156	4.0285	4.6564	4.7593	4.7902
WTI spot	4.3293	0.3721	3.4103	3.5541	4.5371	4.6657	4.6688
WTI 1M	4.3421	0.3689	3.3817	3.5251	4.5374	4.6736	4.6841
WTI 2M	4.3712	0.3352	3.4141	3.7030	4.5440	4.6689	4.6779
WTI 3M	4.3957	0.2974	3.6778	3.7794	4.5454	4.6636	4.6655
WTI 4M	4.4142	0.2720	3.7810	3.8238	4.5474	4.6490	4.6706
WTI 5M	4.4295	0.2501	3.8315	3.8725	4.5451	4.6442	4.6742
WTI 6M	4.4438	0.2329	3.8493	3.8888	4.5440	4.6464	4.6762

Note: All numbers in log numbers. The spot prices are monthly averages. The futures prices are monthly observations on a fixed date. Brent numbers are ICE-numbers and WTI-numbers are from NYMEX, all data retrieved using *Datastream*.

From Table 1 and Table 2, one can see that the in most cases, the mean increases with maturity, except for WTI in the total period, where it decreases with maturity. The standard deviation increases with maturity for the total period, but decreases with maturity for the sub period. Further, Brent Blend has a higher price than WTI during both periods. The numbers for the total period are however not directly comparable, due to the difference in time frame for the historical data for Brent Blend and WTI. One can also see implications of the Brent Blend being in contango for both the total and sub period, as the futures prices are above the spot prices. The numbers for WTI implies backwardation for the total period and contango for the sub period. This will be further explored in section 4.6.

4.5 The Augmented Dickey-Fuller test

In this section, results from tests of stationarity and order of integration will be presented. Graphs showing the price development for the different maturities of the futures contracts can be seen in appendix C for Brent Blend and Appendix D for WTI. A graphical presentation of the spot prices can be seen in figure 1 in section 1.1.

Table 3. ADF test results for the total period

	Log prices in levels		Log prices in first differences	
	Constant	Constant and trend	Constant	Constant and trend
Brent spot	-1.5791	-2.0526	-59.1931***	-59.1937***
Brent 1M	-1.4952	-1.7997	-61.6657***	-61.6669***
Brent 2M	-2.0683	-1.0951	-41.1248***	-41.2202***
Brent 3M	-2.1164	-1.0889	-41.0076***	-41.1110***
Brent 4M	-2.1656	-1.0849	-40.9013***	-41.0123***
Brent 5M	-2.2177	-1.0866	-40.8315***	-40.9494***
Brent 6M	-2.2684	-1.0895	-40.7988***	-40.9232***
WTI spot	-1.6259	-2.9879	-65.4328***	-65.4287***
WTI 1M	-1.5912	-2.9246	-66.6454***	-66.6413***
WTI 2M	-1.4405	-2.6457	-64.2150***	-64.2111***
WTI 3M	-1.3485	-2.4709	-64.0513***	-64.0474***
WTI 4M	-1.2703	-2.3097	-64.1370***	-64.1332***
WTI 5M	-1.2254	-2.2423	-64.2242***	-64.2203***
WTI 6M	-1.1930	-2.1968	-64.5273***	-64.5233***

Note: Critical values for ADF-test with constant for 10%, 5% and 1% is -3.43, -2.86 and -2.57, respectively. Critical values for ADF-test with constant and time trend for 10%, 5% and 1% is -3.96, -3.41 and -3.12, respectively. *** denotes rejection of null hypothesis at the 1% level

A visual inspection of the spot prices in Figure 1 and the futures prices in Appendix C and D, suggests that the data have a constant, as the prices appear to be weakly fluctuating around some positive value other than zero, pushing and pulling the prices up and down. There does not appear to be a time trend. However, as one cannot rule out that there is a weak time trend, the ADF-tests have been performed both with a constant, and with a constant and a time trend.

Lags have been chosen in accordance with the Akaike Information Criterion (AIC). The results from the ADF-test for the total period is presented in table 3, while the results from the test of the sub period is presented in table 4. For all tests, the null hypothesis is that the data is non-stationary. As evident from the tables presented, for all contracts and periods, the null hypothesis for the log prices in level cannot be rejected, while the null hypotheses for the first differences are rejected at a significance level of 1%. Consequently, all data is *I(1)* and applicable for use in the cointegration analysis.

Table 4. ADF test results for the total period

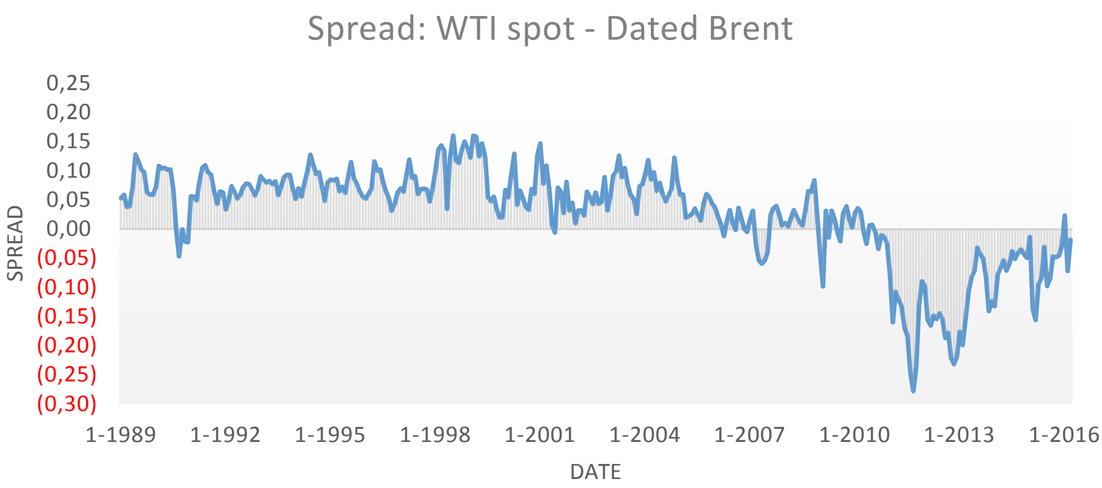
	Log prices in level		Log prices in first differences	
	Constant	Constant and trend	Constant	Constant and trend
Brent spot	-0.5622	-2.0438	-4.9821***	-5.0351***
Brent 1M	1.4431	-0.3682	-3.5433***	-4.2257***
Brent 2M	0.6535	-1.2754	-4.5845***	-5.0837***
Brent 3M	0.0447	-1.4769	-4.5311***	-4.9360***
Brent 4M	-0.0911	-2.0386	-4.5785***	-4.7234***
Brent 5M	-0.1899	-1.6858	-4.5255***	-4.9952***
Brent 6M	0.2138	-1.2533	-4.2072***	-4.5871***
WTI spot	-1.0355	-2.186	-4.6613***	-4.6613***
WTI 1M	0.4947	-1.046	-4.1630***	-4.4727***
WTI 2M	0.7882	-0.9068	-3.8701***	-4.2796***
WTI 3M	0.098	-1.2722	-4.3288***	-4.6391***
WTI 4M	0.0042	-1.6462	-4.5369***	-4.7252***
WTI 5M	-0.3598	-1.7208	-4.3503***	-4.6170***
WTI 6M	-0.0021	-1.4313	-4.3024***	-4.6253***

Note: Critical values for ADF-test with constant for 10%, 5% and 1% is -3.43, -2.86 and -2.57, respectively. Critical values for ADF-test with constant and time trend for 10%, 5% and 1% is -3.96, -3.41 and -3.12, respectively. *** denotes rejection of null hypothesis at the 1% level

4.6 Contango and backwardation analysis

Figure 5 shows the development of the spread between monthly average log prices for WTI and dated Brent. For those instances where the spread is positive, the WTI price is above the Brent Blend spot price, while when the spread is negative; the Brent Blend spot price was higher than the WTI spot price. According to Milonas and Henker (2001), WTI has a slightly higher price than the Brent blend, as the quality of WTI results in slightly more gasoline, which is more valuable, and slightly less heating oil, which is less valuable. One must assume that the qualities of the two crudes have not changed significantly since 2001. The development in spread shown in Figure 5 does however indicate that around 2011 and onward, something has changed. According to EIA, the reason for the increased spread in 2012 was increasing oil production from North Dakota and Texas that exceeded the capacity of the existing pipeline infrastructure to bring the crude to refining centers on the Gulf coast (U.S. Energy Information Administration, 2013b). More expensive transportation methods such as railroads and trucks had to be used to compensate for the limited capacity of the pipelines. This increased the costs of the inland crudes such as WTI, and consequently decreased the price of WTI to account for the increased costs. This is useful information to keep in mind when investigating the backwardation/contango relationships.

Figure 5. WTI spot – Brent spot spread for monthly average log prices



Note: Prices are monthly averages, all numbers in log. The data for WTI (NYMEX) and dated Brent (ICE) is retrieved using *Datastream*.

Table 5 shows the results of a simplified analysis of backwardation/contango relationships for the total period. Table 6 shows the same calculations for the sub period. Basis has first been estimated on a monthly basis, using the monthly average spot prices subtracting monthly observations of futures prices. The average basis has further been computed based on those calculations. It must be emphasized that the calculations are very simple and meant more as an indication of the contango/backwardation-state than a thorough analysis. If on average the spot price has exceeded the futures price, the contract pair has been classified as in backwardation. If on average the spot price has been below the futures price, the contract pair has been classified as in contango.

Considering the total period, Table 5 shows that Brent spot/Brent futures and WTI spot/Brent futures were clearly in contango as the spot price was below the futures price. The gap was increasing with increasing maturities. Brent spot/WTI futures were also in contango, but the gap was decreasing with increasing maturities. Finally, WTI spot/WTI futures were in a backwardation- shaped curve where spot prices exceeded the futures prices, with increasing differences between spot and futures prices with increasing maturities.

Table 5. Contango/Backwardation- calculations for the total period

Variable	Brent 1M	Brent 2M	Brent 3M	Brent 4M	Brent 5M	Brent 6M
Brent spot	-0.00522	-0.00996	-0.01543	-0.01908	-0.02181	-0.02375
WTI spot	-0.03954	-0.04428	-0.04975	-0.05340	-0.05612	-0.05807

Variable	WTI 1M	WTI 2M	WTI 3M	WTI 4M	WTI 5M	WTI 6M
Brent spot	-0.02423	-0.02481	-0.02409	-0.02218	-0.02094	-0.01938
WTI spot	0.00054	0.00093	0.00209	0.00406	0.00518	0.00658

Note: The table shows the average of spot minus futures prices per contract for Brent and WTI for the total period, where M is an abbreviation for months to maturity for the futures contracts. Calculations are based on monthly averages, all numbers in log. Negative values indicate that the spot price was on average lower than the futures price for the contract. Positive values indicate that the spot price was on average higher than the futures price.

Table 6. Contango/Backwardation- calculations for the sub period

Variable	Brent 1M	Brent 2M	Brent 3M	Brent 4M	Brent 5M	Brent 6M
Brent spot	-0.01116	-0.01274	-0.01697	-0.01951	-0.02163	-0.02287
WTI spot	-0.10876	-0.11033	-0.11456	-0.11711	-0.11923	-0.12047

Variable	WTI 1M	WTI 2M	WTI 3M	WTI 4M	WTI 5M	WTI 6M
Brent spot	0.10343	0.09568	0.08957	0.08517	0.08184	0.07973
WTI spot	0.00583	-0.00192	-0.00803	-0.01242	-0.01576	-0.01786

Note: The table shows the average of spot minus futures prices per contract for Brent and WTI for the sub period, where M is an abbreviation for months to maturity for the futures contract. Calculations are based on monthly averages, all numbers in log. Negative values indicate that the spot price was on average lower than the futures price for the contract. Positive values indicate that the spot price was on average higher than the futures price.

For the sub period, Table 6 shows that Brent spot/Brent futures and WTI spot/Brent futures displayed the typical characteristics of contango. Brent spot/WTI futures were in backwardation, but the differences between the spot and futures prices were decreasing with increasing maturities. Finally, the curve for WTI spot/WTI futures was in backwardation for the 1M contract, but in contango for the rest of the contracts, with an increasing gap between spot and futures prices.

Please note that the WTI numbers go back to 1987 while the Brent numbers only go back to 2004, and as such, the contango/backwardation states of the different crude oil types are not directly comparable for the total period. It is however interesting to observe that while WTI was in backwardation for the 1987-2016 period, it was in contango for the years 2012-2016. The results will be further discussed in the discussion section 6.2.

5 Results

In this section, first the results from the Johansen cointegration test will be presented. Finally follows a presentation of the results from the tests of weak exogeneity.

5.1 The Johansen cointegration test

The results of the Johansen cointegration analyses are presented below. The results can be seen in Table 7 for the total period, and Table 8 for the sub period. Column 1 describes the cointegration pair investigated, where the first and second contract is one cointegration pair, the third and fourth contract is one cointegration pair, and so on. Futures contracts are marked with M with a corresponding number denoting the number of months to maturity, for instance the Brent 1 month futures is denoted “Brent 1M”. The null hypothesis tested regarding cointegration is shown in column 2, while the associated trace statistic is listed in column 3. Column 4 shows the estimated beta for the cointegration pair. Column 5 lists the test statistic for the test of the joint hypothesis, $\alpha = 0$ and $\beta = 1$, with p-value shown in brackets. Column 6 and 7 show the test statistics for test of weak exogeneity, with p-values included in brackets.

The significance level was set to 5%. If the p-value was less than or equal to the significance level, the null hypothesis was rejected. If the p-value was above 0.05, the null hypothesis could not be rejected. Weak exogeneity was only tested and commented for those contract pairs that were cointegrated at a significance level up to 10%. The results will be presented with own headings for each combination of spot/futures contracts.

5.1.1 Brent spot/Brent futures

As can be seen in table 7, when considering the total period, Brent spot was cointegrated with Brent 1M and 2M at a 1% significance level, with 3M, 4M and 6M at a 5% level, and the 5M on a 10% significance level. The joint hypothesis of $\alpha=0$ *and* $\beta=1$ was rejected in all cases except for the 1M contract, meaning that according to the definition of market efficiency applied in this thesis, the market has only been efficient for the contract with the shortest maturity.

Turning to the sub period as shown in table 8, the spot price was cointegrated with the 1M, 2M, 3M and 4M futures at a 1% significance level. There was no significant cointegration between Brent spot and the 5M and 6M contracts. Further, the results suggest that the market has only been efficient for the 4M contract for the Brent spot/Brent futures combination, as this was the only contract where there was both significant cointegration and a lack of rejection of the joint hypothesis of $\alpha=0$ and $\beta=1$ at a 5% significance level. Although also the 1M, 2M and 3M contracts showed significant cointegration with the spot price on a 1% level, the joint hypothesis was rejected.

5.1.2 WTI spot/WTI futures

For WTI, the spot price was cointegrated with WTI futures prices for all maturities at a 1 % significance level for the overall period, as can be seen in table 7. Considering the sub period, table 8 shows there was cointegration for the 1M, 2M, 3M and 4M contracts on a 1% level and with the 5M contract on a 5% level. The joint hypothesis could not be rejected for the 1M contract for the total period (p-value > 5%), and for the 2M, 4M and 5M contracts for the sub period, implying market efficiency for those four contracts.

5.1.3 Brent spot/WTI futures

Brent spot was cointegrated with the WTI 1M at a 1% level, the 2M and 3M at a 5% level, and the 4M and 5M at a 10% level for the total period, as shown in table 7. The cointegration with the 6M contract was on a significance level above 10%. Considering the results for the sub period shown in table 8, Brent spot was only cointegrated with the WTI 5M at a 10% level. The joint hypothesis was rejected in all cases, meaning that the market was not defined as efficient for any of the contracts, in neither the total period nor sub period.

5.1.4 WTI spot/Brent futures

Finally, for the total period, the WTI spot price was cointegrated at a significant level with all maturities of the Brent futures, as shown in table 7. For the 2M it was at a 5% level, while for the rest it was at a 1% level. Regarding the sub period, table 8 shows that the WTI spot price was only significantly cointegrated with the 2M, 3M and 4M contracts, at a 1% level. The joint hypothesis could not be rejected for the 3M, 4M, 5M and 6M contracts for the total period and for the 2M, 3M and 4M contracts for the sub period, which could be interpreted as a sign of market efficiency for those contracts.

Table 7. Results from cointegration analysis, test of joint hypothesis and weak exogeneity for the total period

Contract	H_0	Cointegration trace statistic	β	Joint test $H_0 : \alpha=0, \beta=1$	$H_0 : \alpha_{St} = 0$	$H_0 : \alpha_{Ft} = 0$
Brent spot	r = 0	147.75***	1.0149	3.55 (0.06)	2.34 (0.13)	131.39 (0.00)
Brent 1M	r ≤ 1	5.56				
Brent spot	r = 0	34.89***	1.0404	6.82 (0.01)	1.77 (0.18)	27.62 (0.00)
Brent 2M	r ≤ 1	3.32				
Brent spot	r = 0	19.99**	1.0951	8.15 (0.00)	0.87 (0.35)	9.33 (0.00)
Brent 3M	r ≤ 1	4.27				
Brent spot	r = 0	20.18**	1.1419	7.43 (0.01)	1.18 (0.28)	7.64 (0.01)
Brent 4M	r ≤ 1	5.57				
Brent spot	r = 0	16.95*	1.1637	7.17 (0.01)	0.09 (0.77)	8.62 (0.00)
Brent 5M	r ≤ 1	3.88				
Brent spot	r = 0	19.96**	1.1313	3.83 (0.05)	0.00 (0.96)	7.71 (0.01)
Brent 6M	r ≤ 1	6.11				
WTI spot	r = 0	63.14***	1.0037	1.63 (0.20)	1.65 (0.20)	58.21 (0.00)
WTI 1M	r ≤ 1	2.45				
WTI spot	r = 0	208.18***	0.9939	5.49 (0.02)	14.80 (0.00)	182.43 (0.00)
WTI 2M	r ≤ 1	2.62				
WTI spot	r = 0	85.15***	0.9848	9.14 (0.00)	1.02 (0.31)	75.35 (0.00)
WTI 3M	r ≤ 1	2.17				
WTI spot	r = 0	50.34***	0.9781	7.39 (0.01)	0.29 (0.59)	46.32 (0.00)
WTI 4M	r ≤ 1	1.86				
WTI spot	r = 0	55.20***	0.9728	8.52 (0.00)	0.68 (0.41)	50.35 (0.00)
WTI 5M	r ≤ 1	1.94				
WTI spot	r = 0	32.03***	0.9663	7.14 (0.01)	2.40 (0.12)	27.52 (0.00)
WTI 6M	r ≤ 1	1.18				
Brent spot	r = 0	27.77***	1.1047	15.70 (0.00)	0.32 (0.57)	23.41 (0.00)
WTI 1M	r ≤ 1	2.16				
Brent spot	r = 0	21.03**	1.0909	9.97 (0.00)	2.37 (0.12)	14.65 (0.00)
WTI 2M	r ≤ 1	2.01				
Brent spot	r = 0	18.57**	1.0833	7.86 (0.01)	1.63 (0.20)	12.88 (0.00)
WTI 3M	r ≤ 1	1.60				
Brent spot	r = 0	16.49*	1.0766	5.67 (0.02)	0.49 (0.48)	12.59 (0.00)
WTI 4M	r ≤ 1	1.56				
Brent spot	r = 0	16.08*	1.0655	3.75 (0.05)	0.80 (0.37)	11.31 (0.00)
WTI 5M	r ≤ 1	1.85				
Brent spot	r = 0	14.82	1.0599	2.89 (0.09)	-	-
WTI 6M	r ≤ 1	1.48				
WTI spot	r = 0	26.19***	0.8143	8.93 (0.00)	4.86 (0.03)	13.76 (0.00)
Brent 1M	r ≤ 1	5.21				
WTI spot	r = 0	21.52**	0.8640	4.45 (0.03)	0.01 (0.91)	12.47 (0.00)
Brent 2M	r ≤ 1	4.17				
WTI spot	r = 0	26.12***	0.8916	3.46 (0.06)	0.14 (0.71)	16.69 (0.00)
Brent 3M	r ≤ 1	4.69				
WTI spot	r = 0	29.11***	0.9001	3.61 (0.06)	0.16 (0.69)	20.26 (0.00)
Brent 4M	r ≤ 1	4.42				
WTI spot	r = 0	23.75***	0.8761	3.19 (0.07)	0.75 (0.39)	9.99 (0.00)
Brent 5M	r ≤ 1	6.77*				
WTI spot	r = 0	26.51***	0.8881	3.00 (0.08)	1.09 (0.30)	12.36 (0.00)
Brent 6M	r ≤ 1	6.81*				

Note: *, ** and *** denotes rejection of null hypothesis at the 10%, 5% and 1% level, respectively. For the test of joint hypothesis and weak exogeneity, p-value is included in brackets.

Table 8. Results from cointegration analysis, test of joint hypothesis and weak exogeneity for the sub period.

Contract	H_0	Cointegration trace statistic	β	Joint test H_0 : α=0, β=1	$H_0 : \alpha_{St} = 0$	$H_0 : \alpha_{Ft} = 0$
Brent spot	r = 0	64.92***	1.0226	5.20 (0.02)	0.57 (0.45)	63.73 (0.00)
Brent 1M	r ≤ 1	0.08				
Brent spot	r = 0	108.50***	1.0686	14.43 (0.00)	0.64 (0.42)	107.32 (0.00)
Brent 2M	r ≤ 1	0.58				
Brent spot	r = 0	101.95***	1.0962	18.35 (0.00)	1.73 (0.19)	101.46 (0.00)
Brent 3M	r ≤ 1	0.22				
Brent spot	r = 0	25.69***	1.2305	2.93 (0.09)	2.77 (0.10)	21.14 (0.00)
Brent 4M	r ≤ 1	0.02				
Brent spot	r = 0	14.21	1.3904	2.67 (0.10)	-	-
Brent 5M	r ≤ 1	0.04				
Brent spot	r = 0	10.88	1.4447	1.68 (0.20)	-	-
Brent 6M	r ≤ 1	0.14				
WTI spot	r = 0	38.39***	0.9835	4.45 (0.03)	0.14 (0.71)	37.70 (0.00)
WTI 1M	r ≤ 1	0.15				
WTI spot	r = 0	141.56***	1.0163	3.05 (0.08)	3.50 (0.06)	140.37 (0.00)
WTI 2M	r ≤ 1	0.00				
WTI spot	r = 0	139.16***	1.0653	29.71 (0.00)	1.28 (0.26)	133.38 (0.00)
WTI 3M	r ≤ 1	0.13				
WTI spot	r = 0	31.43***	1.1000	0.94 (0.33)	5.15 (0.02)	26.81 (0.00)
WTI 4M	r ≤ 1	0.13				
WTI spot	r = 0	19.52**	1.2039	1.36 (0.24)	1.73 (0.19)	13.87 (0.00)
WTI 5M	r ≤ 1	0.12				
WTI spot	r = 0	11.70	1.2734	0.89 (0.34)	-	-
WTI 6M	r ≤ 1	0.04				
Brent spot	r = 0	10.27	1.0031	0.00 (0.96)	-	-
WTI 1M	r ≤ 1	0.04				
Brent spot	r = 0	8.68	1.1603	3.86 (0.05)	-	-
WTI 2M	r ≤ 1	0.55				
Brent spot	r = 0	5.67	1.1549	2.33 (0.13)	-	-
WTI 3M	r ≤ 1	0.29				
Brent spot	r = 0	21.24	1.2065	1.88 (0.17)	-	-
WTI 4M	r ≤ 1	0.03				
Brent spot	r = 0	16.76*	1.3357	2.51 (0.11)	0.70 (0.40)	13.00 (0.00)
WTI 5M	r ≤ 1	0.01				
Brent spot	r = 0	9.91	1.4983	1.99 (0.16)	-	-
WTI 6M	r ≤ 1	0.16				
WTI spot	r = 0	12.97	0.9036	3.32 (0.07)	-	-
Brent 1M	r ≤ 1	0.40				
WTI spot	r = 0	52.04***	1.0022	0.00 (0.95)	2.54 (0.11)	48.20 (0.00)
Brent 2M	r ≤ 1	0.26				
WTI spot	r = 0	40.04***	1.0700	1.16 (0.28)	8.31 (0.00)	35.70 (0.00)
Brent 3M	r ≤ 1	0.02				
WTI spot	r = 0	31.77***	1.1117	1.12 (0.29)	4.29 (0.04)	23.24 (0.00)
Brent 4M	r ≤ 1	0.00				
WTI spot	r = 0	15.21	1.2241	1.14 (0.29)	-	-
Brent 5M	r ≤ 1	0.05				
WTI spot	r = 0	12.26	1.2182	0.56 (0.46)	-	-
Brent 6M	r ≤ 1	0.00				

Note: *, ** and *** denotes rejection of null hypothesis at the 10%, 5% and 1% level, respectively. For the test of joint hypothesis and weak exogeneity, p-value is included in brackets.

5.1.5 Weak exogeneity

Considering the tests of weak exogeneity, the null hypothesis $H_{0:}\ \alpha_{St} = 0$ could only be rejected on a significant level for the WTI spot/WTI 2M and WTI spot/Brent 1M for the total period, and the WTI spot/WTI 4M, WTI spot/Brent 3M and WTI spot/Brent 4M for the sub period. In other words, in most cases, it is found that the futures price has led the spot price.

The hypothesis of $H_{0:}\ \alpha_{Ft} = 0$ is rejected on a significant level for all cointegrated relationships. Consequently, the tests of weak exogeneity imply that in general, the futures price has lead the spot price.

6 Discussion

In this section, first a summary of key findings and a discussion of possible explanations and what the results imply will be presented. Then follows some comments regarding the contango/backwardation state of the market. Next, there will be a presentation of implications of the findings for the different investors followed by a presentation of limitations of the study performed, as well as suggestions for further work. Finally, a summary of the discussion and the final conclusions will be presented.

6.1 Discussion of the results of the cointegration analysis

Market efficiency is in this thesis defined as significant cointegration, while at the same time meeting the requirements $\alpha=0$ and $\beta=1$. Summarizing the results for the total period, when considering contracts of the same blend, the market has been efficient for the 1M contracts for the cointegration pairs Brent spot/Brent futures and WTI spot/WTI futures. Further, it was efficient for the combination WTI spot/Brent futures for the 3M, 4M, 5M and 6M contracts. For the sub period, the tests showed market efficiency for the cointegration-pairs Brent spot/Brent 4M, WTI spot/ WTI 2M, WTI spot/WTI 4M and WTI spot/ WTI 5M. Finally, there was findings suggesting that the market was efficient for the combinations WTI spot/Brent 2M, WTI spot/Brent 3M and WTI spot/Brent 4M futures.

It should be noted that in many cases, there were significant cointegration relationships, but as the joint hypothesis was rejected, they did not follow the definition of efficient markets according to this thesis. Regarding the weak exogeneity, the conclusion is that in general the futures price has led the spot price.

Summarizing the results, there are three aspects in particular that need to be addressed:

i. For the total period, why was the market only efficient for the one month contract for Brent spot/Brent futures and WTI spot/WTI futures, and not for the contracts with longer maturities?
ii. For the combination Brent spot/WTI futures, what does the results of no market efficiency imply, and what can be possible explanations for this result?
iii. For the sub period, the test results for the contracts with shortest maturitites implied market inefficiency, while the test results for some of the contracts with longer maturities for Brent spot/Brent futures, WTI spot/WTI futures and WTI spot/Brent futures implied market efficiency. This was also the case for the WTI spot/Brent futures for the total period. What could be possible explanations for these seemingly sporadic findings of efficiency?

Possible explanations for these questions will be presented below.

i. For the total period, why was the market only efficient for the one month contract for Brent spot/Brent futures and WTI spot/WTI futures, and not for the contracts with longer maturities?

The finding of market efficiency for the 1 month contracts only is similar to the conclusion of Silvapulle and Moosa (1999) when they investigated WTI one month, three month and six month futures contracts. They referred to Moosa (1996) who found that crude oil market speculation was based on the price of the contract with maturity one month ahead of present time, due to uncertainty. Quan (1992) also found that only the one and three month contracts were cointegrated with the spot price when analyzing cointegration and price discovery for one, three, six and nine month forward contracts for WTI for the period January 1984 to January 1989. Furthermore, the results are similar to the findings of Switzer and El-Khoury (2007) who found market efficiency for the one month WTI futures contract. There is however a difference between the result of Silvapulle and Moosa (1999), Quan (1992) and the result in this thesis, as Silvapulle and Moosa only found cointegration for the one month contract and Quan only found cointegration for the one and three month contracts. This thesis has found significant cointegration for all of the futures contracts for WTI for the total period, and for the four shortest maturities for the sub period. This is interesting, as it implies that the spot and futures prices might be more closely linked today than they were previously. However, as this thesis has not investigated the differences between the periods in particular, this is just a comment and no conclusions can be drawn on the matter of increasing long-term relationship between the variables.

The line of reasoning regarding the one month futures contract being used for speculation might still be valid as a possible explanation as to why only the shortest contracts display the characteristics of market efficiency. According to Wang and Wu (2013), different types of investors in the market have different time horizons. Short-term investors such as traders or speculators trade with short time horizons, focus on daily and weekly price changes and might trade large volumes even when there are only minor changes in the price. In contrast, long-term investors such as governments and oil producers focus rather on the quarterly or annual price developments, and they might not trade unless the prices change over a longer period. In other words, the investors can be considered heterogeneous. Using non-linear methods, Wang and Wu found that the relationships between spot and futures prices were different in the short run and long run, as in the short run, futures prices played the role of price discovery, while in the long run, the relationship was bidirectional. Comparing to the test of weak exogeneity performed in this thesis, there were no findings of bidirectional relationship in the price formation. However, Silvapulle and Moosa (1999) found that when using a linear method, the futures price led the spot price, while using a non-linear method, the relationship was established as bidirectional. Consequently, it might be that the weak exogeneity test of the thesis does not reflect properly the relationship, as it is built on a linear model. The findings of Wang and Wu (2013) and Silvapulle and Moosa (1999) might explain why the joint hypothesis was considered valid only for the shortest maturity.

ii. For the combination Brent spot/WTI futures, what does the result of no market efficiency imply, and what can be possible explanations for this result?

It is quite interesting that while WTI spot/Brent futures were cointegrated for all contracts for the total period and for some contracts for the sub period, Brent spot/WTI futures are only cointegrated on a significant level for the shortest three maturities for the total period, and for none in the sub period. In other words, there does not appear to be the same long-term relationship between Brent spot and WTI futures as is present the other way around. A possible explanation for this lack of relationship between the variables might be that Brent spot is “less” spot than the WTI spot. If the pipeline capacity permits it, WTI crude oil is ready for immediate delivery the following day after purchase. The North-Sea based Brent Blend however is on average available 17 days after purchase (Caumon & Bower, 2004). Caumon and Bower claim that there in fact is no spot market for the dated Brent, it should rather be characterized as a futures contract with shorter maturity than the one month contract. It should also be mentioned that the one month contract for Brent was not cointegrated with the WTI-futures in the sub period, while the contracts with longer maturity were cointegrated with the spot price.

The implication of the lack of cointegration between the spot price and futures prices, is that the price development of the variables does not seem to be significantly connected. One can draw a parallel from the example mentioned earlier of the drunken man walking his dog; there was not found any leash binding the Brent spot and the WTI futures together during the sub period nor for the three longest contracts during the total period. As the joint hypothesis was rejected in all cases for both the total period and the sub period, it suggests that the WTI futures does not have a role in the price discovery of the Brent spot. Furthermore, the lack of cointegration implies speculation opportunities.

iii. For the sub period, the test results for the contracts with shortest maturities implied market inefficiency, while the test results for some of the contracts with longer maturities for Brent spot/Brent futures, WTI spot/WTI futures and WTI spot/Brent futures implied market efficiency. This was also the case for the WTI spot/Brent futures for the total period. What could be possible explanations for these seemingly sporadic findings of efficiency?

It must be emphasized that except for the WTI spot/Brent 1M contract, which were not cointegrated, it was a consistent finding for the relationships mentioned in the heading that the four or five shortest contracts were significantly cointegrated with the spot price. The more seemingly sporadic market efficiency results were related to the tests of price discovery and constant restrictions of the joint hypothesis. Intuitively, the pattern regarding which cointegration relationships that meet the requirements of market efficiency appear a bit random and challenging to rationalize. It must be noted that several potential sources of errors might have caused false results. First, the sub period consists of data from a very turbulent period, and no outlier removal or other data trimming has been performed. For the total period, it might have been evened out by the amount of data from the "normal" periods. For instance, Jiang et al. (2014) found the crude oil market to be efficient when the overall period was considered. When examining periods including turbulent events only, such as the Gulf War, the market was however found to be inefficient. Second, it should be noted that although market efficiency is implied for some of the relationships, that does not mean that it is proven. It might be random results giving false results. A lack of rejecting the hypothesis of market efficiency is not the same as proving the existence of market efficiency. Third, the Johansen cointegration test assumes a linear relationship, while for instance Silvapulle and Moosa (1999) and Wang and

Wu (2013), have found the spot/futures- relationship to be non-linear. This might have caused false or random results. In addition, the number of lags affects the result of for instance the tests of the joint hypothesis, if the lags were chosen differently, the results might have also been different. For instance, Sjö (2008) recommended to have only two lags and instead create dummy codes for the outliers to reduce white noise. Finally, previous empirical work of for instance Maslyuk and Smyth (2009) suggest the existence of structural breaks. As this thesis did not apply a method that incorporated such breaks, structural breaks might have caused unusual results.

However, although the results sometimes appear seemingly random, one can not dismiss the possibility that contracts with longer maturities might in fact be efficient while contracts with shorter maturities are inefficient. There might exist a time-varying risk premium, as found by Moosa and Al-Loughani (1994).

Further, Moosa (1996) as referred in Silvapulle and Moosa (1999) found that speculation was based on the one month contract due to uncertainty, and this led to market efficiency for the contract. One might explore the possibility that in periods with rapid changes/declines, the investors instead use the longer contracts for speculation based on an expectation of the prices to return to normal considering a longer time horizon, a so-called reversal effect. The findings of Moosa implied that uncertainty led the investors to prefer the short contract. It might be that in periods with extreme short- term volatility in spot prices, the price development within a short time horizon is considered more uncertain and unpredictable than the price development for a longer time horizon, leading the speculators towards the contracts with longer maturities instead. However, as the work of Moosa (1996) is not available, this is just comments based on how Silvapulle and Moosa (1999) referred to his findings. A more thorough reading of his work would be necessary to further explore this idea.

Another possible explanation considers the heterogeneity of the investors. Wang and Wu (2013) noted that the crude oil supply and demand elasticity was different for the short term horizon compared to the long term horizon. They referred to an article of Wang et.al. not yet published, that found that oil producers did not respond to occasional shocks, and that the produced amount was only altered if the oil price changed significantly over a longer period of time. Consequently, the supply elasticity was close to zero in the short term and a positive value for the long term horizon. Combining this with the fact that the main investors with short term horizons and the main investors with long term horizons are heterogeneous (Wang & Wu, 2013), one might consider if in fact the crude oil market might rather be perceived as several markets with different market participants, even when examining only one crude oil type. From this perspective, it might very well be that different maturities have different efficiencies, as there are different investors with different time horizons.

6.2 Comments regarding the contango/backwardation- relationships

The results in section 5.1 showed that the joint hypothesis could not be rejected for the one month contracts for WTI and Brent for the total period, as well as for a few other contracts. In most cases however, the joint hypothesis was rejected. Consequently, the analyses implied that there were other factors affecting the spot price instead of, or in addition to, the futures price. Considerations regarding the spread between the two spot prices as well as the development in contango/backwardation- relationships might shed a light on some of the dynamics of the crude oil market after the shale oil revolution. As the analysis performed in this thesis does not include volumes produced, storage levels or price volatility, it is limited which conclusions can be drawn when discussing the below mentioned perspectives. The following section should therefore be considered only as comments and not conclusions.

Table 5 showed that for the total period, the WTI spot/WTI futures were in backwardation, while the rest of the spot/futures- relationships were in contango. The difference between spot and futures prices was decreasing with increasing maturities for Brent spot/WTI futures. For the sub period, table 6 showed that Brent spot/Brent futures and WTI spot/Brent futures were all in contango, while Brent spot/WTI futures were in backwardation, and WTI spot/WTI futures were in backwardation for the 1M contract but then the curve followed a contango for the rest of the maturities.

There are several possible explanations to the state of contango. Referring to the theory of storage (Brennan, 1958; Godfrey, 1978; Holbrook, 1949; Telser, 1958), contango can be seen as a result of either increasing interest costs, higher costs of storage or lower convenience yield, all else held equal. Comparing to the total period for WTI, which includes periods where the interest rates have been higher compared to the period for the Brent data which starts at 2004, interest rates do not really explain the contango. Data for storage costs is not as easily available, therefore it will not be commented further. Rather, the focus will be kept on the concept of convenience yield, in addition to the possibility of a risk premium.

From a supply/demand-imbalance perspective, investigated by Milonas and Henker (2001) among others, the contango state of the market can be explained as a decreasing convenience yield due to an increasing storage of crude oil, as they found convenience yield to be a negative function of the level of stocks. Backwardation and contango can also be explained using risk

premium theories, where futures markets function as risk transfer mechanisms between investors with different levels of risk aversion. Kolb (1992) built his work upon the rationale of Keynes(1930a, 1930b). Sellers of futures contracts can be seen as highly risk- averse short-traders, who use futures to hedge unwanted risk. In order to have sufficient traders going long in the futures to meet the demand of the risk-averse investors going short, the investors entering a long position must be offered a risk premium to be compensated for the riskiness of the position. As a consequence, the futures price is typically below the spot price, meaning that the market is in backwardation, if the investors short in futures are more risk-averse than those investors that are in long positions. On the other hand, if those in short positions are less risk-averse than the investors in a long position, the market will be in contango. Considering the low spot prices of for instance 2014/2015, this intuitively makes sense. Producers expected the price to incline, and did not wish to lock the price at the current low levels. Risk-averse hedgers however did wish to lock the price to ensure that the costs would not be unexpectedly high in the future. That the futures price was higher than the spot price, implies that the buyer of the futures was the one paying for the risk premium. Kolb (1992) did however not find any evidence of risk premium in his analysis, but others, such as Considine and Larson (2001), have found that crude oil inventory assets contained a risk premium, and that it rose sharply with increasing volatility. It could have been interesting to see whether there actually existed such risk premiums following the shale oil revolution in particular, considering the unusual demand/supply- imbalance situation caused by the shale oil increase.
It is further interesting to see that the WTI spot/WTI 1M- relationship was in backwardation for the sub period, while the rest of the WTI spot/WTI futures were in contango. According to Kolb (1992), backwardation can imply that the sellers of the futures contract are more risk averse than the buyers of the futures contract. Another possible explanation is based on option price theory, where oil reserves are considered a call option on oil, with a call value larger the larger the volatility of the oil price (Litzenberger & Rabinowitz, 1995). The model was tested using WTI futures prices, oil option prices, US oil production and US oil reserves for the period December 1986 to December 1991. Their findings indicated that production only occurred if the discounted futures price was below the spot price, implying that backwardation is a necessary condition for production.

Finally, the findings of contango, in contrast to the assumption of “normal backwardation” described by Keynes (1930a), is similar to what Kolb (1992) found. Investigating 29 commodities based on daily settlement prices for the years 1957 to 1988, he found strong evidence of the crude oil market following a contango. The result of the extensive analysis showed that most commodities did not follow a special trend regarding backwardation or contango. Consequently, Kolb concluded that normal backwardation is not a general feature of futures market, as he made clear with his ending remark: "…normal backwardation is not normal." (Kolb, 1992, p. 90). The contango/backwardation-analysis in this thesis implies that the quite bold remark might very well be valid.

6.3 Implications of the findings for different investors

The findings of market efficiency for only a few of the many relationships investigated implies that using futures as a risk management tool might not be economically beneficial for all maturities. The simplified analysis, which showed that in many cases the market was in contango as the futures price was above the spot price at maturity, suggests that risk-averse buyers of futures contract might not have an economical gain by hedging risk using futures contracts in the crude oil market. However, for a risk averse hedger, it might be that the gain from reducing risk outweighs the cost of paying a higher price. From this perspective, the hedger prefers to pay the risk premium in order to reduce the risk. Finally, it should be noted that the relationships where there was a lack of cointegration might imply possible speculation opportunities.

6.4 Limitations and suggestions for further work

The following section will summarize some of the weaknesses of this study, as well as suggestions for further work. The Johansen cointegration analysis applied assumes a linear relationship between spot and futures, and does not incorporate any structural breaks. The results of sometimes seemingly spurious lack of rejection of the joint hypothesis might be a consequence of the model not correctly reflecting the real-life dynamics. It could be interesting to instead use a method allowing for structural breaks or non-linearity, to see if it would give other results. It is also important to mention that fixed dates were used as monthly observation for futures prices and monthly averages were used as monthly observations for spot prices. There is a possibility that extreme values and outliers might have affected the monthly observation values. Further, the number of lags applied for the Johansen cointegration test in order to remove autocorrelation is high. Sjö (2008) suggested as an alternative to have 2 lags and include dummy variables for the outliers to remove white noise. This might have provided easier interpretable results. A simple simulation for one of the pairs with high amount of lags where the joint hypothesis was rejected, showed that by reducing the amount of lags to 2, the joint hypothesis was no longer rejected. Consequently, the amount of lags directly affects the power of the test statistics. However, removing outliers as Sjö suggested might not be suitable. As previously discussed in section 4.3, there is a risk of removing some of the evidence of market inefficiencies.

6.5 Summary and conclusions

The results of the analyses of this study are extensive and sometimes challenging to interpret. It should however be mentioned that had the analyses included for instance WTI for the total period only, which is what most previous empirical studies presented in this thesis have done, the conclusion might have been simply that the results were similar to the results of for instance Switzer and El-Khoury (2007), who found market efficiency for the one month contract only.

Here follows a summary of some of the most interesting findings from the study performed in this thesis:

- For the total period, there was a high degree of cointegration between most variables, implying that they were influenced by the same stochastic variables. Compared to the previous work of for instance Silvapulle and Moosa (1999), it implies that the prices of the spot and futures contracts possibly might be more closely linked than previously, as they only found cointegration for the one month contract.
- For the sub period, in general the contracts with shortest maturities were cointegrated with the spot prices. The exceptions were WTI spot/Brent 1M, and, maybe even more interestingly, that none of the WTI futures contracts had significant cointegration with the Brent Blend spot price. Compared to the cointegration relationships found for the total period, this implies that the dynamics in the market following the shale oil revolution might actually have changed, or at least that the dynamics were different during the turbulent sub period.
- The tests of weak exogeneity showed that in general, the futures prices led the spot prices, as the hypothesis of the futures price leading the spot price was only rejected for 5 of the cointegrated pairs. The hypothesis of the spot price leading the futures price was however rejected for all cointegrated pairs.
- Considering the total period, the market was found to be efficient for the 1M contracts for Brent and WTI when considering the same blend, and for the four contracts with longest maturities considering the WTI spot/Brent futures. For the sub period however, the market efficiency results appeared to be a bit more random.

- The assumption of “normal backwardation” does not seem to be applicable for the crude oil markets and the periods here investigated, as many of the relationships were found to be in contango.

The questions to be answered in this thesis were:

1. Was the crude oil futures market for Brent and WTI efficient during the price decline that started in 2014?
2. Has the crude oil futures market for Brent and WTI been efficient considering the total period, when including the price decline of 2014/2015?

Considering the first question, the answer is that some of the cointegration pairs during the sub period did meet the criteria of market efficiency as defined in this thesis. The results did however appear to be a bit random.
Regarding the second question, the answer is that the market was found to be efficient for the one month contracts for WTI and Brent Blend for the total period when considering the same blend, as well as for the four contracts with longest maturities for WTI spot/Brent futures. However, similar to the findings for the sub period, the results show that the futures prices alone explained only a few of the relationships.

It is evident from the above summary that there still exists questions that has to be further explored. Perhaps could a non-linear method better reflect the dynamics of the crude oil market dynamics, especially for the turbulent sub period, or a model including for instance a time-varying risk premium, since the findings suggest that the futures price has been an unbiased estimator of the spot price on only a few occasions.

The headlines of Norwegian newspapers are constant reminders that something has changed within the oil industry. People losing their jobs has become a part of the everyday reality. One might get the impression that the oil era is over. And maybe the oil era, as we know it, has passed. However, it is important to remember that the oil sector is still of significant importance for a considerate amount of countries and economies, and will continue to be so for many years to come. The billions being invested in the Johan Sverdrup- field surely do imply that. As mentioned in the introduction, BP estimated in their Energy Outlook to 2035 that fossil fuels will provide approximately 80% of the total energy supply in 2035 (BP, 2016). The estimate does perhaps seem a bit high, but even if the actual number turns out to be lower, it signals that the crude oil industry will continue to be of interest for many years to come, and consequently, so will probably the questions regarding market efficiency in the crude oil futures market. Maybe some of the remaining questions mentioned above will find their answers.

7 References

Articles and books

Bera, A. K., & Jarque, C. M. (1980). Efficient tests for normality, homoscedasticity and serial independence of regression residuals. *Economics Letters*, *6*(3), 255-259.

Black, J., & Tonks, I. (2000). Time series volatility of commodity futures prices. *Journal of Futures Markets, 20*(2), 127-144.

Bodie, Z., Marcus, A. J., & Kane, A. (2014). *Investments* (10th global ed. ed.). Berkshire: McGraw-Hill Education.

Box, G. E. P., Jenkins, G. M., & Reinsel, G. C. (2008). *Time series analysis : forecasting and control* (4th ed. ed.). Hoboken, N.J: Wiley.

Brennan, M. J. (1958). The Supply of Storage. *The American Economic Review, 48*(1), 50-72.

Breusch, T. S. (1978). TESTING FOR AUTOCORRELATION IN DYNAMIC LINEAR MODELS*. *Australian Economic Papers*, *17*(31), 334-355.

Caumon, F., & Bower, J. (2004). *Redefining the Convenience Yield in the North Sea Crude Oil Market*. Oxford, UK: Oxford Institute for Energy Studies.

Chen, P.-F., Lee, C.-C., & Zeng, J.-H. (2014). The relationship between spot and futures oil prices: Do structural breaks matter? *Energy Economics, 43*, 206-217.

Chowdhury, A. R. (1991). Futures market efficiency: evidence from cointegration tests. *Journal of Futures Markets, 11*(5), 577.

Clark, I. J. (2014). *Commodity Option Pricing : A Practitioner's Guide*. Hoboken: Wiley.

Considine, T. J., & Larson, D. F. (2001). Risk premiums on inventory assets: the case of crude oil and natural gas. *Journal of Futures Markets, 21*(2), 109-126.

Crowder, W. J., & Hamed, A. (1993). A cointegration test for oil futures market efficiency. *Journal of Futures Markets, 13*(8), 933-941.

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the Estimators for Autoregressive Time Series With a Unit Root. *Journal of the American Statistical Association*, *74*(366), 427-431.

Dickey, D. A., & Fuller, W. A. (1981). Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. *Econometrica*, *49*(4), 1057-1072.

Dwyer, G. P., & Wallace, M. S. (1992). Cointegration and market efficiency. *Journal of International Money and Finance, 11*(4), 318-327.

Enders, W. (2010). *Applied econometric time series* (3rd ed. ed.). Hoboken, N.J: Wiley.

Engle, R. F. (1982). Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. *Econometrica, 50*(4), 987-1007.

Fabozzi, F. J., Focardi, S. M., Rachev, S. T., & Arshanapalli, B. G. (2014). *Cointegration*. Hoboken, NJ, USA: Hoboken, NJ, USA: John Wiley & Sons, Inc.

Fabozzi, F. J., Fuss, R., & Kaiser, D. G. (2008). *The Handbook of Commodity Investing* (Vol. v.156). Chichester: Wiley.

Fama, E. F. (1970). Efficient Capital Markets: A Review of Theory and Empirical Work. *Journal of Finance, 25*(2), 383-417.

Fama, E. F. (1998). Market efficiency, long-term returns, and behavioral finance. *Journal of Financial Economics, 49*(3), 283-306.

Godfrey, L. (1978). TESTING AGAINST GENERAL AUTOREGRESSIVE AND MOVING AVERAGE ERROR MODELS WHEN THE REGRESSORS INCLUDE LAGGED DEPENDENT VARIABLES. *Econometrica (pre-1986), 46*(6), 1293.

Granger, C. W. J. (1986). Developments in the Study of Cointegrated Economic Variables. *Oxford Bulletin of Economics and Statistics, 48*(3), 213-228.

Gülen, S. G. (1998). Efficiency in the crude oil futures market. *Journal of Energy Finance and Development, 3*(1), 13-21.

Hakkio, C. S., & Rush, M. (1989). Market efficiency and cointegration: an application to the sterling and deutschemark exchange markets. *Journal of International Money and Finance, 8*(1), 75-88.

Hill, R. C., Lim, G. C., & Griffiths, W. E. (2012). *Principles of econometrics* (4th ed. ed.). Hoboken, N.J: Wiley.

Holbrook, W. (1949). The Theory of Price of Storage. *The American Economic Review, 39*(6), 1254.

Hull, J. (2015). *Options, futures, and other derivatives* (9th ed. ed.). Boston, Mass: Pearson.

Jiang, Z.-Q., Xie, W.-J., & Zhou, W.-X. (2014). Testing the weak-form efficiency of the WTI crude oil futures market. *Physica A: Statistical Mechanics and its Applications, 405*, 235-244.

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control, 12*(2), 231-254.

Johansen, S. (1991). Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models. *Econometrica, 59*(6), 1551-1580.

Johansen, S., & Juselius, K. (1990). MAXIMUM LIKELIHOOD ESTIMATION AND INFERENCE ON COINTEGRATION — WITH APPLICATIONS TO THE DEMAND FOR MONEY. *Oxford Bulletin of Economics and Statistics, 52*(2), 169-210.

Juselius, K. (2006). *The cointegrated VAR model : methodology and applications*. Oxford: Oxford University Press.

Keynes, J. M. (1930a). *A treatise on money : 1 : The Pure theory of money* (Vol. 1). London: McMillan.

Keynes, J. M. (1930b). *A treatise on money : 2 : The Applied theory of money* (Vol. 2). London: McMillan.

Kocenda, E., & Cerny, A. (2014). *Elements of Time Series Econometrics : An Applied Approach* (2nd ed. ed.). Prague: Charles University in Prague, Karolinum Press.

Kolb, R. W. (1992). Is normal backwardation normal? *Journal of Futures Markets, 12*(1), 75.

Kristoufek, L., & Vosvrda, M. (2014). Commodity futures and market efficiency. *Energy Economics, 42*, 50-57.

Lai, K. S., & Lai, M. (1991). A cointegration test for market efficiency. *Journal of Futures Markets, 11*(5), 567-575.

Litzenberger, R. H., & Rabinowitz, N. (1995). Backwardation in Oil Futures Markets: Theory and Empirical Evidence. *Journal of Finance, 50*(5), 1517-1545.

Lo, A. W., & Mackinlay, A. C. M. (1999). *A non-random walk down Wall Street*. Princeton, N.J.: Princeton, N.J. : Princeton University Press.

Malkiel, B. G. (2003). The Efficient Market Hypothesis and Its Critics. *Journal of Economic Perspectives, 17*(1), 59-82.

Masih, A. M. M., & Masih, R. (2002). Propagative causal price transmission among international stock markets: evidence from the pre- and postglobalization period. *Global Finance Journal, 13*(1), 63-91.

Maslyuk, S., & Smyth, R. (2009). Cointegration between oil spot and future prices of the same and different grades in the presence of structural change. *Energy Policy, 37*(5), 1687-1693.

Milonas, N. T., & Henker, T. (2001). Price spread and convenience yield behaviour in the international oil market. *Applied Financial Economics, 11*(1), 23-36.

Moosa, I. A., & Al-Loughani, N. E. (1994). Unbiasedness and time varying risk premia in the crude oil futures market. *Energy Economics, 16*(2), 99-105.

Quan, J. (1992). Two-step testing procedure for price discovery role of futures prices. *Journal of Futures Markets, 12*(2), 139.

Silvapulle, P., & Moosa, I. A. (1999). The relationship between spot and futures prices: Evidence from the crude oil market. *Journal of Futures Markets, 19*(2), 175-193.

Switzer, L. N., & El-Khoury, M. (2007). Extreme volatility, speculative efficiency, and the hedging effectiveness of the oil futures markets. *Journal of Futures Markets, 27*(1), 61-84.

Telser, L. G. (1958). Futures Trading and the Storage of Cotton and Wheat. *The Journal of Political Economy, 66*(3), 233.

Wang, Y., & Wu, C. (2013). Are crude oil spot and futures prices cointegrated? Not always! *Economic Modelling, 33*, 641-650.

Wooldridge, J. M. (2013). *Introductory econometrics : a modern approach* (5th ed., international ed. ed.). S.l.: South-Western, Cengage Learning.

Yin-Wong, C., & Lai, K. S. (1993). Finite-sample sizes of Johansen's likelihood ratio tests for cointegration. *Oxford Bulletin of Economics & Statistics, 55*(3), 313.

Webpages

BP. (2016). *Outlook to 2035 - energy use to rise by a third*. Retrieved on June 9, 2016 from http://www.bp.com/en/global/corporate/energy-economics/energy-outlook-2035/energy-outlook-to-2035.html.

Canadian Association of Petroleum Producers. (2015). *2015 Crude Oil Forecast, Markets and Transportation.* Retrieved on June 9, 2016 from http://capp.ca/publications-and-statistics/publications/264673.

Sjö, Bo. (2008). *Testing for Unit Roots and Cointegration.* Retrieved on February 1, 2016 from https://www.iei.liu.se/nek/ekonometrisk-teori-7-5-hp-730a07/labbar/1.233753/dfdistab7b.pdf.

The ICE. (2016). *Brent Crude Futures.* Retrieved on May 9, 2016 from https://www.theice.com/products/219.

U.S. Energy Information Administration. (2016a). *Tight in the United States.* Retrieved on May 9, 2016 from http://www.eia.gov/energy_in_brief/article/tight_in_the_united_states.cfm.

US. Energy Information Administration. (2016b). *Definitions, Sources and Explanatory Notes.* Retreived on May 9, 2016 from http://www.eia.gov/dnav/pet/TblDefs/pet_pri_fut_tbldef2.asp.

U.S. Energy Information Administration. (2013a). *Summer maintenance affects North Sea crude oil production and prices.* Retrieved on May 10, 2016 from http://www.eia.gov/todayinenergy/detail.cfm?id=12751.

U.S. Energy Information Administration. (2013b). *Spread narrows between Brent and WTI crude oil benchmark prices.* Retrieved on June 6, 2016 from http://www.eia.gov/todayinenergy/detail.cfm?id=12391.

Appendix A – Lag selection for the Johansen Cointegration test I

Table 9 Lag selection for the Johansen Cointegration test for the total period

Criterion	Brent spot Brent 1M	Brent spot Brent 2M	Brent spot Brent 3M	Brent spot Brent 4M	Brent spot Brent 5M	Brent spot Brent 6M
AIC	2*	5*	8*	9*	10*	9*
HQ	2	2	6	8	8	9
SC	2	2	3	4	8	9
FPE	2	5	8	9	10	9
Lags chosen	2	5	8	9	10	9

Criterion	WTI spot WTI 1M	WTI spot WTI 2M	WTI spot WTI 3M	WTI spot WTI 4M	WTI spot WTI 5M	WTI spot WTI 6M
AIC	6*	3*	5*	7*	7*	10*
HQ	1	3	5	5	7	8
SC	1	3	4	5	6	7
FPE	6	3	5	7	7	10
Lags chosen	6	3	5	7	7	10

Criterion	Brent spot WTI 1M	Brent spot WTI 2M	Brent spot WTI 3M	Brent spot WTI 4M	Brent spot WTI 5M	Brent spot WTI 6M
AIC	4*	5*	6*	7*	8*	9*
HQ	4	5	6	7	8	9
SC	4	5	4	5	6	8
FPE	4	5	6	7	8	9
Lags chosen	4	5	6	7	8	9

Criterion	WTI spot Brent 1M	WTI spot Brent 2M	WTI spot Brent 3M	WTI spot Brent 4M	WTI spot Brent 5M	WTI spot Brent 6M
AIC	3*	5*	5*	6*	9*	9*
HQ	3	4	5	6	6	6
SC	3	3	4	4	5	6
FPE	3	5	5	6	9	9
Lags chosen	3	5	5	6	9	9

Note: Table A1 list the suggested amount of lags for an unrestricted VAR- model according to *R Software* using the lag-select function "VARselect" in the "vars"- package. * denotes the lag selection criterion chosen, and the number of lags chosen is also listed in the bottom of every table. The number listed is the number of lags for the VAR-model, which is the input used in the "ca.jo"- command in the "urca"-package for the Johansen cointegration model. The amount of lags applied in the VECM is one less than the lags appropriate for a VAR-model, but *R Software* corrects this automatically. ***Abbreviations:*** AIC = Akaike Information Criterion, HQ = Hannan-Quinn Criterion, SC = Schwarz Bayesian Information Criterion, FPE = Final Prediction Error Criterion.

Appendix B – Lag selection for the Johansen Cointegration test II

Table 10 Lag selection for the Johansen Cointegration test for the sub period

Criterion	Brent spot Brent 1M	Brent spot Brent 2M	Brent spot Brent 3M	Brent spot Brent 4M	Brent spot Brent 5M	Brent spot Brent 6M
AIC	13	13	13	13	13	13
HQ	13	13	13	13	13	13
SC	13	13	13	13	13	13
FPE	14	14	14	14	14	14
Lags chosen	2	2	3	2	2	2

Criterion	WTI spot WTI 1M	WTI spot WTI 2M	WTI spot WTI 3M	WTI spot WTI 4M	WTI spot WTI 5M	WTI spot WTI 6M
AIC	13	13	13	13	13	13
HQ	13	13	13	13	13	13
SC	13	13	13	13	13	13
FPE	14	14	14	14	14	14
Lags chosen	2	2	3	2	2	2

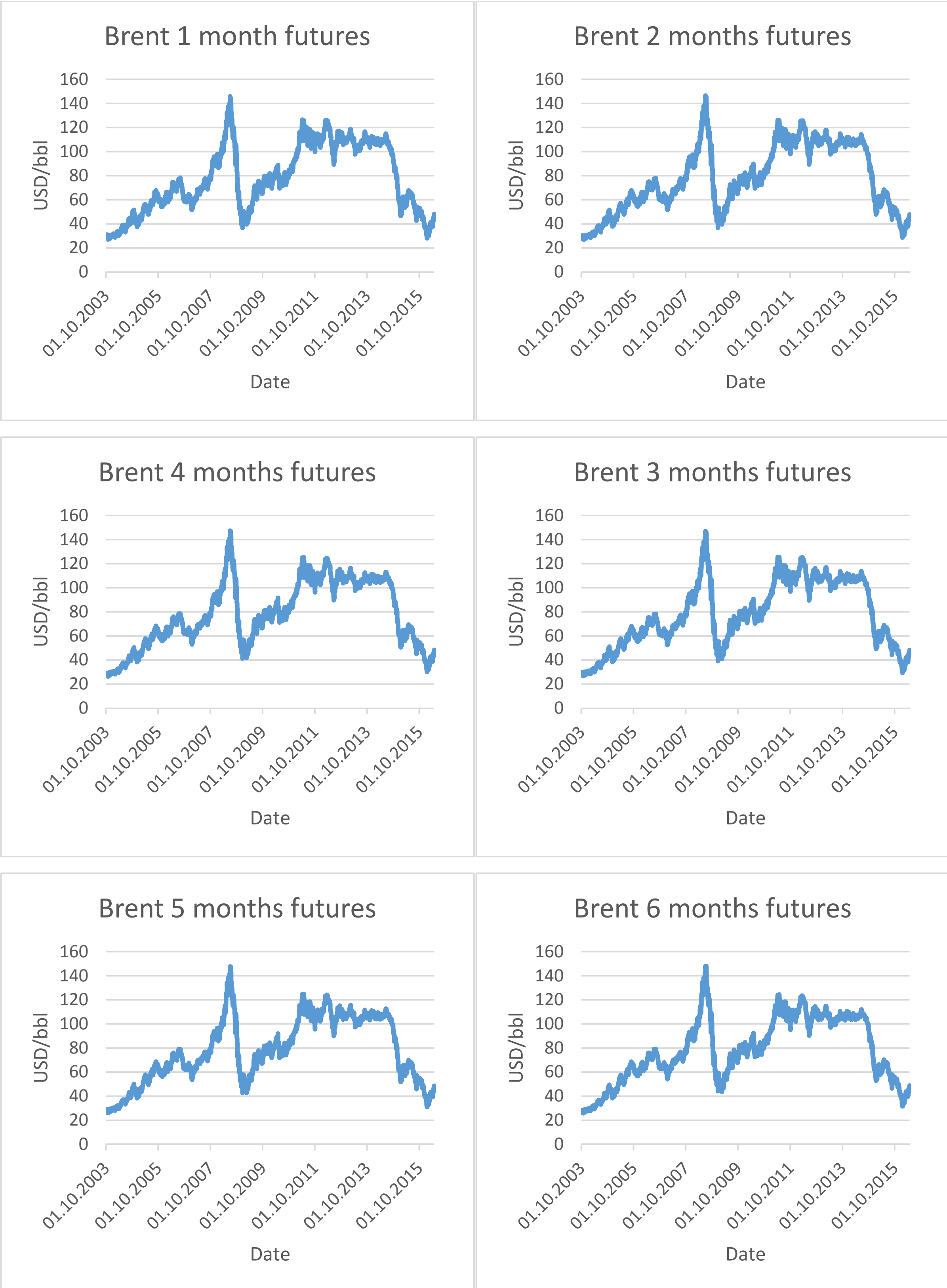
Criterion	Brent spot WTI 1M	Brent spot WTI 2M	Brent spot WTI 3M	Brent spot WTI 4M	Brent spot WTI 5M	Brent spot WTI 6M
AIC	13	13	13	13	13	13
HQ	13	13	13	13	13	13
SC	13	13	13	13	13	13
FPE	14	14	14	14	14	14
Lags chosen	2	3	4	2	2	2

Criterion	WTI spot Brent 1M	WTI spot Brent 2M	WTI spot Brent 3M	WTI spot Brent 4M	WTI spot Brent 5M	WTI spot Brent 6M
AIC	13	13	13	13	13	13
HQ	13	13	13	13	13	13
SC	13	13	13	13	13	13
FPE	14	14	14	14	14	14
Lags chosen	2	2	2	2	2	2

Note: The tables list the suggested amount of lags for an unrestricted VAR- model according to R Software using the lag-select function "VARselect" in the "vars"- package. The numbers listed in the bottom of the tables are the number of lags for the VAR-models, which is the input used in the "ca.jo"- command in the "urca"-package for the Johansen cointegration model. The amount of lags applied in the VECM is one less than the lags appropriate for a VAR-model, but *R Software* corrects this automatically. For description of how lags were chosen for the sub period, see section 0. ***Abbreviations:*** AIC = Akaike Information Criterion, HQ = Hannan-Quinn Criterion, SC = Schwarz Bayesian Information Criterion, FPE = Final Prediction Error Criterion.

Appendix C – Daily prices Brent Blend futures

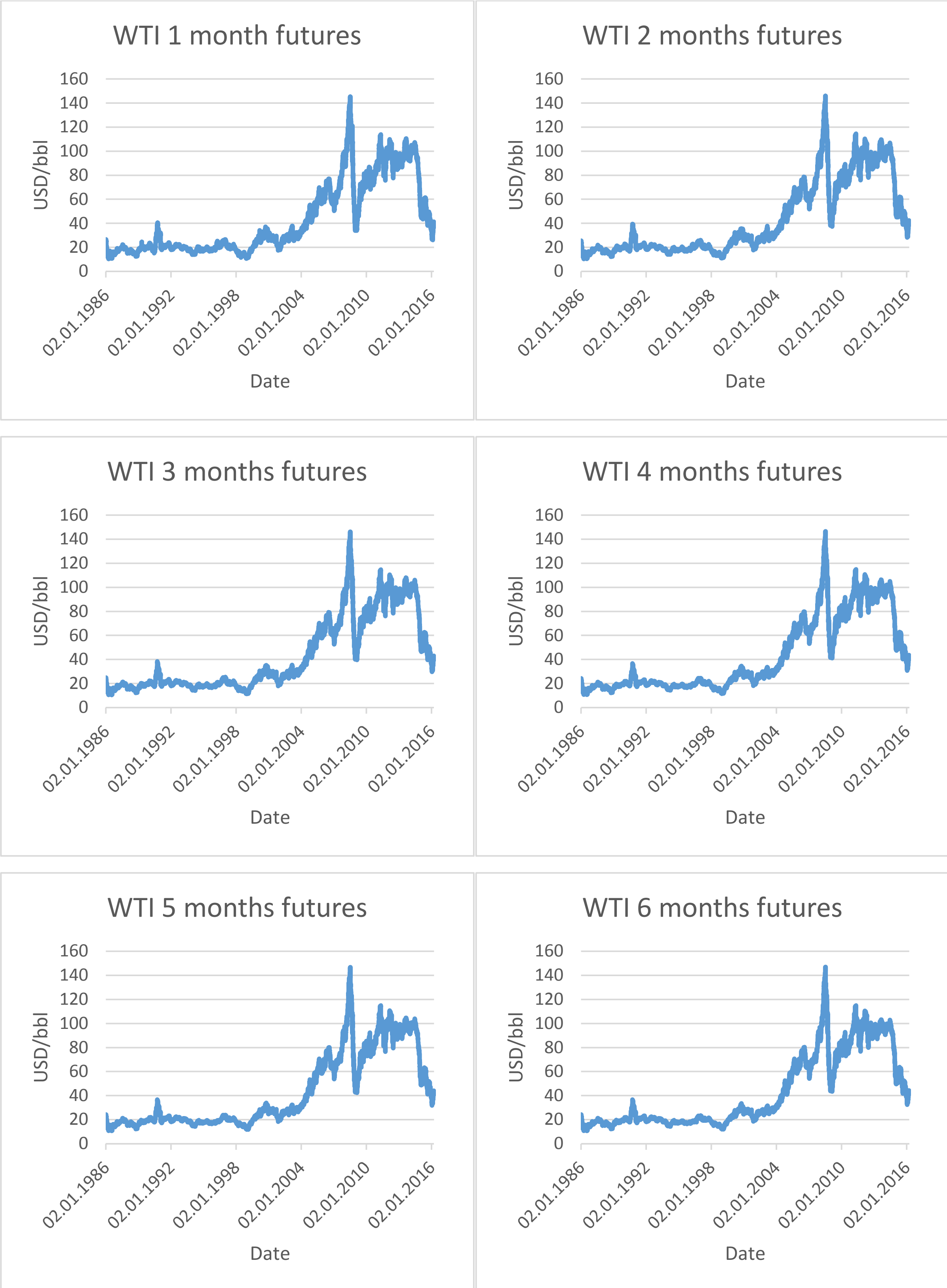
Figure 6 Daily prices Brent Blend futures for the period October 2003 to March 2016



Note: The graphs show daily closing prices in USD/bbl for Brent Blend futures (ICE) for the period October 2003 to March 2016. The data was retrieved using *Datastream*.

Appendix D – Daily prices WTI futures

Figure 7 Daily prices Brent Blend futures for the period October 2003 to March 2016



Note: The graphs show daily closing prices in USD/bbl for WTI futures (NYMEX) for the period October 2003 to March 2016. The data was retrieved using *Datastream*.

Appendix E: Portmanteau-, ARCH- and Jarque- Bera- test results I

Table 11 Test statistics for the tests of residuals for the total period

Test statistic	Brent spot Brent 1M	Brent spot Brent 2M	Brent spot Brent 3M	Brent spot Brent 4M	Brent spot Brent 5M	Brent spot Brent 6M
Portmanteau	61.61 (0.2824)	45.79 (0.3979)	25.59 (0.7817)	23.16 (0.7252)	23.69 (0.4793)	32.65 (0.2499)
ARCH	115.43 (0.0000)	103.66 (0.0000)	73.85 (0.0043)	55.01 (0.1458)	66.95 (0.0185)	63.09 (0.0387)
Jarque- Bera	19.20 (0.0007)	7.11 (0.1300)	15.01 (0.0047)	23.31 (0.0000)	35.26 (0.0000)	25.78 (0.0000)

Test statistic	WTI spot WTI 1M	WTI spot WTI 2M	WTI spot WTI 3M	WTI spot WTI 4M	WTI spot WTI 5M	WTI spot WTI 6M
Portmanteau	49.79 (0.1379)	59.27 (0.2275)	60.09 (0.0536)	47.36 (0.0975)	48.91 (0.0741)	31.84 (0.1311)
ARCH	123.35 (0.0000)	135.6 (0.0000)	135.88 (0.0000)	123.39 (0.0000)	99.36 (0.0000)	84.77 (0.0003)
Jarque- Bera	235.02 (0.0000)	140.94 (0.0000)	141.72 (0.0000)	132.35 (0.0000)	133.19 (0.0000)	123.41 (0.0000)

Test statistic	Brent spot WTI 1M	Brent spot WTI 2M	Brent spot WTI 3M	Brent spot WTI 4M	Brent spot WTI 5M	Brent spot WTI 6M
Portmanteau	49.94 (0.3960)	53.09 (0.1636)	47.47 (0.1946)	39.13 (0.3311)	38.12 (0.2109)	33.09 (0.2324)
ARCH	86.21 (0.0002)	108.75 (0.0000)	110.32 (0.0000)	121.32 (0.0000)	141.04 (0.0000)	87.441 (0.0002)
Jarque- Bera	259.86 (0.0000)	123.04 (0.0000)	92.69 (0.0000)	79.53 (0.0000)	87.13 (0.0000)	79.59 (0.0000)

Test statistic	WTI spot Brent 1M	WTI spot Brent 2M	WTI spot Brent 3M	WTI spot Brent 4M	WTI spot Brent 5M	WTI spot Brent 6M
Portmanteau	44.80 (0.7503)	34.623 (0.8434)	35.05 (0.8302)	31.09 (0.8426)	19.89 (0.8686)	19.80 (0.8718)
ARCH	105.33 (0.0000)	103.04 (0.0000)	89.71 (0.0000)	88.73 (0.0001)	105.45 (0.0000)	80.66 (0.0009)
Jarque- Bera	18.80 (0.0009)	17.42 (0.0016)	24.88 (0.0000)	20.97 (0.0003)	4.99 (0.2879)	2.93 (0.5694)

Note: The table lists the test statistics for the Portmanteau-, ARCH- and Jarque- Bera- test for the total period for the different cointegration pairs. P-values are included in brackets behind the test statistics.

Appendix F: Portmanteau-, ARCH- and Jarque- Bera- test results II

Table 12 Test statistics for the tests of residuals for the sub period

Test statistic	Brent spot Brent 1M	Brent spot Brent 2M	Brent spot Brent 3M	Brent spot Brent 4M	Brent spot Brent 5M	Brent spot Brent 6M
Portmanteau	57.94 (0.4037)	66.02 (0.1691)	55.34 (0.3499)	50.94 (0.6662)	56.43 (0.4587)	53.75 (0.5605)
ARCH	86.44 (0.0002)	93.93 (0.0000)	75.28 (0.0031)	95.05 (0.0000)	81.04 (0.0008)	93.81 (0.0000)
Jarque- Bera	8.24 (0.0833)	38.15 (0.0000)	40.91 (0.0000)	3.27 (0.5134)	2.67 (0.6141)	2.24 (0.6920)

Test statistic	WTI spot WTI 1M	WTI spot WTI 2M	WTI spot WTI 3M	WTI spot WTI 4M	WTI spot WTI 5M	WTI spot WTI 6M
Portmanteau	45.93 (0.8292)	44.22 (0.8726)	68.12 (0.0661)	57.19 (0.4307)	55.52 (0.4931)	65.76 (0.1746)
ARCH	54.44 (0.1581)	43.61 (0.5311)	62.76 (0.0410)	89.30 (0.0000)	69.14 (0.0119)	63.82 (0.0338)
Jarque- Bera	0.94 (0.9188)	1.97 (0.7412)	7.21 (0.1254)	0.85 (0.9309)	0.56 (0.9679)	4.08 (0.3954)

Test statistic	Brent spot WTI 1M	Brent spot WTI 2M	Brent spot WTI 3M	Brent spot WTI 4M	Brent spot WTI 5M	Brent spot WTI 6M
Portmanteau	48.45 (0.7532)	44.15 (0.7721)	39.98 (0.7881)	55.30 (0.5013)	54.14 (0.5456)	64.52 (0.2034)
ARCH	81.65 (0.0007)	51.04 (0.2484)	51.39 (0.2377)	90.55 (0.0000)	83.25 (0.0005)	100.47 (0.0000)
Jarque- Bera	1.07 (0.8988)	2.64 (0.6193)	1.56 (0.8162)	2.86 (0.5808)	3.55 (0.4710)	8.12 (0.0874)

Test statistic	WTI spot Brent 1M	WTI spot Brent 2M	WTI spot Brent 3M	WTI spot Brent 4M	WTI spot Brent 5M	WTI spot Brent 6M
Portmanteau	62.87 (0.2462)	67.72 (0.1356)	60.37 (0.3207)	46.80 (0.8047)	52.85 (0.5949)	53.60 (0.5664)
ARCH	52.62 (0.2030)	75.45 (0.0030)	78.96 (0.0013)	68.34 (0.0140)	62.37 (0.0441)	69.14 (0.0119)
Jarque- Bera	17.86 (0.0013)	3.16 (0.5317)	2.63 (0.6209)	0.27 (0.9916)	2.77 (0.5964)	1.25 (0.8693)

Note: The table lists the test statistics for the Portmanteau-, ARCH- and Jarque- Bera- test for the sub period for the different cointegration pairs. P-values are included in brackets behind the test statistics.