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Crude Oil Price Differentials

An empirical analysis on the factors behind the price divergence between WTI and Brent

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Abstract

The main purpose of our thesis is to examine the long-run relationship between WTI and Brent. Historically, the prices fluctuated around a constant differential, where WTI traded above Brent due to its slightly higher quality. Recently, the differential has been reversed as Brent has traded at a premium to WTI since 2010. We analyze the unusual behavior in the price relationship with the use of an Engle-Granger two-step test for cointegration to assess if the relationship has ended, and whether a new has been formed. We also decompose the WTI-Brent spread to examine if the deviation can be accrued to supply or demand conditions. Finally, we build an empirical model to determine what factors have had a significant impact on the spread's divergence.

We find that the long-run relationship between WTI and Brent ended in January 2010, and that a new relationship was established early 2014. However, the new relationship is different from its predecessor as Brent is now being traded at a premium to WTI. From our empirical findings we infer that insufficient pipeline infrastructure at Cushing is significant in explaining the spread's divergence. We also conclude that shipping costs significantly affected the spread and have prolonged the divergence between WTI and Brent.

Foreword

After five years at the Norwegian School of Economics, it is with pride that we finally hand in our master thesis. It marks the end of an important chapter in our lives. This Master of Science thesis is the result of extensive research and hard work over the past months.

Our thesis aims to examine the recent price divergence between WTI and Brent, the two most traded commodities in the world. Although our findings are not exhaustive in explaining the divergence, we believe our thesis highlights the most relevant factors behind the decoupling of the crude oil prices.

We want to sincerely thank our supervisor, Linda Nøstbakken, for her advice and guidance throughout the process. We had prolific discussions with Linda where she provided valuable feedback and new perspectives on our work. We would also like to thank Ragnhild Balsvik for her valuable contributions to our econometric analysis.

We hope that our thesis will be as interesting to read, as it was for us writing it.

Bergen, December 2014

Martin Heier Sindre Skoglund

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1. Introduction

West Texas Intermediate (WTI) has been trading at an unusual discount relative to Brent since 2010. Historically, the two have moved in unison, with WTI trading at a premium to Brent due to its slightly higher quality. Now, however, the two crudes have set on different paths, with WTI experiencing a fall in prices without a corresponding fall in the price of Brent. That two international benchmarks have decoupled from their long-term price relationship could have widespread implications for the oil industry.

We wish to examine the price divergence between WTI and Brent. First we will try to establish when the price relationship between the two ended. If a break is found, we will examine whether it was only a temporary occurrence and if WTI and Brent have formed a new relationship. To further study the unusual price movements, we break down the spread between WTI and Brent into supply and demand components, and build an empirical model to quantify what factors have affected the spread.

The North American benchmark WTI is of great importance in today's oil pricing system. The crude underlies sweet crude contracts traded at the New York Mercantile Index, and is one of the most significant commodity contracts on the market. Its European counterpart Brent is financially traded on the Intercontinental Exchange in London, and accounts for over two thirds of the world's total trade in physical oil (Intercontinental Exchange, 2013). As a consequence, Brent is widely referred to as the leading global crude benchmark.

The WTI and Brent benchmarks are integral parts of the crude oil pricing system, comprising the price foundation for nearly all other crudes. The similar qualities between the crudes are key to the benchmarking system, with their price differences being fairly constant. Historically this is said to be true, with WTI being priced $1-4 per barrel above Brent due to its slight quality premium (Carollo, 2011). Bassam Fattouh (2009) contributes the constant price differential between the crudes to the oil market being one great pool. An implication of his theory is that crudes of similar quality will move closely together, as supply and demand shocks that affect one crude should be transferred to others.

The almost constant price differential between WTI and Brent was for a long time a stated fact. However, since 2010 the price differential, or spread, has diverged from its historic trend and Brent is currently traded at a premium to its North American counterpart. The spread reached its peak in August 2011, when Brent traded at a $26 premium to WTI. According to Fattouh's (2009) research, the prices of the two should behave similarly, with the price fluctuations of one affecting the other. This, however, has not been the case.

Although there is abundance of research, both on the price movements of crude oil and the divergence of the WTI-Brent spread, less research has been conducted towards pinpointing the end of the relationship and examining whether the crudes have formed a new relationship. With the help of econometrical techniques we wish to examine the price relationship between WTI and Brent, as well as quantifying certain effects behind the divergence.

We start by presenting our hypotheses in section 2. A presentation of the properties of crude oil, the modern history of the oil market and a description of the crude oil market is outlined in section 3. We review literature relevant to our thesis in section 4, before presenting specific events that affect crude oil prices in section 5. To easier comprehend crude oil price fluctuations we present a theoretical analysis on crude oil price movements in section 6. Our empirical analysis is presented in section 7 and is divided into sections for our sample data, cointegration analysis, spread decomposition and empirical findings. We discuss limitations and implications of our research in the same section, before presenting our final conclusions in section 8.

2. Hypotheses

In this section we present and explain our hypotheses. They all originate from the unusual behavior in the spread between WTI and Brent and literature pertaining to the subject.

2.1.1 Hypothesis 1: The Long-Term Relationship

Our first hypothesis is based on the fact that WTI has traded at a discount to Brent since 2010. Historically, WTI and Brent moved in tandem with a spread of $1-4 per barrel in favor of WTI (Carollo, 2011). The reversal in the price relationship could imply that the widely acknowledged long-run relationship between the crudes has ended.

> **Hypothesis 1a:** The long-term relationship between WTI and Brent ended in early 2010.

Between 2010 and 2014 Brent traded at an unusual premium to WTI, but has recently moved towards the once familiar price differential. This may have established a new relationship between the crudes, where WTI is traded at a small discount to Brent.

> **Hypothesis 1b:** A new relationship between WTI and Brent was established at the beginning of 2014.

We also want to determine what caused the unusual behavior in the spread. Crude oil has a physical dimension that anchors its price to fundamentals in the oil market. The unusual price difference between WTI and Brent is therefore likely to be caused by changes in these fundamentals.

2.1.2 Hypothesis 2: The Structural Changes in North America

There are indications that fundamentals in the North American market have caused the price divergence between WTI and Brent. Increasing crude oil production, leading to a greater inflow of crude oil to Cushing, caused storage facilities to reach maximum capacity in 2010. A lack of pipeline infrastructure constrained transportation of the excess crude to coastal refineries, with the combined factors leading to a decrease in the price of WTI.

Hypothesis 2: Increasing crude oil production in North America, as well as insufficient pipeline infrastructure out of Cushing, caused the unusual behavior in the WTI-Brent spread.

In addition to having a physical dimension, crude oil is traded as a financial instrument. Some of these instruments can impact crude oil prices, causing shifts beyond their underlying fundamental value.

2.1.3 Hypothesis 3: The Financial Market Activity

The futures contracts for WTI and Brent are the most traded commodity contracts in the world. In 2011 a relative weight change in favor of Brent in the world's largest commodity indices allocated large money flows in the financial market from WTI into Brent futures. The relative weight change increased the open interest, an indicator for activity and liquidity in the financial market, for Brent relative to WTI. However, these changes may already be accounted for by market participants and embedded in the prices, and so will not have an effect on the spread.

Hypothesis 3: The open interest for WTI and Brent futures did not have a significant impact on the price divergence between WTI and Brent.

We will test our hypotheses in several sections. In section 7.2 we test the relationship between WTI and Brent with an Engle-Granger two-step test for cointegration. We decompose the spread into time and commodity spreads to understand the underlying shifts in section 7.3. Finally, we present an empirical model to quantify the underlying shifts in section 7.5.

3. Theory

In this section we present theory concerning the crude oil market and the formation of crude oil prices. Without an understanding of the fundamentals in the crude oil market, it will be difficult to comprehend the implications of our empirical findings.

3.1 What is Crude Oil[1]

Crude oil is a heterogeneous commodity and its appearance varies, from an almost brown sludge to a light colorless liquid. Fossil fuels, such as crude oil, are non-renewable energy sources, implying that the resource does not renew itself at a sufficient rate for sustainable economic extraction in meaningful human time frames. In its most simple form crude oil consists of molecules and hydrocarbon chains of varying length.

The number of hydrocarbons, in addition to the heat at which the hydrocarbons form, determines the density and classification of the crude oil. The American Petroleum Institute (API) classifies crude oil as either light, medium or heavy in density. The API gravity index is a measure of how heavy or light the crude oil is compared to water. The less dense the crude oil, the higher the API gravity, hence high gravity crudes are known as light crudes while low gravity crudes are referred to as heavy crudes.

Light crudes usually have an API gravity between 35 and 40 degrees. Due to fewer long-chain molecules and lower wax content, it has lower viscosity and is therefore easier to both extract and transport. This leads to lower operating costs for both producers and refiners, which in turn has historically led to higher demand.

Heavy crudes, on the other hand, usually have an API gravity between 16 and 20 degrees. What identifies heavier crudes is higher viscosity and that they contain high concentrations of sulfur and metals. These properties make them difficult to extract and transport through pipeline, making refining more costly.

[1] This section is based on Deutsche Bank's report "Oil & Gas for Beginners" (2013).

In addition to hydrocarbons, all crudes contain sulfur, released on combustion as sulfur dioxide. The sulfur needs to be removed from the oil before refining, leading to higher demand for crude oils with low percentage of sulfur. Crudes containing lower percentage of sulfur are known as sweet, whereas those with high percentage are known as sour. Crude oil is classified as sweet if it contains less than 0.5% sulfur. Light sweet crude oil contains a disproportionate amount of high-quality distillate products and is therefore the most sought after crude.

If the total sulfide level in the crude is over 1% it is defined as sour and contains impurities such as hydrogen and carbon dioxide. Since these impurities must be removed before the crude can be utilized, the cost of refining increases. Due to these increased costs, sour oils are in lower demand and sold with a discount compared to high quality crudes.

Crude oil itself cannot be utilized; it has to be refined into usable products. Refining produces a wide variety of products, from heating oil to petroleum gas. The range of products from a barrel of crude oil is dependent on the quality of the crude. For WTI and Brent a typical yield, the proportion of refined products in one barrel of crude, is shown in table 1.

Table 1 - Typical Light Sweet Crude Yield (Deutsche Bank, 2013)

Product	Light Sweet Crude Yield
Petroleum Gas	3 %
Naptha	6 %
Gasoline	21 %
Kerosene	6 %
Gasoil/Diesel (Middle distillates)	36 %
Fuel Oil	19 %
Others (Residual, lubricants)	9 %

Not all outputs have the same market value. Some outputs, such as diesel, sell at a premium to heavier fuels. In addition, the heavier outputs tend to be more easily substitutable with other energy alternatives, capping their price movements even at higher crude oil prices.

3.1.1 Properties of WTI and Brent

A variety of crude oils are produced around the world with their market value defined by quality characteristics. WTI and Brent are today the key international benchmarks for crude oil, with their prices used as a barometer for a majority of the industry. Their similarities can be seen in the spot price development between 2000 and 2014, where the two move in tandem until 2010. Their price development is depicted in figure 1.

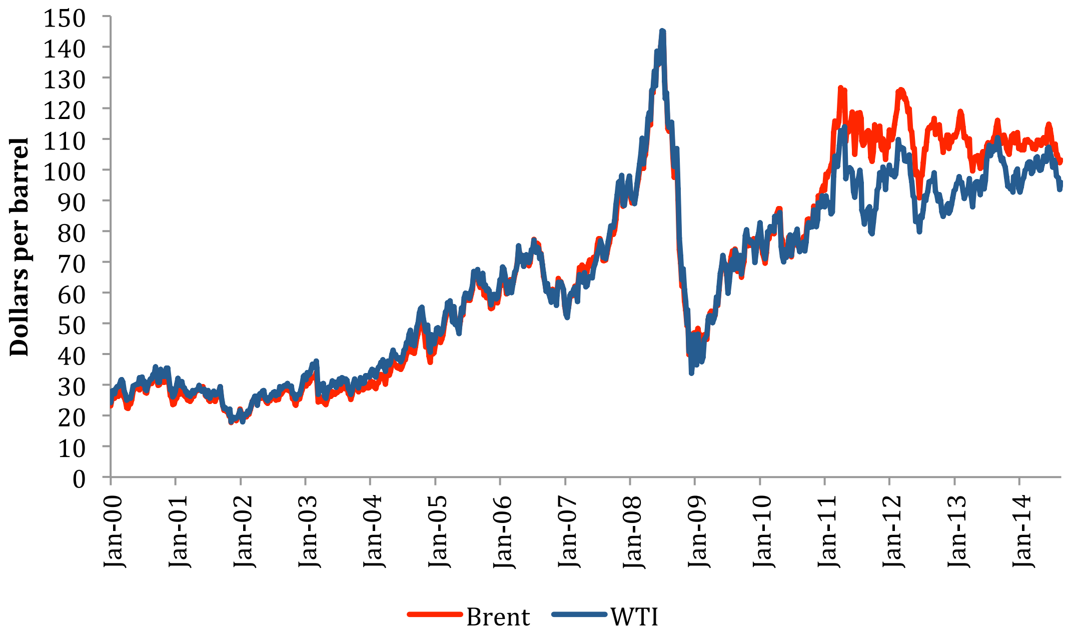

Figure 1 - Spot Price Development WTI and Brent (Bloomberg L.P., 2014e)

To further illustrate, the specific quality characteristics of the WTI and Brent are outlined in table 2. WTI is of a slightly higher quality than Brent as its sulfur content is lower. All else equal, the lower sulfur content implies that WTI should be sold at a slight premium relative to Brent.

Table 2 - API Gravity and Sulfur Content of WTI and Brent (U.S. EIA, 2012b)

Crude Oil	API Gravity	Sulfur Content
WTI	39.6°	0.24%
Brent	38.3°	0.37%

3.1.1.1 The Brent Benchmark[2]

The crudes comprising the Brent benchmark is extracted from the North Sea and acts as a representative for a wide variety of crudes. Brent as a benchmark has evolved from one single crude representing the whole North Sea, to a mix of several crudes.

Brent was the first crude to act as a representative for the North Sea, and is a mixture of oil produced from several fields delivering to the terminal at Sullom Voe in the Shetland Islands, United Kingdom. As production started to decline in the 1980s, Brent was comingled with Ninian to stop opportunities of manipulation and distortion. The new benchmark was named Brent Blend.

Brent Blend was used as a benchmark until 2002, when production hit an all-time low. In order to counter this, the Brent Blend was broadened to include Forties and Oseberg. The new benchmark was known as Brent-Forties-Oseberg (BFO). With the inclusion of these two crudes it resulted in a distribution over a wider range of companies, reducing the dominance of oil producing companies and decreasing opportunities to distort the benchmark.

In 2007, Ekofisk was included in the benchmark, leading to the creation of the benchmark that is in use today, Brent-Forties-Oseberg-Ekofisk (BFOE). The inclusion of Ekofisk increased the physical base of the benchmark, and is the status quo of today.

The inclusion of the different crude oils with diverse quality aspects has had implications on the pricing of the benchmark. Any of the four crudes can be delivered against a BFOE contract, and thus sellers wish to deliver the cheapest grade of crude. In the BFOE blend, Forties has the lowest quality with regard to API and sulfur content and thus sets the price and quality grade of the benchmark.

[2] The assessment of the Brent benchmark is based on the article ”An Anatomy of the Crude Oil Pricing System” written by Bassam Fattouh for the Oxford Instititute for Energy Studies (2011).

Table 3 - API Gravity and Sulfur Content of BFOE (U.S. EIA, 2012b)

Crude Oil	API Gravity	Sulfur Content
Brent Blend	38.3°	0.37%
Forties Blend	40.3°	0.56%
Oseberg Blend	37.8°	0.27%
Ekofisk Blend	37.5°	0.23%

There are several aspects that favor the choice of Brent as a benchmark. Brent is seaborne and can be transported to refineries in Europe and other parts of the world when arbitrage opportunities deem transportation profitable, making it easily marketable. The geographic location makes it an ideal benchmark as the North Sea is close to refineries both in Europe and the United States (U.S.). With four different crudes constituting the benchmark, the large production volume makes it difficult to manipulate.

However, it is not just the volume of production that makes it an ideal benchmark. An important aspect is that the United Kingdom's government acts as an overseer for Brent, providing a transparent legal and regulatory body. In addition, due to its inclusion of several crudes, no producer has monopoly on the blend, which is one of the most important aspects of a benchmark (Horsnell & Mabro, 1993).

The Brent benchmark sets the price for most of the global crude market, which underlines its importance. Around 70% of the world's crude is priced relative to the Brent benchmark (RBN Energy, 2013).

3.1.1.2 The WTI Benchmark[3]

WTI has its origin in the crude oil fields of Texas, Oklahoma, Kansas and New Mexico. The crude oil is landlocked, as opposed to the seaborne Brent, and is thus subject to domestic infrastructure problems. Deliveries of the crude are made to Cushing, Oklahoma, which is strategically placed to serve the refineries along the Gulf of Mexico.

[3] The assessment of the WTI benchmark is based on the article "An Anatomy of the Crude Oil Pricing System" written by Bassam Fattouh for the Oxford Institute for Energy Studies (2011).

The U.S. market consists of several crudes besides WTI. One of these crudes is the Light Louisiana Sweet (LLS), which has become a local benchmark for sweet crude along the Gulf Coast. LLS is seaborne and can easily be transported to meet world demand or stockpiled cheaply on floating storage facilities, making it less exposed to the domestic problems WTI might experience. LLS is of similar quality to WTI and Brent. Another crude oil of significance in the U.S. is the West Texas Sour (WTS), a lower quality crude being stored at Cushing, OK. Both crudes' qualitiy aspects are depicted in table 4.

Table 4 - API Gravity and Sulfur Content of LLS and WTS (U.S. EIA, 2012b)

Crude Oil	API Gravity	Sulfur Content
LLS	35.6°	0.37%
WTS	31.7°	1.28%

Despite there being a wide variety of crudes, WTI has become the main benchmark for pricing crude in the U.S. This is because WTI underlies the Light Sweet Crude Oil futures contract, one of the largest and most actively traded commodity futures contract. In addition, WTI is traded in smaller volumes than other crudes, making it easier for investors to find the necessary credit and storage facilities to participate in its trading. Furthermore, its liquidity is high, solidifying it as an apt benchmark for the U.S. crude market (CME Group, 2010).

Unlike Brent, WTI has seen a surge in production, especially from unconventional oil from Canada and the U.S. A surge in crude oil prices over a prolonged period spurred innovations that lead to these resources becoming economically viable. Unconventional oil represented a major shift in supply side conditions, with North American crude production accounting for 14% of global crude production in 2012 (Erbach, 2014).

Canada has large deposits of oil sand, representing the largest undeveloped, oil resource globally. These reserves contain heavy, thick deposits of bitumen-coated sand, which require significant amounts of energy, making its extraction capital intensive.

The unconventional oil deposits in the U.S. are mainly tight oil from the Bakken field in North Dakota and the Eagle Ford Plays in Texas. Tight oil is a subset of tight hydrocarbons with the key, differentiating factor being that its reservoir rock, shale, is also the source rock for the oil.

3.2 Modern History of the Oil Market[4]

The current oil pricing system has emerged in response to changing power balances, shifts in political and economic structures, as well as fundamental changes to supply and demand. It has gone from a monopolistic pricing system to the market based system we know today.

Until late 1950s the oil price was controlled by multinational companies, known as the Seven Sisters[5], who accounted for 85% of the oil production outside Canada, the U.S., the USSR and China. These multinationals had interests in both up- and downstream production, owning the whole value chain from exploration to refining. Governments received royalties and taxes, but did not participate in pricing the oil. Until the 1970s the pricing system, known as the posted price, was built on these royalties. The period was characterized by a market with few participants and imperfect competition, where multinational companies set prices to minimize their tax liabilities around the world.

In 1960 the Organization of the Petroleum Exporting Countries (OPEC) was formed by Iran, Iraq, Kuwait, Saudi Arabia and Venezuela to coordinate tax and royalty policies, obtain resources from private companies, as well as preventing declining revenues for its members. Even though large multinational companies still dominated the market in the 1960s, smaller independent companies were entering the market. This was due to the fact that countries, like Venezuela and Libya, granted concessions to smaller participants as they saw an opportunity to gain higher government tax and royalties.

[4] This section is sourced from "An Anatomy of the Crude Oil Pricing System" written for the Oxford Institute for Energy Studies by Bassam Fattouh (2011).

[5] Anglo-Persian Oil Company (now BP), Gulf Oil, Standard Oil of California (SoCal), Texaco (now Chevron), Royal Dutch Shell, Standard Oil of New Jersey (now Esso) and Standard Oil Company of New York (Now ExxonMobil).

In the period between 1965 and 1973 the global demand for oil increased rapidly. As a response, OPEC increased production to meet the surging demand. In 1973, in response to having gained a significant share of the world crude market, power shifted in favor of OPEC as they for the first time sat a posted price.

During the 1970s the concept of marker price was introduced, a predecessor to what is now known as crude benchmarking. This further shifted the power of oil pricing from the multinational companies to OPEC. Arabian Light from Saudi Arabia was chosen as the first marker crude and prices were set relative to this.

The Iranian crisis in 1979 led to an abrupt disruption in the supply of crude oil. This forced multinational companies to buy crude in the open market to meet their refineries' demand. As a consequence, a new spot market emerged with higher transparency, making it easier for non-OPEC countries and private companies to establish themselves in the oil market.

In the early 1980s, OPEC increased its production in response to higher crude oil prices. However, the worldwide recession in the mid 1980s caused a decline in the demand for oil. This represented a major challenge to OPEC's marker pricing system, ultimately leading to its demise.

Another factor leading to the demise of OPEC's marker pricing system was that more oil reached international markets as non-OPEC members made new discoveries and increased production. As non-OPEC members priced their oil to market conditions, they were able to charge a lower price for their crude compared to OPEC. Suppliers, who had an excess of crude, undercut prices in the spot market, ultimately leading to a decline in the demand for OPEC crude.

As it became clear to OPEC that attempts to defend the marker price would only result in a lower market share, they adopted a new pricing system, the netback pricing system. Other oil exporting countries adopted the system, which provided companies with a guaranteed refinery margin. This led refineries to oversupply the market with refined products, leading to the oil price collapse in 1986.

After the crisis a new market system for pricing crude oil emerged, known as formula pricing. The system is an arrangement where a buyer and seller agree in advance on the price to be paid for a product delivered in the future. This benchmark price is based upon a pre-determined calculation, and is still in use today. OPEC abandoned its netback pricing system and adopted the new market system, and so transferred the pricing power to the market.

In 1988 the new market related pricing system was widely accepted amongst most oil-exporting countries. In the subsequent years the technological revolution made electronic 24-hour trading possible from anywhere in the world. The revolution enabled the development of a complex pricing system of interlinked oil markets, consisting of spot, physical forwards, futures and other derivatives in the paper market.

With the exception of the time period around the Iranian crisis in 1979, crudes prices normally fluctuated around $20 to $30 per barrel. However, since 1998, crude prices have soared to a record high of $145 in July 2008, before falling during the financial crisis. At the time of writing, WTI and Brent is traded at around $70 dollar per barrel. The annual average of the historic oil price is depicted in figure 2.

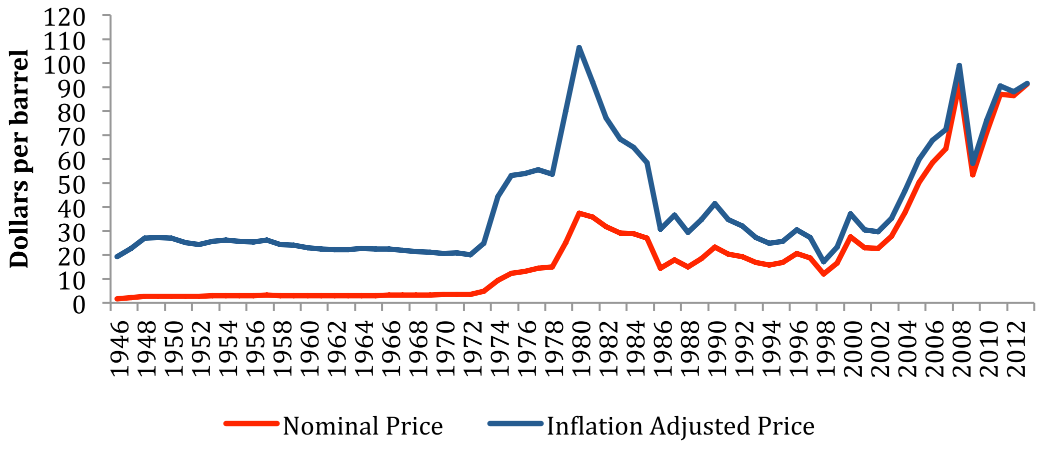

Figure 2 – Annual Average Historic Oil Price (Inflation Data, 2014)

3.3 World Oil Markets Today

The global oil market is the largest energy market, measured in both value and volume. In 2011 crude oil served around 33% of the global energy needs (Deutsche Bank, 2013).

The New York Mercantile Index (NYMEX) and the Intercontinental Exchange (ICE) are the main international exchanges for the trading of crude oil. The exchanges allow for trade in both the spot market for immediate delivery and the forward and futures market for deliveries at a predetermined date. This provides market participants with hedging, speculation and price discovery opportunities.

Due to the large number of crudes around the world, benchmarks are widely used to set prices, both for physical delivery and in the financial market. The two most important are, as previously mentioned WTI and Brent. All other crudes, with some exceptions, are traded at a discount or premium to these benchmarks, depending on their quality aspects, as explained in section 3.1.

3.3.1 Futures Market

Futures trading, as we know it today, evolved when farmers and merchants committed to future exchanges of grain for cash in the 19th century. A century later, in 1983, NYMEX introduced trading in crude oil futures with delivery of light sweet crude oil at Cushing, Oklahoma. A few years later the International Petroleum Exchange, now ICE, introduced futures trading in Brent derivatives (Gülen, 1998). Since the introduction of formula pricing in 1988, and the technological development of trading, futures have played an increasing part in pricing crude oil deliveries, and has evolved into a foundation for determining spot prices for North American crude (Deutsche Bank, 2013).

The largest exchange-traded commodity in the world was for a long time WTI, trading at a volume nearly four times that of Brent (Clayton, 2013). The futures contract is often bought by refineries located on the Gulf Coast and in the mid-continent of the U.S., and is thus highly sensitive to regional supply and demand factors.

Due to the liquidity of the WTI futures contracts and the fact that the U.S. is the largest oil consumer globally, WTI is of great importance and a point of reference for the domestic market (U.S. EIA, 2014b). In addition, futures contracts for WTI are the best visible real-time reference price for the market. Negotiations in the spot market will therefore use the futures price as a reference point (Platts, 2010).

The Brent futures contract traded on ICE surpassed the WTI contract in 2013, and is today the largest traded crude oil future in the world (Clayton, 2013). Brent futures are, unlike WTI, settled financially. The settlement is a weighted average of all trades in the physical market for the month in question for each underlying component of the Brent benchmark. The financial instrument is far more complex than WTI, due to the inclusion of four crudes, Brent-Forties-Oseberg-Ekofisk, in one instrument (Fattouh, 2011).

Crude oil has, unlike pure financial assets, a physical dimension that anchors expectations to fundamentals of the oil market. Every day millions of barrels are bought and sold at prices determined in the market. By the law of one price a good must sell for the same price in all locations, and thus the futures market should eventually converge with the spot market to remove the possibility of arbitrage. However, if perceptions of future market fundamentals are uncertain, exaggerated or both, the futures market can diverge away from the underlying fundamental value and create a bubble (Deutsche Bank, 2013).

Market participants use the futures market in different ways to make a profit or hedge against loss. Commercial traders, producers and consumers of crude and refined products, optimize their portfolio by hedging exposure. Mainstream institutional and retail investors trade in the market to profit from movements in the price, often known to be hedge funds or pension funds. Traders and commodity trading advisor's attempt to profit from price deviations between regions and commodities or to anticipate the future price of crude oil (Deutsche Bank, 2013).

3.3.2 Forward Curve

The forward curve is the series of sequential prices for future delivery of crude oil or expected future settlements of an index. It has increased in importance along with the growing financial market, with expectations of supply and demand being reflected in the curve. An upward sloping forward curve indicates higher prices in the future. This again indicates that one expects demand to increase more relative to supply, that supply is going to tighten, or that spare capacity of crude oil is more limited in the future.

An upward sloping forward curve, referred to as contango, where the futures price of a commodity increase with time, is considered normal, stripped from all expectations of future demand and supply. This is due to the fact that cost of carry, i.e., the cost of storing the crude, is included in the curve and thus the price will be higher for future delivery. If the curve slopes downwards, referred to as backwardation, it implies that the market expects either demand to decrease more relative to supply, a surge in supply or that the spare capacity of crude oil is less limited in the future (Deutsche Bank, 2013).

4. Literature Review

In this section we present relevant literature for our thesis. We review literature regarding the pricing of non-renewable resources, and more specifically WTI and Brent. Literature pertaining to the crude oil markets and the WTI-Brent spread is also presented. Based on the literature review we give a brief discussion on how we utilize earlier research in our thesis.

The pricing of crude oil has been widely reviewed by several papers (see e.g. Hotelling, 1931; Horsnell & Mabro, 1993; Bacon & Tordo, 2004; Hamilton, 2008; Carollo, 2011; Amadeo, 2014). All reviews are based on the fact that crude oil is a finite resource; meaning that at some point in time oil reserves might be depleted. It was Harold Hotelling who first described the evolution of non-renewable resource pricing. In his article “The Economics of Exhaustible Resources” from 1931, Hotelling states that the price of a finite resource must rise at a rate equal to the discount rate, known as the Hotelling’s rule or scarcity rent. He also showed that in competitive markets, his rule maximizes the value of the resource stock. As a consequence, all else equal, the price of crude oil must rise and continue to rise in the future.

However, Hotelling's model does not fully reflect reality, as his assumptions are simplifications of the real world. Hotelling assumes perfect competition and that the stock is fully known. Further, he assumes that the resource extracted is used completely with no waste, nothing left for reuse and that there are no externalities or market failures. Lastly, Hotelling assumes that the cost of extraction is constant and that there are no alternatives to the resource.

Hotelling's model has been extended in various ways in later papers. Krautkraemer (1998) finds that the Hotelling model has not been consistent with empirical studies of non-renewable resource prices, as there has not been a persistent increase in prices over the last 125 years. His review emphasizes that, as non-renewable stocks are not known, technological progress that lowers the cost of extraction and processing, and the discovery of new deposits, has played a greater role than finite availability in pricing non-renewable resources. His empirical analysis also proves that non-renewable resources often have usable residuals from production, and thus must be calculated in the total price of the non-renewable resource.

In a theoretical analysis in the same research paper, Krautkraemer reviews the effects of backstop technology on the price of non-renewable resources. As a finite resource increases in price, other alternative resources, backstops, will become relatively cheaper and thus preferable for consumers. He also illustrates how heterogeneous quality aspects affect the price of a non-renewable resource. Based on his review, Krautkraemer extends the basic model to account for these factors.

Recently, attention has been focused towards incorporating the issue of climate policy in the Hotelling model. Kolstad and Toman (2001) argue that crude oil prices should reflect climate issues, and modifies the model to take into account how increased greenhouse gas emissions causes reduction in welfare over time.

Hotelling's model and later research on the subject have provided a deeper understanding of how prices of non-renewable resources are formed. Thus, the intuition behind the model and its extensions is essential when interpreting our empirical analysis based on the price divergence between WTI and Brent.

Hamilton (2008) surveys crude oil prices in the period between 1970 and 2008. He attributes strong growth in demand from emerging economies, coupled with a failure of global production to increase, as reasons behind the exuberant rise in oil prices since 2000. However, his article does not examine specific crude prices, only general crude price movements. A natural extension of Hamilton's work would be to study specific crudes, such as WTI and Brent, seeing as not all exogenous factors move crude prices with the same strength. Our thesis will build on Hamilton's research and extend the time period analyzed to capture the shale oil revolution in the U.S., and its impact on crude oil prices.

In an extensive research effort by Kilian (2009; 2014), crude oil prices were retrieved back to 1975 and decomposed to examine whether historical oil price shocks could best be explained by demand or supply conditions. The three-way decomposition consisted of (*i*) crude oil supply shocks (*ii*) increased aggregated, global demand for all industrial commodities and (*iii*) a preventative increase in demand for crude oil. Kilian finds that demand conditions has the largest effect on price fluctuations, both in the short and long-term. His findings broke with earlier supposed truisms, that supply conditions best could explain oil price movements. In our empirical analysis, we use these findings by decomposing the spread to study whether the divergence between WTI and Brent can be explained by supply or demand conditions.

In an empirical study of the global crude market, Nordhaus (2009) concludes that the crude oil market is integrated, where the sum of total demand and supply and inventory levels determine the price. Nordhaus emphasizes the fact that crude oils from different geographic regions are largely interchangeable when of similar quality. They are as such fungible; shipping the same or similar oil from elsewhere can make up for a shortfall in a specific region. However, his findings do not imply that short-term deviations from a more or less constant long-run relationship between crudes signify an ending of a relationship. As Balke and Fomby (1997) observe, due to the existence of adjustment and transaction costs, movements toward the long-run equilibrium do not occur in a linear fashion or instantaneously. In our work we wish to examine if the divergence in the WTI-Brent spread is only a short-term occurrence and whether prices are moving back towards their long-term relationship.

To examine whether there is a long-term relationship between WTI and Brent prices, Reboredo (2011) uses a copula approach. His paper examines the dependence structure between crude oil benchmarks, suggesting that crude prices co-move and are linked with the same intensity during bear and bull markets. These findings support Nordhaus' (2009) conclusion of the crude oil market being one great pool. However, these articles do not examine the reasons behind the co-movements. As WTI and Brent have diverged from their long-term price relationship, we extend their research and study what affects WTI and Brent prices, and if their relationship has altered.

The claim that the crude market is one globalized pool is backed up by arbitrage theory. Several empirical papers (see e.g. Hamilton, 2008; Fattouh, 2011) as well as theoretical papers (see e.g. Schwarz & Szakmary, 1994; Al-Loughani & Moosa, 1995; Bacon & Tordo, 2005) have supported this claim. Their results indicate that the world crude oil market, in the long run, is a large integrated market where prices co-move. These results imply that price differences between crude oils should reflect quality differences and transportation costs in the long run. The recent divergence between WTI and Brent has, at least in the short term, disproved this theory, and we therefore examine the factors behind the divergence.

Theoretical research supporting the case for a globalized crude oil market has been empirically tested. Fattouh (2009) finds, with the help of standard root tests, that crude oil prices cannot deviate without restrictions and are thus linked, confirming the globalization theory. One implication of Fattouh's research is that crudes of similar quality in different markets should move in unison such that their spread is more or less constant in the long run. He presents a relationship between WTI and Brent built on his assumption of the crude oil market being one globalized pool, formally:

$$P_{BR,t} + C_{BR} + D = P_{WTI,t} \quad (1)$$

Here P_{BR} and P_{WTI} are the prices for Brent and WTI at time *t*, C_{BR} represents the cost of carrying Brent and *D* is the quality discount. If the WTI-Brent differential is greater than zero it will lead to arbitrage, i.e., U.S. refineries will import Brent, and continue to do so until the price relationship is again attained. Fatthouh's findings are in contrast to what has recently occurred in the spread between WTI and Brent, where WTI has been sold at a discount to Brent over a prolonged period of time. This has led us to postulate a new price relationship between the crudes:

$$P_{BR,t} + C_{BR} + D + S = P_{WTI,t} \tag{2}$$

Based on our hypothesis, we have added a term, S, to capture structural changes in North America. In our empirical analysis we will quantify the factors that has affected the spread. If these have a significant affect, it will give validation to our extended model.

In an earlier paper, Fattouh (2007) claims that the long-term price relationship between WTI and Brent started to show signs of weakness already in 2006. He implies that pipeline logistics and the insufficient of infrastructure is a significant factor in what he terms as a breakdown of the WTI price. Fattouh also highlights the fact that Brent is a seaborne crude, as opposed to WTI, and hence does not suffer from the same pipeline bottlenecks. However, these findings are not based on statistical evidence, but rather on descriptive data on the price movements of WTI. An empirical analysis would have strengthened the conclusions of Fattouh. Further, his article was written in 2007, and is thus outdated given recent events. We add to Fattouh's observations by formally testing his findings by using cointegration analysis to see whether the long-run relationship between WTI and Brent has temporarily ended.

In an analysis of the WTI-Brent spread, Büyükşahin et al. (2012) find that WTI has periodically traded at what they refer to as unheard of discounts to Brent since the fall of 2008. They find structural breaks in the long-term relationship in 2008 and 2010 and provide empirical evidence using an econometric model where financial and macroeconomic variables help predict the observed spread levels. Our thesis builds on these structural breaks in the relationship, but use a cointegration approach to formally examine if WTI and Brent were in a long-term relationship. We wish to empirically test the divergence in the spread by decomposing it into time and commodity spreads. We extend their research by testing an updated data sample and quantifying what factors caused the recent price divergence between WTI and Brent. In addition we examine whether the two crudes are back in a long-term relationship, an occurrence Büyükşahin et al. did not test for.

In the same research paper, they also examined if financial aspects caused a structural break between WTI and Brent. Two major indices for commodities, the Standard & Poor's GSCI commodity index and Dow-Jones UBS commodity price index shifted its relative crude oil exposure away from WTI over to Brent. These two indices are the most widely used benchmarks for commodity index funds, and the shift towards Brent caused large money flows from WTI into Brent futures. Büyükşahin et al. finds evidence for a structural break in the WTI-Brent spread in December 2010. This result is a good indicator for a possible ending of the long-term relationship between the two crudes, and their findings lead us to empirically test whether the financial market has had a significant effect on the spread between WTI and Brent.

5. Events that Affects the Oil Price

As the presented theory and literature has shown, there are several factors that move the price of WTI and Brent, both independently and simultaneously. However, the theory presented in the literature review can only explain oil price movements up to a certain point. We present specific events that affect crude prices. In addition, we also present specific events that affect the prices of WTI and Brent individually, as they are produced in separate parts of the world, and will thus be influenced by local occurrences. These events will be implemented in our empirical research.

5.1.1 Events that Affect Prices Simultaneously

Economic growth has a positive effect on all crude prices. In the build-up to the financial crisis in 2008, low interest rate policies led to excess liquidity and economic growth that put upward pressure on crude prices. With the collapse of Lehman Brothers and the following financial crisis, the sudden evaporation of economic growth was followed by a reduction in the price of crude. In our empirical model we account for both the U.S. and world economy to control for shifts in economic growth.

The commodity market is highly linked to stress stemming from global financial markets. In times of high levels of financial stress, demand declines leading to decreased commodity prices. We control for this in our empirical model by isolating fluctuations in demand stemming from financial stress.

Lighter crudes, like WTI and Brent, are usually sold at a premium relative to the heavier crudes. This light-heavy spread reflects the yield produced from distillation. The fact that lighter products are in higher demand, forces an upward shift in the price of lighter crudes in times of tightness in the crude oil markets. This is augmented by the fact that spare capacity in the market is mainly from producers of heavy crude. They can alleviate the tightness in the market, but not satisfy the demand for lighter products. This in sum has the implication of increasing the light-heavy spread in tight markets. When decomposing the spread into different components, we examine the light-heavy spread between WTI and WTS to study if there are spillover effects from the unusual behavior in the WTI-Brent spread.

Certain economies with excess supply of crude keep oil in reserve or adjust production for political or economic reasons. OPEC and the U.S. hold reserves to be able to have spare capacity on hand for market management. Both reserves are readily available and can change supply in the market, altering the price of crudes and distillate products in a way the countries see fit. In addition, Saudi Arabia, the largest producer in OPEC, adjusts production for political or economic reasons. The U.S. and Saudi Arabian crude production, and OPEC spare capacity, is controlled for in our empirical model, as they affect prices of both Brent and WTI.

5.1.2 Events that Influence the Price of WTI

The growing inflow of crude oil to Cushing, as a response to increased production in North America, explained in section 3.1.2, led storage facilities to almost reach peak capacity. This has induced the expansion of storage capacity, doubling Cushing's storage to meet the increased production (CME Group, 2010). Additional capacity prompted the increased trading of WTI, solidifying Cushing as a trading hub of great importance. In addition to the increased capacity, pipelines were built to increase the influx of crude. In total, this has managed to alleviate pressure on pipeline infrastructure into Cushing and its surrounding storage facilities.

However, the production of pipelines to shift crude out of Cushing has not kept the same pace. Between 2010 and 2013 capacity for delivering crude to Cushing increased significantly due to the construction of pipelines, such as the TransCanada Keystone pipeline that originates in Alberta, Canada. The growing supply of crude oil to Cushing far surpassed the surrounding refinery and pipeline take-away capacity. This has resulted in a bottleneck in Cushing, causing a large build-up of crude and depressing the WTI price (Genscape, 2014). We empirically test whether these pipeline and capacity issues have had a significant impact on the spread and its unusual behavior.

Local weather conditions can also have an effect on the WTI price. The Gulf of Mexico and the Southern U.S. has witnessed extreme weather such as hurricanes. In 2005 hurricanes forced refineries and production sites along the Gulf Coast to shut down, which immediately increased the price of WTI as supply dropped (U.S. EIA, 2014d). As we wish to test for certain supply conditions in North America, we need to isolate drops in supply stemming from these weather conditions. We therefore control for hurricanes in our empirical model.

5.1.3 Events that Influence the Price of Brent

Brent, as opposed to WTI, is a seaborne crude, making it more sensitive to demand from global and emerging markets. After Japan shut down its nuclear facilities after the Fukushima incident in 2011, their demand for fossil fuel greatly increased. These factors put upward pressure on the Brent crude price (The Economist, 2011). In our empirical model we account for factors that affect the demand for seaborne crudes, by both including the immediate demand for Brent and world economic activity.

The demand for Brent has also been affected by geopolitical situations. With the Tunisian revolution and the subsequent political turmoil during the Arab Spring, crude oil supplies from these areas have been under risk. The Libyan crisis removed a large supply of sweet crude, and the continuing turmoil in other parts of the Middle East have put production facilities under duress. As Brent is a close substitute to these crudes, this has put upward pressure on the price. In our empirical model, we account for political unrest to isolate the fluctuations caused by supply disruptions and the risk premium added by investors.

6. Stylized Theoretical Analysis

In the following section we use the theory presented so far and apply it in a theoretical framework to easier comprehend why crude prices fluctuate. The focus of our stylized theoretical analysis will be on the North American market, as we hypothesized that the problems in Cushing have been the main driver behind the divergence between WTI and Brent. In the presentation of each scenario, we apply the theoretical framework to real life occurrences, which will be a useful backdrop when interpreting our empirical analysis in section 7. Before we present our theoretical analysis, we address certain assumptions that are inherent throughout all scenarios.

6.1.1 Assumptions

The depiction of the crude oil market is static and focuses only on short-term effects. In the long run, quality differences and transportation costs determine the price. The market for crude is global, with no regional differences. These assumptions are supported by previous research, as discussed in the literature review. We further assume that the market is perfectly competitive, with no supplier or consumer having any form of market power.

Two types of crude oil supply the market. Seaborne crude from the North Sea referred to as Brent and landlocked crude sourced in Cushing, referred to as WTI. The price of Brent is a proxy for world price in our scenarios. The crudes are assumed to be aggregated and thus depict the market as a whole. Due to the small quality differences between WTI and Brent, we assume them to be identical products with no switching cost for the buyers.

We depict two markets in our theoretical analysis. The first is the inland North American market, denoted Landlocked, representing the crude oil market north of Cushing. The second market is the market south of Cushing, denoted Seaborne, able to utilize WTI, Brent or a combination.

The landlocked crude, WTI, faces capacity constraints from its selling point Cushing to the Seaborne market. Pipelines that supply Cushing with oil have enough capacity to handle increased supply, whereas the pipelines that transport oil out of Cushing to the Seaborne market does not have the ability to handle increased production. This implies that demand for crude in the Seaborne market can only be supplied by WTI up until the point of maximum pipeline capacity. The vertical line denoted capacity constraint illustrates this.

We illustrate several scenarios to depict how crude oil prices are affected by exogenous changes in supply and demand. First we present two scenarios that illustrate how supply and demand shocks affect the price of WTI in the Seaborne market without the possibility of importing Brent. We subsequently expand both scenarios to account for capacity constraints at Cushing. The next scenario depicts the Landlocked market's ability to shift WTI to the Seaborne market, with and without capacity constraints. In this scenario we allow for the import of Brent. Finally, we present a cost-differential model, where the short-term assumption is eased to examine how different modes of transportation to the Seaborne market can affect the price and quantity supplied of each crude.

All scenarios are based on the assumption that the market is in equilibrium prior to any exogenous change. Furthermore, we assume downward sloping demand functions, illustrating the fact that demand falls with rising crude oil prices. The supply curve is upward sloping, reflecting increasing costs as output increases.

Table 5 gives an overview of the different scenarios.

Table 5 – Scenarios and Assumptions

Assumption	**Demand Shock**		**Supply Shock**		**Two-Region Model**		**Long-Term Equilibrium**
Capacity Constraint	Without	With	Without	With	Without	With	With
Landlocked Perspective					x	x	x
Seaborne Perspective	x	x	x	x			x
Isolated Market	x	x	x	x			
Brent Price Given					x	x	

6.1.2 Demand Shock

The first scenario illustrates the effect of a positive demand shock to the Seaborne market. We assume the market is isolated in that only WTI can be supplied and discuss the scenario with and without capacity constraints. The effects are illustrated in figure 3.

Without constraints, a positive shock will increase demand for crude oil in the Seaborne market, increasing quantity, regardless of price. This relates to a positive shift in the demand curve, increasing both the price and quantity demanded of WTI, from [P_o, Q_0] to a new equilibrium [P_1, Q_1].

However, with a constraint, the inability to increase supply out of Cushing to the Seaborne market will have a feedback-effect on the price. Consumers will outbid each other to gain access to the limited supply of WTI crude, increasing its price above what would have been the market price without capacity constraints. The price increase will continue until the market is again at equilibrium, with higher prices and no change in quantity [P_2, Q_0]. The feedback effect arises because at the quantity supplied, marginal willingness to pay is higher than marginal cost. Hence, consumers outbid each other until equilibrium is established where marginal cost equals willingness to pay.

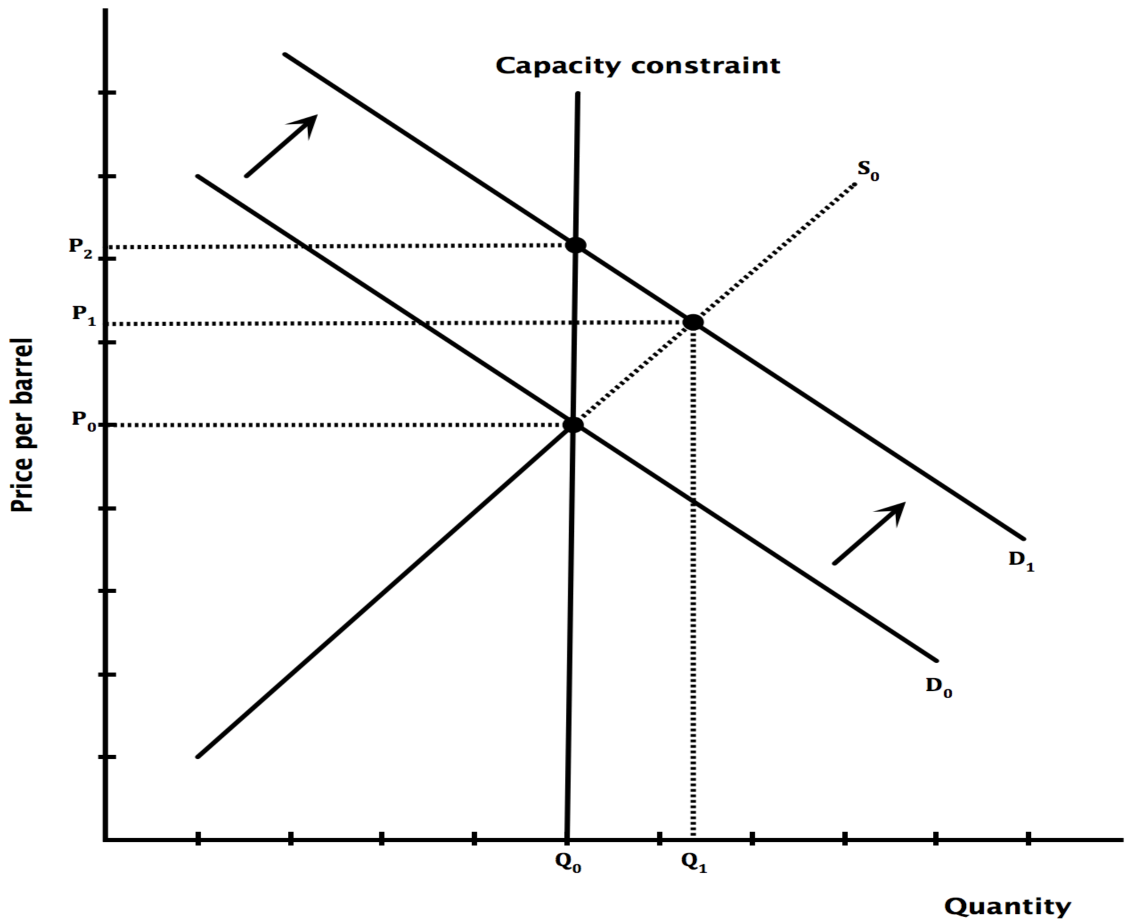

Figure 3 - Demand Shock

The market for WTI has over the last decade experienced increased demand without being able to supply the market south of Cushing with crude. The U.S. demand for oil has grown almost every year, increasing pressure on Cushing to pump oil to the market. Without pipeline expansion from Cushing to refineries on the coast, the bottleneck will have the effect of increasing prices for WTI, all else equal.

6.1.3 Supply Shock

This scenario depicts the effects of a positive supply shock to the Seaborne market. As in the first scenario, we assume that the Seaborne market is isolated and we discuss the scenario with and without constraints. The effects of a supply shock are illustrated in figure 4.

A positive shock to supply without capacity constraints increases the supply of oil to the Seaborne market. The supply curve experiences a positive shift, decreasing prices but increasing the quantity supplied. The market is now in a new equilibrium, moving from [P_0, Q_0] to [P_1, Q_1].

With capacity constraint, a supply shock will decrease WTI prices further. Again we assume that the market is in equilibrium at [P_0, Q_0] prior to the supply shock. With increased supply of WTI, no increase in demand and a capacity constraint, competition between producers will cause a decrease in price. As the increased supply into Cushing cannot be supplied to the Seaborne market, competition increases further as oil producers with low marginal cost cut prices to keep market shares. This feedback effect gives rise to a new equilibrium at [P_2, Q_0] with the same quantity consumed, but at a lower price.

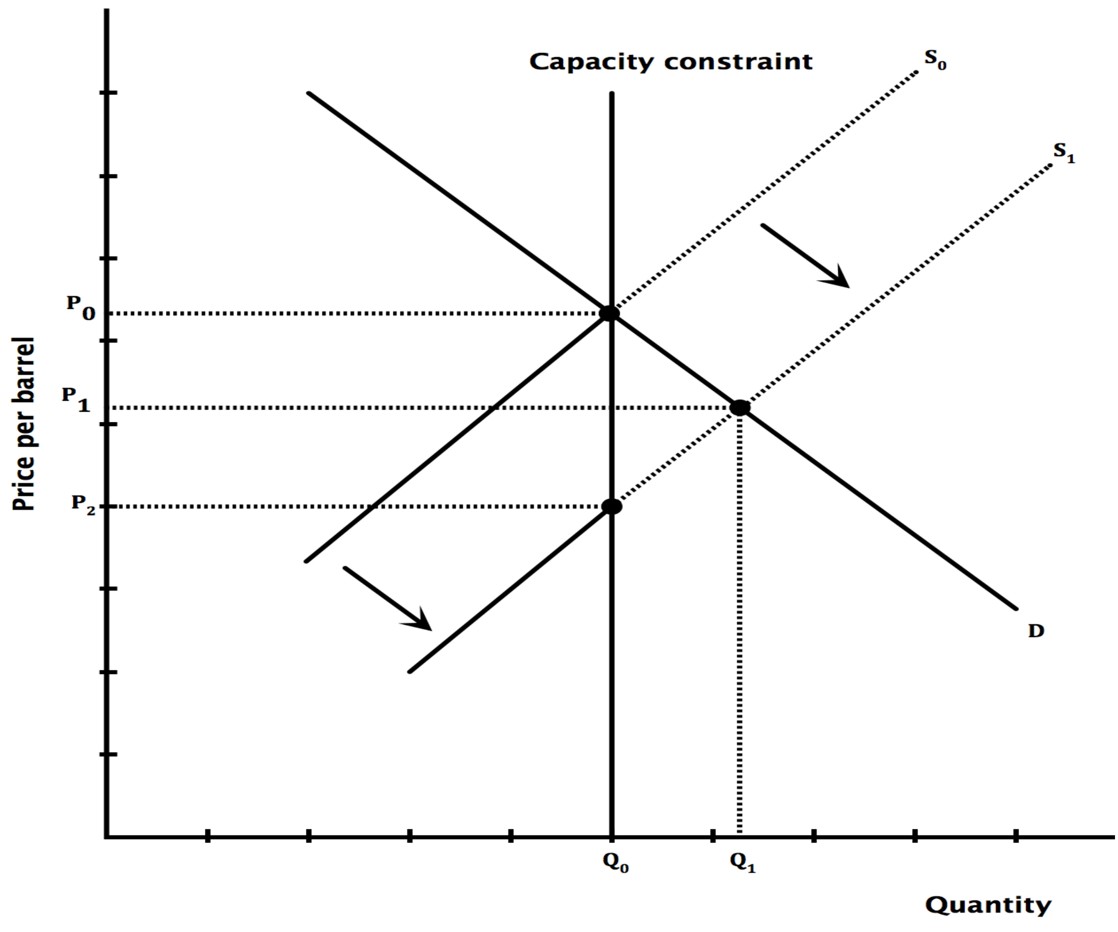

Figure 4 - Supply Shock

WTI has been subject to increased production volumes due to the unconventional oil revolution in North America. As a consequence, producers were eager to expand pipeline capacity into Cushing, leading to a rush in pipeline construction. Amongst the projects was the Keystone XL pipeline in 2011 (Reuters, 2013). Though pipelines leading into Cushing increased, pipeline projects sending oil out were insufficient in handling the increased crude volumes. This led to large accumulations of oil at Cushing, leading to a depression of the WTI price.

6.1.4 Capacity Constraints in a Two-Region Model

In this scenario we depict the Landlocked market's ability to shift WTI to the Seaborne market. The Seaborne market has the possibility of consuming WTI, Brent or a combination of the two. We assume that the price of Brent is given, as the quantity shifted from the Landlocked to the Seaborne market has little or no impact on the world price. It is assumed that the price of Brent is higher than WTI as the glut of oil in the Landlocked market has depreciated prices relative to Brent. We will discuss the scenario with and without capacity constraints to illustrate the effects of a pipeline bottleneck on the WTI price. The initial equilibrium in the Landlocked market is [P_0, Q_0], before we open for the possibility of shifting oil to the Seaborne market. All effects are illustrated in figure 5.

Without a constraint on the possibility of shifting oil to the Seaborne market, producers of WTI will increase their production until the cost of the marginal producer equals the price of Brent. This will lead to an increased production of WTI equal to [Q_2], with producers being able to charge the world price, [P_{Brent}]. The new equilibrium in the Landlocked market is [P_{Brent}, Q_1], with producers of WTI supplying [Q_2-Q_1] to the Seaborne market.

If the same scenario is depicted with capacity constraints, the Landlocked market can only shift oil to the Seaborne market until maximum capacity. This will constrict the supply of WTI to the Seaborne market, having the effect of decoupling WTI and world prices. The effect of the constraint is that producers with lower marginal costs will decrease prices to stay competitive. With the constraint producers can only increase production to [Q_4], obtaining price [P_1]. This leads to a new equilibrium in the Landlocked market [Q_3, P_1], with the Seaborne market being supplied with [Q_4-Q_3] from producers of WTI.

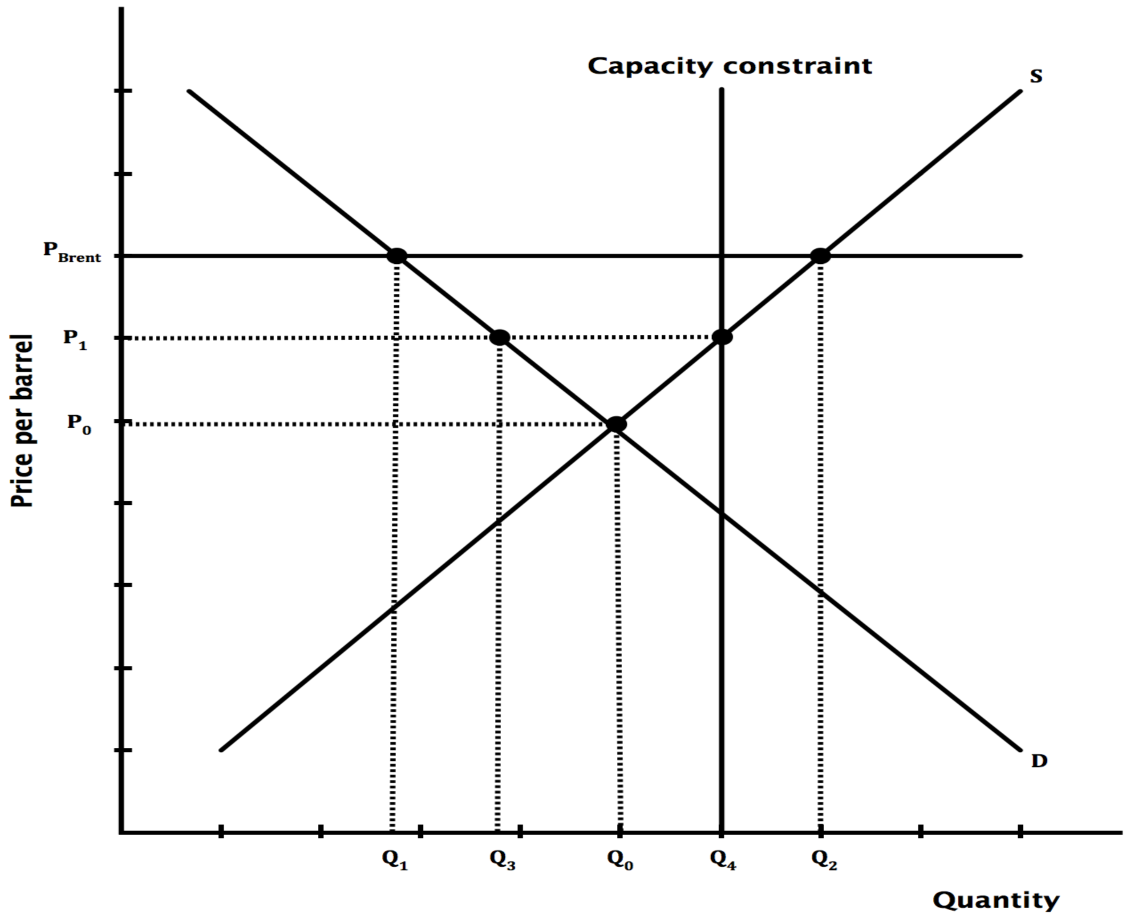

Figure 5 - Two-Region Model

This scenario illustrates the price divergence that has occurred in recent years between WTI and Brent. With increasing volumes of unconventional oil flowing into Cushing, without the same possibility of shifting it to consumers south of Cushing, prices diverged. This resulted in an increased inflow of other crudes to the Seaborne market to saturate demand.

6.1.5 Long-Term Equilibrium

We are also interested in examining the effects of a capacity constraint when the short-term assumption is eased and increase the number of transportation alternatives. We will look at both the marginal costs of transporting WTI from the Landlocked to the Seaborne market and the marginal cost of transporting Brent. The model depicts the different marginal cost per barrel to illustrate the price spread. The model itself does not predict a price spread between the crudes, but is implied in the transaction. We will first depict the short-term market where only pipelines are able to transport

WTI, before we ease the short-term assumption and include other means of transportation.

The marginal cost of shifting oil through pipelines from the Landlocked to the Seaborne market is initially lower than the marginal cost of Brent, reflecting the fact that pumping oil through existing pipelines is almost perfectly elastic. However, when maximum capacity is reached, the marginal cost curve is kinked 90 degrees, implying that supply is perfectly inelastic. As a consequence, producers of WTI can only supply [$Q_{Pipeline}$] to the Seaborne market in the very short run.

The seaborne Brent has a higher marginal cost than WTI, as new tankers are required to transport additional crude. We assume no shortage of oil tankers, as Brent is not affected by the same capacity constraints as WTI. For each additional tanker hired, the price of carry by sea will rise, increasing marginal costs.

Given these assumptions, producers of WTI can only supply the market with [$Q_{Pipeline}$], while the producers of Brent supply the remaining demand [Q_{Brent}-$Q_{Pipeline}$] in the very short run. Even if the marginal cost of production for WTI is lower than Brent, it is unable to be transported to the coastal market where it can be sold at world prices. This is illustrated in figure 6.

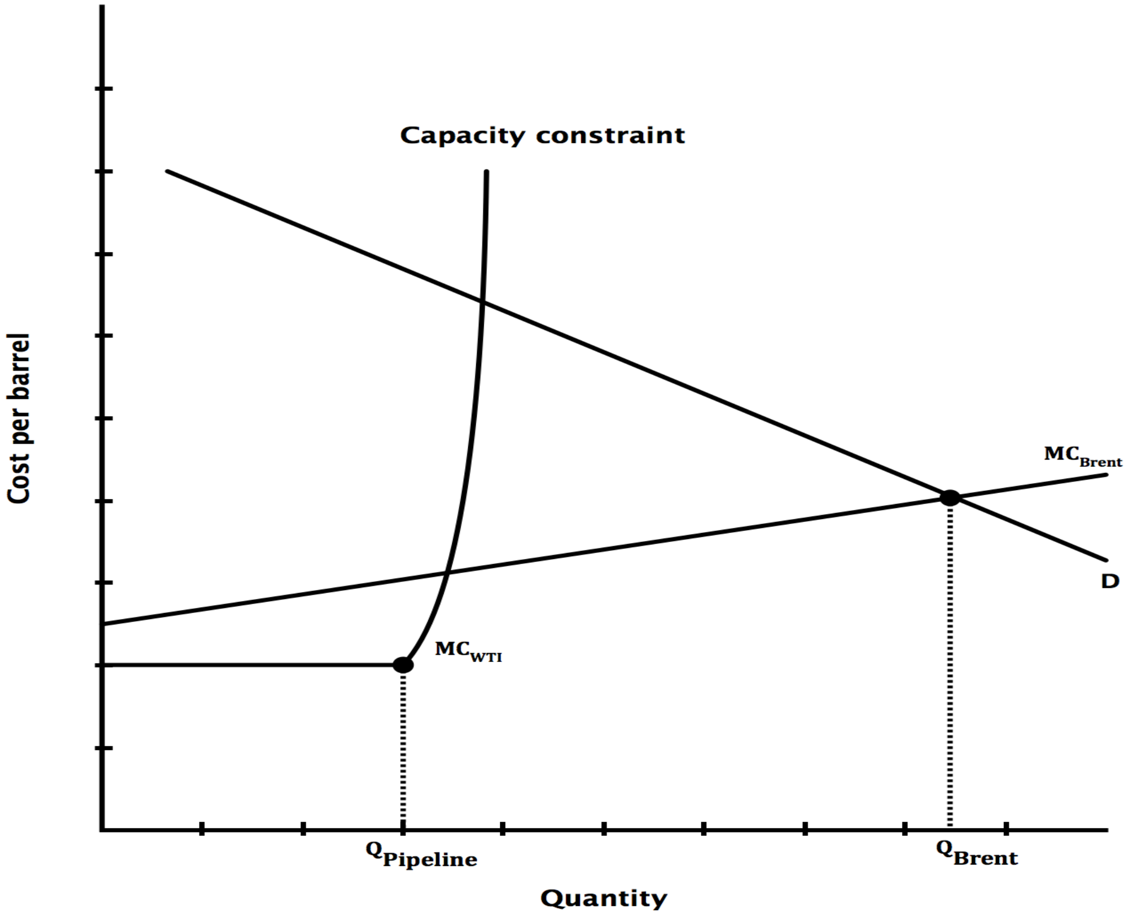

Figure 6 - Short-Term Equilibrium

By easing the short-term assumption, other modes of transportation can be made available for WTI. These modes of transportation have a higher marginal cost than pipelines, and are thus only economically viable after the maximum pipeline capacity has been reached.

The most common transport alternatives in North America are barges, trucks and rail, with each measure having an individual marginal cost function. The cheapest alternative is transportation by barge, denoted [MC_{Barges}]. We assume that there is no natural capacity constraint on this mode of transportation. Barges experience increasing marginal costs at a faster rate than rail, as producers must increase the freight rates to employ additional barges. This makes rail the preferred alternative after [Q_{Barges}].

Railroads also face capacity issues due to natural constraints on infrastructure. As the assumption of short-term time horizon has not been eased completely, the infrastructure of railway is given, such that the marginal cost becomes completely inelastic after capacity is reached. We assume the capacity is reached at [$Q_{Railway}$]. After the maximum capacity by rail is reached, producers can choose to transport crude by trucks, with its marginal cost denoted [MC_{Trucks}]. The marginal cost for trucks increase at a faster rate than the marginal cost of transporting Brent, and as a consequence Brent becomes the preferred alternative after the two marginal cost curves intersect.

As new modes of transport are made available the quantity of WTI supplied to the Seaborne market will increase, but at a higher marginal cost. This is shown by the marginal cost curve for WTI, which increases as new modes of transportation are introduced.

This illustrates that producers of WTI are unable to earn the rent they could have achieved without constraints between the Landlocked and Seaborne market. New modes of transport enable the producers of WTI to shift more crude out on the Seaborne market, but at a higher marginal cost. This is illustrated in figure 7.

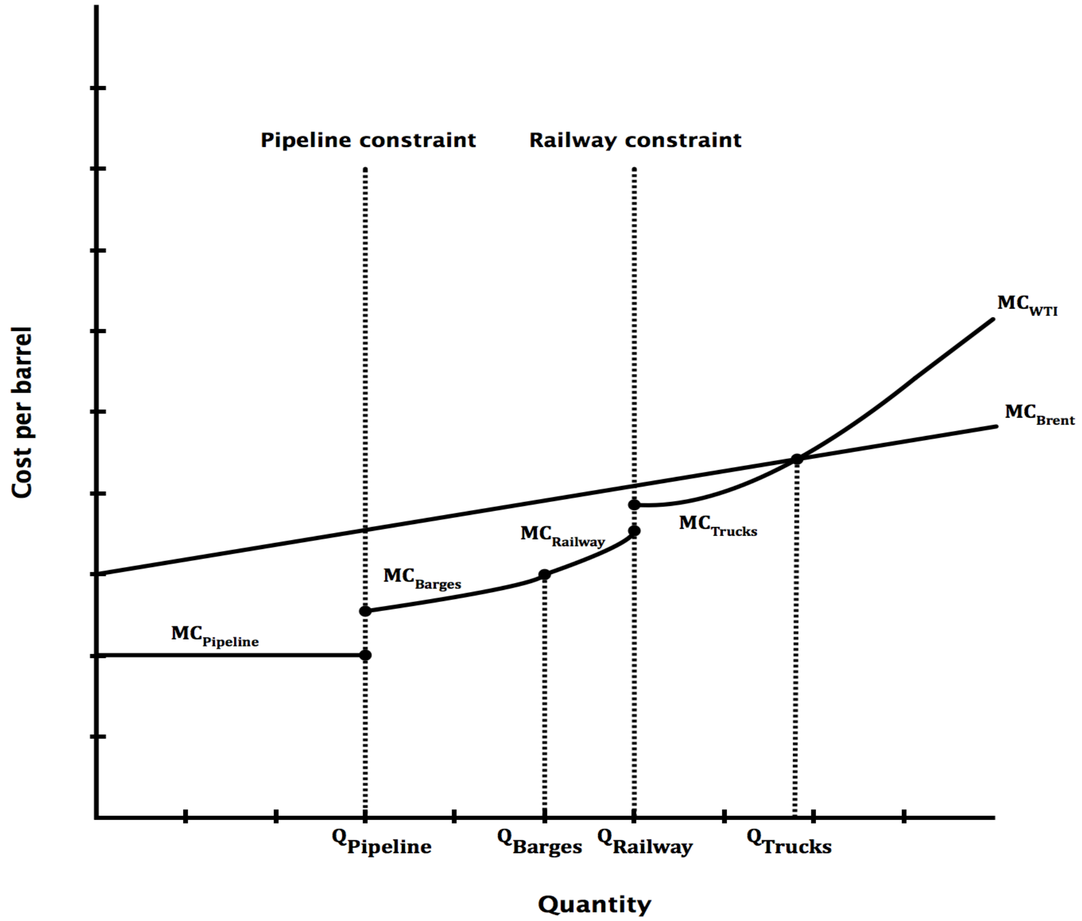

Figure 7 - Long-Term Equilibrium

Since 2007 pipelines have been transporting oil at maximum capacity, forcing other means of transportation to be considered. According to Forbes Magazine (2014), the most common transport alternatives out of Cushing, besides pipeline, are barges, trucks and railways, with barges comprising the majority of transport. However, these modes of transport come at a higher price. In a report from the Congressional Research Service (2014), transportation through pipeline was by far the cheapest with marginal costs of $5 per barrel, followed by barges, railway and trucks costing in the region of $8-12 per barrel.

The pipeline capacity constraint has in effect revolutionized crude transportation. Producers of WTI have been incentivized, by the possibility of arbitrage, to look for alternative means of transportation between the market north and south of Cushing. The U.S. fleet of over 3,000 inland barges has been pressed into service, shipping oil south to the Gulf Coast, lifting day rates and boosting revenues for barge owners. The same effects have also been felt in the railway sector. In 2009, 73% of the crude moved out of North Dakota was shipped via pipeline, with only 1% transported by rail. In December 2012, however, over 66% of the crude was carried by rail (Brown Brothers Harriman, 2013).

7. Empirical Analysis

After gaining an understanding of the crude oil market and what affects crude oil prices, we turn to our empirical research. In this section we answer our hypotheses by the use of econometrical techniques. First we present our sample data, before explaining the method behind our econometrical approach. We hypothesized that the relationship between WTI and Brent ended in 2010 and that a new relationship was established early 2014. We will examine this by the use of an Engle-Granger two-step test for cointegration. After this, we decompose the spread into three components to further analyze the spread. Lastly, we build an empirical model to quantify the different component's effect on the spread.

7.1 Data

Based on our discussion in section 4 and 5, we utilize variables that influence the individual prices of WTI and Brent, as well as variables that affect both crudes. All prices are specified in U.S. dollars. Our sample data runs from 01/01/2000, as we wanted to have a sufficient data sample for inferring causal relationships when testing our empirical model.

We use different time annotations in our empirical analysis. For our analysis of the relationship of the spread, we utilize daily data, which stretches to 24/10/2014. The daily data captures short-term fluctuations in prices and can better pinpoint when the relationship between WTI and Brent ended, and if a new relationship has been established. We continue using daily data on futures and spot prices for WTI, Brent, LLS and WTS in the spread decomposition.

In our empirical model we use weekly data that runs to 27/06/2014, as several of our independent variables are only available on a weekly basis. This will not weaken our results, as weekly data manages to capture most of the short-term fluctuations (Baumeister, Guérin & Kilian, 2014).

It must be noted that some of our variables are non-stationary. Econometric analysis is often built on the assumption that the mean and variance of an underlying process are constant. When the time series is non-stationary, this assumption does not hold, and can lead to spurious regression results. However, if both dependent and independent variables are non-stationary and cointegrated they can be used in regressions (Stock & Watson, 2012). We will therefore check all our variables of interest for non-stationarity and if they are cointegration with the spread, to see if we can apply them in our empirical model. These issues are examined in section 7.5.1.

7.1.1 Crude Oil Price Data

We obtain historic spot prices for WTI, Brent, LLS and WTS from Bloomberg (2014e). For some assessments we use the futures prices and open interest of WTI and Brent, retrieved from Bloomberg (2014c; 2014d) and NYMEX (2014a; 2014b) respectively. The open interest can be used to measure the effect of increased demand for WTI and Brent futures contracts and the liquidity of the two (The Economic Times, 2014). If the open interest increases for a specific crude, it suggests increasing demand for this particular crude. This implies that if the open interest increases for Brent, without a corresponding in the open interest for WTI, the spread should move in favor of Brent.

7.1.2 Demand Variables

Because WTI is a landlocked crude oil with its price partly dictated by infrastructure logistics, the demand for Brent and WTI are not completely integrated. As there is no global aggregate indicator for demand in the commodities market, we use indicators for U.S. and world economic activity, as proxies for demand of WTI and Brent respectively.

7.1.2.1 World Economic Activity

For the world economic activity, we could use gross domestic product (GDP) as an approximation. A drawback with GDP is that there are no weekly or monthly observations on an aggregated level. In addition, GDP data is smoothed and too broad an index for our purposes, as we are interested in a proxy for the demand for commodities. Consequently, these factors contribute to the measure of GDP being an imprecise and unsuitable approximation for the world economy. We instead utilize the relationship between real economic activity and the demand for shipping, as demand for shipping is driven by world economic activity (Klovland, 2002).

Kilian (2009) introduces an index for global economic activity built on single-voyage freight rates for bulk dry commodity cargoes and accounts for different fixed effects for different routes, commodities and ship sizes. However, the monthly index is not updated to fit our needs and we therefore use another proxy for real economic activity, the Baltic Dry Index. Sørensen (2009) use the Baltic Dry Index as a proxy for real economic activity in his study of oil price shocks and stock return predictability. He proves that the relation between Kilian's Index and the Baltic Dry Index is strong, with a correlation coefficient of 0.96 in the period between 1985 and 2009.

Even though the indices are built on different data, the correlation indicates that they capture similar effects. We use weekly data on the Baltic Dry Index, obtained from Bloomberg (2014a). The index captures effects from countries where data is difficult to extract. Using measures of economic activity for each individual country would require extensive time series data and correct weighing for each country. In addition, changes in currencies could lead to measurement errors. The Baltic Dry Index takes all these factors into account indirectly, as it accumulates real economic activity automatically. If the index increases in strength, the global demand for commodities is assumed to be increasing. This again implies that the global economy is experiencing an upturn. With increasing global demand, the price of the seaborne Brent should increase as well, which infers a reduction in the spread between WTI and Brent, all else equal.

7.1.2.2 The U.S. Economy

For the U.S. economy we obtain data on the daily ADS index first developed by Aruoba, Diebold and Scotti (2008). The index tracks daily business conditions in the U.S. by aggregating several underlying economic indicators. Intuitively, a strong demand for local crude oil is associated with a strong economy. We therefore expect the variable to be positively correlated with the spread between WTI and Brent. The data is available from the Federal Reserve Bank of Philadelphia (Aruoba, Diebold, & Scotti, 2009) and is updated weekly. We convert it from daily to weekly by taking averages over each week.

The second variable is the historic data on the New York Stock Exchange Composite Index, which consist of all indices traded on the exchange. The data is retrieved from New York Stock Exchange (2014b), and used as a proxy for the economic conditions in the U.S. The index includes more than 1,500 companies from all sectors of the economy (New York Stock Exchange, 2014a), and it is this breadth that makes it a good proxy. When the index experiences a prolonged fall one would expect the economy to be on the verge of a downturn.

7.1.2.3 Financial Stress

To account for elevated levels of financial market stress in our empirical analysis, we include the TED spread, obtained from Bloomberg (2014g). The spread is the difference between the 30-day U.S. dollar London Interbank Offered Rate (LIBOR) and the 30-day Treasury bill yield. LIBOR provides an indication of the average rate at which a LIBOR contributor bank can obtain unsecured funding in the London interbank market for a given period and currency (Intercontinental Exchange, 2014). The Treasury bill yield is a short-term obligation backed by the U.S. government with maturity of less than a year. The bills are issued through a competitive bidding process where the appreciation of the bond provides the return to the holder (U.S. Department of the Treasury, 2014). The TED spread is thus an indicator of perceived credit risk in the general economy.

The variable is included because in periods of high market stress, traders and other market participants are less willing to engage in trades and cross-market arbitraging (Gromb & Vayanos, 2010). We expect, all else equal, the spread to increase during periods of elevated levels of financial stress.

7.1.3 Supply Variables

Recognizing that WTI and Brent are not fully integrated we include variables in our dataset that can summarize supply balances for WTI and Brent.

7.1.3.1 The U.S. Crude Oil Production

The production of WTI has, unlike Brent, spiked since the shale oil revolution. To capture this effect we need to account for the U.S. production of crude. We account for this by using the number of operating crude rigs as a proxy for production, sourced from Baker Hughes and Weatherford International (2014). The data includes all operating crude oil rigs in the U.S., both onshore and offshore. The number of rigs has increased as more are put into use in U.S. crude production. This leads us to believe that, all else equal, an increase in the number of rotary rigs puts downward pressure on the WTI price as more crude oil is supplied to the market. The production volumes from the Bakken Field in North Dakota and imported crude from Canada can be seen in figure 14 in the appendix, to illustrate the production increase from unconventional our sources.

7.1.3.2 OPEC Surplus Capacity

Büyüksahin et al. (2011) argued that OPEC historically has tried to maintain a surplus production capacity, defined as the volume of production that can be brought online within 30 days and sustained for at least 90 days (U.S. EIA, 2014d). Over the last decade however, global economic growth has increased the demand for crude oil, almost exhausting OPEC's spare capacity, which led to a sharp increase in the world oil price.

In this way we can infer that lower energy prices amid greater surplus production capacity, reflects a weak macroeconomic environment. This implies that, all else equal, there should be an inverse relationship between the price of Brent and the OPEC spare capacity, as can be seen in section 10.1.2 in the appendix.

7.1.3.3 Saudi Arabian Crude Oil Production

The Saudi Arabian crude oil production is included to capture the general market conditions for crudes that are seaborne, such as Brent. Saudi Arabia is of great importance in the crude oil market, as it maintains the world's largest crude oil production capacity. This infers that an increase in Saudi Arabian production decreases the price of Brent and other seaborne crudes. We collect data on Saudi Arabian crude oil production from Bloomberg (2014f).

7.1.4 Other Control and Dummy Variables

7.1.4.1 Currency Fluctuations

As all crude is traded in dollars we control for fluctuations in the value of the U.S. dollar. We do this by including the exchange rate for the U.S. dollar to Euro in our empirical analysis, obtained from Bloomberg (2014h). We use the Euro as a proxy for the European market, which is a large consumer of Brent. If the dollar value increases, all else equal, it would lead to other countries having less purchasing power and declining demand Brent.

7.1.4.2 The Arab Spring

To control for disruptions in the supply of crude from the Middle East, we include a dummy variable for the political unrest caused by the Arab Spring. We date the outbreak of the Arab Spring to February 11^{th} 2011 when Hosni Mobarak resigned (BBC, 2014). We include a dummy variable, which denotes 0 in the period before the Arab Spring and 1 from February 11^{th} 2011. As conflicts in the Middle East are still apparent, the dummy is upheld throughout our sample period. The Arab Spring has put upward pressure on the price of Brent, as the uncertainty of future supply from Middle Eastern producers leads competing crudes, such as Brent, to be in higher demand.

7.1.4.3 Hurricanes

We also control for extreme weather conditions, specifically hurricanes. According to the Energy Information Administration (EIA) hurricanes can affect crude oil prices in the U.S. Consequently, we include a dummy variable for all hurricanes in our sample period of certain strength, making landfall in the U.S. We assume that hurricanes, all else equal, will increase WTI prices, as production facilities are forced to close.

7.2 Cointegration

In this section we set out to answer our hypotheses regarding the long-term relationship of the WTI-Brent spread. We hypothesized that the relationship ended early 2010, and that the two crudes were back in a new relationship in 2014. The data analyzed are historic futures for WTI and Brent.

To formally test our hypotheses, we analyze our sample data with the use of an Engle-Granger two-step test for cointegration. Cointegration is a statistical property of time series variables, where two or more time series are cointegrated if they share a common stochastic drift (Engle & Granger, 1987). We will use a technique, in combination with the Engle-Granger test, called recursive analysis, to pinpoint when the relationship may have ended and returned. We first introduce the Engle-Granger test and the recursive analysis before presenting our results. In addition, we test the structural validity of our findings by carrying out robustness checks.

7.2.1.1 Engle-Granger Cointegration Test

The Engle-Granger two-step test for cointegration examines whether two variables are in a cointegrated relationship. To conduct the Engle-Granger test the individual price series must be non-stationary and the differentiated price series stationary. A stationary time series has a constant probability distribution over time, which implies that the correlation between two variables is the same, independent of time (Wooldridge, 2012). For non-stationary time series the effects of exogenous shocks will not be reduced as a function over time. This can lead to spurious regression results. The first step of the Engle-Granger test confirms that the assumptions for cointegration are fulfilled.

A Dickey-Fuller test is used to examine if a time series is non-stationary, in other words, if the process has a unit root. The following explanation of the test uses the WTI price as reference. Starting from an autoregressive order of one process:

$$WTI_t = a_0 + pWTI_{t-1} + e_t \tag{3}$$

The process has a unit root if $p=1$. In that case, we know that test-statistics from this process is not valid. The Dickey-Fuller test examines if the process has unit root by transforming the model, subtracting WTI_{t-1} from both sides of the equation. Because of this transformation, the null hypothesis will also be transformed and is now:

$$H_0: \gamma = (p-1) = 0 \tag{4}$$
$$H_a: \gamma = (p-1) < 0$$

If the null hypothesis is not rejected, the time series is said to have a unit root and is thus non-stationary. If the null hypothesis holds, there will be no further information in the lagged observations of the variable. The test statistic has an asymptotic distribution called the Dickey-Fuller distribution. We can reject the null hypothesis if the test statistic is of lesser value than the critical value of the distribution.

We can augment the Dickey-Fuller test by adding lagged changes of the variable in the regression. To get a valid test statistic, WTI_{t-1} is subtracted from both sides of the equation, resulting in the following equation on augmented form (Wooldridge, 2012):

$$\Delta WTI_{\mathrm{t}} = \alpha_0 + \beta t + \gamma WTI_{t-1} + \sum_{i=1}^{z} \delta \Delta WTI_{t-1} + e_t \quad (5)$$

Here α_0 is the intercept, t controls the trend, γWTI_{t-1} is the first lag of the time series, while $\sum_{i=1}^{z} \delta \Delta WTI_{t-1}$ is the sum of lags for the first differences where z denotes the total number of differences. In cases with autocorrelation, further lags of the dependent variable can help reduce the problem. The conclusions drawn on the basis of these results are more robust than standard Dickey-Fuller tests, since results are less affected by autocorrelation (Wooldridge, 2012).

In the second step of the Engle-Granger test, the time series are tested for cointegration. If two variables are integrated of order one I(1), then in general the linear difference between them is also integrated of order one. The difference between the two variables can be shown as:

$$WTI_t - \beta x_t = e_t \quad (6)$$

In certain cases this difference is stationary, denoted I(0), for some values of β. If this is the case the variables are cointegrated, with β as a cointegration parameter. This implies that the variables share a stochastic trend and never diverge or converge over time (Wooldridge, 2012). The null and alternative hypothesis is:

$$H_o: e_t = \beta' WTI_t \sim I(1)\ (Not\ cointegrated) \qquad (7)$$
$$H_a: e_t = \beta' WTI_t \sim I(0)\ (Cointegrated)$$

7.2.1.2 Recursive Analysis

Long economic time series often experience breaks or structural changes due to shifts in market fundamentals or production technology (Dahl, Oglend, Osmundsen, & Sikveland, 2011). Several tests have been developed to identify these breaks, one of which is the recursive analysis suggested by Bai and Perron (1998; 2003).

The technique starts from a designated point in the sample data and re-estimates the model each time an observation is added. The model can be Ordinary Least Squares or another econometric specification. To establish whether a break in the long-run relationship between WTI and Brent occurred and if a new relationship has been formed we use the second step of the Engle-Granger test as our model. We collect the absolute value of the test-statistics every time the recursive analysis is run and compare them with the absolute critical values.

7.2.2 Ending of the Relationship

In this sub-section we establish if and when the long-run relationship ended between WTI and Brent. Based on our first hypothesis explained in section 2, we believe the relationship ended early 2010, thus we obtain test-statistics from mid-2009 to mid-2010. We first run the recursive analysis on our sample data, before validating our findings with the use of the Engle-Granger two step test for cointegration.

7.2.2.1 Results from the Recursive Analysis

Since we are only using the second step of the Engle-Granger test for cointegration, we are not able to test all Engle-Granger assumptions specified in section 7.2.1.1. The recursive analysis is therefore a preliminary test to uncover if there is a break in the relationship. We will start the recursive analysis in July 2009, and run the test until we find the period at which we can no longer discard our null hypothesis, that the prices are not in a cointegrated relationship, at a 90% level of significance. Figure 8 illustrates the results.

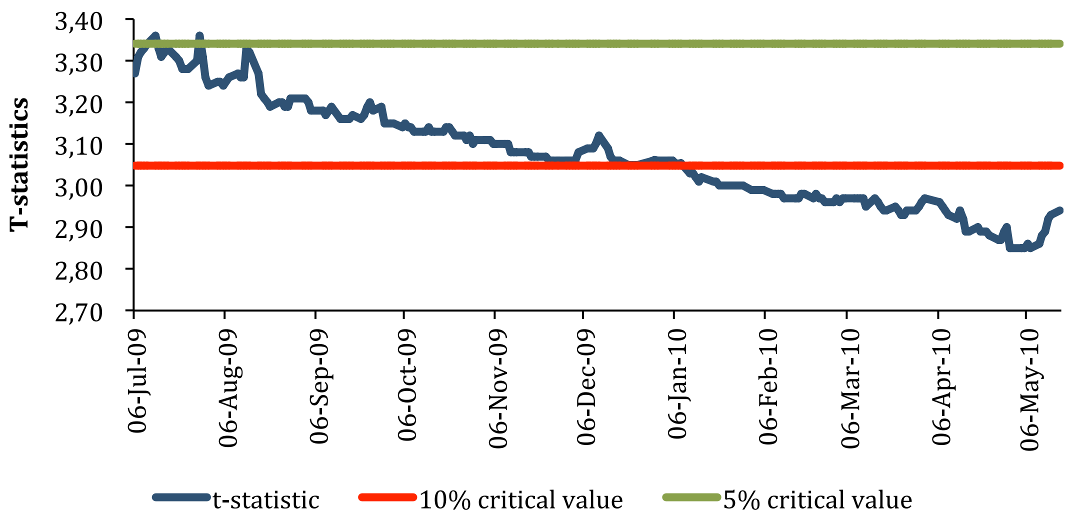

Figure 8 - Recursive Analysis 2009-2010

We see that the t-statistic for the Engle-Granger test is significant at the 95% level at the start of our designated sample period. However, it decreases in value towards our hypothesized end period, and is not significant at the 90% level at the beginning of January 2010.

From these preliminary results we surmise that the cointegrated relationship between WTI and Brent was no longer statistically significant at the 90% level around the first few weeks of January 2010. With the proposed break period we need to check if all assumptions of the Engle-Granger test hold for the time period designated by the recursive analysis. The next section will explore the properties of our findings.

7.2.2.2 Results from the Engle-Granger Test

We wish to confirm our findings in the recursive analysis and thus divide the data into two sub-samples, one sample containing data before the postulated break period and one sample containing data after. The results for the Engle-Granger test are presented stepwise.

The results from the Augmented Dickey-Fuller (ADF) test are presented in table 6. The test is conducted on the two sub-samples based on our postulated break period. The optimal number of lags has been chosen on the basis of the Akaike Information

Criterion since it is most suited for the ADF-test (Stock & Watson, 2012). For details on the Akaike Information Criterion, see appendix section 10.1.3.

The test statistics and critical values are presented for both Brent and WTI in each of the respective periods. If the test statistic is of a lower value than the critical value it implies that the null hypothesis can be discarded and that the time series are stationary. If, on the other hand, the test statistic is of a higher value we cannot reject the null hypothesis and the time series are deemed non-stationary.

Table 6 - Augmented Dickey-Fuller

	2000-2010		**2010-2014**	
Futures	**WTI**	**Brent**	**WTI**	**Brent**
Number of lags	6	11	7	3
Test statistic	-1.185	-1.161	-2.528	-1.914
Differentiated				
Number of lags	12	12	12	2
Test statistic	-12.298	-12.108	-9.73	-20.708
Critical values				
10 %	-2.57		-2.57	
5 %	-2.86		-2.86	
1 %	-3.43		-3.43	

The analysis is consistent for all time periods and both crudes: the test statistics for futures is of a higher value than the 10% critical value, implying that we cannot reject our null hypothesis of non-stationary time series at the 90% level of significance. By being of a higher value than the 10% critical value it is by default higher than the 5% and 1% critical value. For example, the test statistic for the WTI futures for the sample period 2000-2010 is –1.185 while the 10% critical value is –2.57 and the 1% value is –3.43.

For the differentiated price series, test statistics for both sub-samples are below the 1% critical value, which indicates that we can reject our null hypothesis of non-stationary time series at the 99% level of significance. This infers that the time series are stationary.

From the results of the ADF test we can surmise that both assumptions for the Engle-Granger test holds. This implies that we can use the Engle-Granger to examine if the prices for Brent and WTI are cointegrated, i.e., share a common trend. We run the second step of the Engle-Granger test to support our results from the recursive analysis.

In the second step of the Engle-Granger test we estimate the β by the use of Ordinary Least Squares. To formally test the cointegration relationship, we postulate a linear relationship between WTI and Brent. The residuals from the price relationship are tested to assess whether they are stationary. If the null hypothesis of non-stationary residuals is discarded, there is evidence for a stationary relationship between the variables, signifying that the time series are cointegrated.

Table 7 - Second Step Engle-Granger

	2000-2010		2010-2014	
Futures	**WTI**	**Brent**	**WTI**	**Brent**
Test statistic	-8.647		-3.050	
Critical Values				
10 %	-3.046		-3.051	
5 %	-3.338		-3.345	
1 %	-3.900		-3.913	

Table 7 presents the results from the second step of the Engle-Granger test for both sub-periods. If the test statistic is of a lesser value than the critical value we can reject the null hypothesis and imply that the two crude oil futures are cointegrated, i.e., share a common trend. The test statistic for the sub-sample 2000-2010 is –8.647, below the 1% critical value of –3.9. This indicates that the prices were cointegrated in the period leading up to our hypothesized break in the long-term relationship. However, for the second sub-sample from 2010 to 2014 the test statistic is of a higher value than the 10% critical value. This implies that we cannot reject our null hypothesis of non-stationary residuals at the 90% level of significance.

The results displayed from the Engle-Granger test confirm, at the 99% level, that the prices were cointegrated before our postulated break period. We could not, however, reject our null hypothesis of non-cointegration at the 90% level of significance after the postulated break period.

7.2.2.3 Robustness Check

We test the structural validity of our findings by carrying out a robustness check. The robustness check will follow the same recursive Engle-Granger procedure as explained in section 7.2, but we will alter certain parameters by switching from futures to spot prices. The spot and futures markets are highly linked, as discussed in section 3.3.1, and should therefore provide similar results. The results will give us an indication of the structural validity of our results.

We use the same recursive analysis as with futures, and again we conclude that we could not reject our null hypothesis at the 90% level of significance. However, using spot prices, the analysis suggests that the relationship ends in late April as opposed to the beginning of January.

To check if the assumptions for the Engle-Granger test are satisfied we run an ADF test for the whole sample set, on spot and differentiated prices. The assumptions for the Engle-Granger test are all satisfied. The spot price time series could not reject the null hypothesis at the 90% level of significance and the differenced time series were deemed stationary. All relevant tables can be found in section 10.1.4 of the appendix.

The lag in the ending of the relationship when applying spot prices can be explained by the fact that futures contracts react to short-term changes faster than spot prices. Spot prices are more influenced by current physical market conditions and less by future expectations (Reichsfeld & Roache, 2011). Due to this, we reason that there is a natural lag in the break date for spot prices. The fact that spot prices show the same results as futures prices adds strength to our results.

7.2.3 Return of the Relationship

We have already established that WTI and Brent were cointegrated before our postulated break date and that the relationship between the crudes was not significant at the 90% level after 2010. Now we are interested in examining if the long-term relationship between the two crudes has returned. As stated in our first hypothesis, we believe that the relationship was established again in early 2014. Again, we use the recursive Engle-Granger analysis to discover if the prices are in a cointegrated relationship. We first run the recursive analysis, before validating our findings with the Engle-Granger test.

7.2.3.1 Results from the Recursive Analysis

We hypothesized that WTI and Brent have moved back in a long-term relationship. To test this we perform the recursive analysis with the second step of the Engle-Granger test for futures prices, starting from September 2013. The results are illustrated in figure 9.

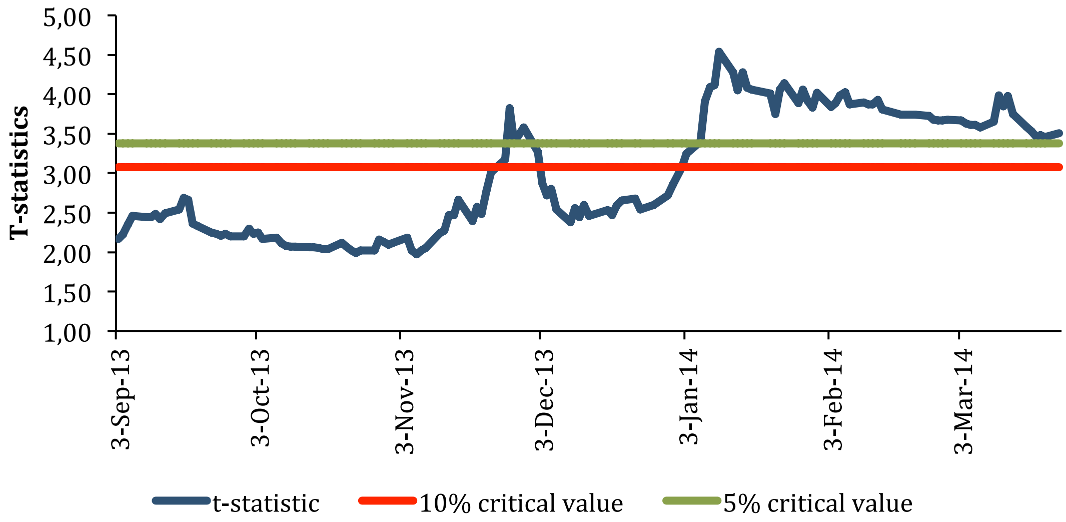

Figure 9 - Recursive Analysis 2013-2014

The test statistic for the Engle-Granger test is of a lower value than the 10% critical value at the start of our sample period, but becomes significant at both the 90% and 95% level for the first time around the start of December 2013. However, this is only a temporary occurrence, with the time series not being significant at the 90% level a few weeks later. The test statistics become significant again at the 95% level at the start of 2014 and stays significant throughout the sample period. This leads us to infer that a new cointegrated relationship has been formed between WTI and Brent around January 2014. Again we need to check if all Engle-Granger assumptions hold for the time period in question. The next section explores the properties of our findings.

7.2.3.2 Results from the Engle-Granger Test

Through the recursive analysis we found evidence for the prices to be in a new cointegrated relationship from 2014. We run the first and second step of the Engle-Granger test for the time period found in the recursive analysis to confirm that all assumptions hold.

The results from the ADF test are presented in table 8. Again we use the Akaike Information Criterion for optimal number of lags.

Table 8 – Augmented Dickey-Fuller Test

	2014	
Futures	**WTI**	**Brent**
Number of lags	4	2
Test statistic	0.476	1.462
Differentiated		
Number of lags	5	12
Test statistic	-5.099	-4.187
Critical values		
10 %	-2.573	
5 %	-2.883	
1 %	-3.476	

We can confirm that the sample-series for both WTI and Brent fulfill the Engle-Granger assumptions, with the price series of Brent's test statistic being 1.462 whereas the 10% critical value is –2.573. We therefore do not discard the null hypothesis of non-stationary at the 90% level. For the differentiated series, the test statistic is of a lower value than the 1% critical value. We can thus discard the null hypothesis and state that the differentiated time series are stationary at the 99% level of significance. We continue with the second step of the Engle-Granger test to support our results found in the recursive analysis.

Table 9 - Second Step Engle-Granger

Futures	2014 WTI Brent
Test statistic	-3.402
Critical Values	
10 %	-3.066
5 %	-3.367
1 %	-3.952

Table 9 presents the second step of the Engle-Granger test for our sample series where we find the relationship to be cointegrated at the 95% level of significance. When we set January 2014 as the start of our sample period we obtain a test statistic of –3.402, while the 5% critical value is –3.367. This supports our findings from the recursive analysis; the two prices are in a new, cointegrated relationship.

7.3 Spread Decomposition

After confirming that the spread's behavior has significantly altered the relationship, this section sets out to explain why the long-term relationship between WTI and Brent has ended. We hypothesized that supply conditions at Cushing depressed WTI prices and thus ended the relationship. We decompose the overall spread into time and commodity spreads to answer our hypothesis. As an extension, we examine if there has been spillover effects from the unusual behavior in the spread on other crudes.

By utilizing historical spot prices for LLS and WTS, as well as historical futures and spot prices for Brent and WTI, we can start to ascertain the reasons behind the price divergence. We decompose the historical futures spread for WTI and Brent as follows:

$$WTI_1 - Brent_1 = (WTI_1 - LLS_0) + (LLS_0 - Brent_0) - (Brent_1 - Brent_0) \qquad (8)$$

A subscript of one or zero denotes historical futures and spot prices respectively. These underlying commodity and time spreads can be used to determine whether the spread is reacting to demand or supply conditions on WTI or Brent. The decomposition will be further explained in the following sections.

7.3.1 The Landlocked Commodity Spread

The landlocked commodity spread, $(WTI_1 - LLS_0)$, captures the part of the spread attributable to short-term conditions at Cushing, such as the possible difficulties of transporting crude from Cushing to the Gulf Coast. It captures supply conditions for the North American market, as excess storage and transportation difficulties affect suppliers of WTI. This decomposition is based on the fact that LLS is of similar quality to WTI, but LLS is seaborne.

7.3.2 The Transatlantic Commodity Spread

The Transatlantic commodity spread, $(LLS_0 - Brent_0)$, captures the cost of shipping light sweet crude across the Atlantic. The spread captures demand conditions as a positive spread, signaling high transportation costs, leads to decreased demand for Brent. A positive WTI-Brent spread, above transportation costs, would signal that the import of Brent is profitable for U.S. refineries. The intuition is that the only difference between LLS and Brent should be transportation costs, as both crudes are seaborne and are of similar quality.

7.3.3 The Brent Nearby Time Spread

The Brent nearby time spread, $(Brent_1 - Brent_0)$, captures the immediacy of demand for Brent. A positive spread implies a positive future demand for Brent and thus increased prices above the cost of carry. This implies that the time spread is only going to have an impact when the forward curve does not reflect the cost of carry. The idea is that the nearby futures prices capture the immediate demand for Brent. If the nearby time spread increases, one should expect the price of Brent to increase relative to WTI in near future.

7.3.4 Factors Behind the Spread

The three abovementioned spreads can be used to break down the WTI-Brent spread to illustrate the ending of the long-term relationship. There are a plethora of reasons behind the movements in crude prices, and with the three decomposed spreads we start to examine these reasons in more detail. Figure 10 illustrates all three decomposed spreads, as well as the WTI-Brent spread for the entire sample period.

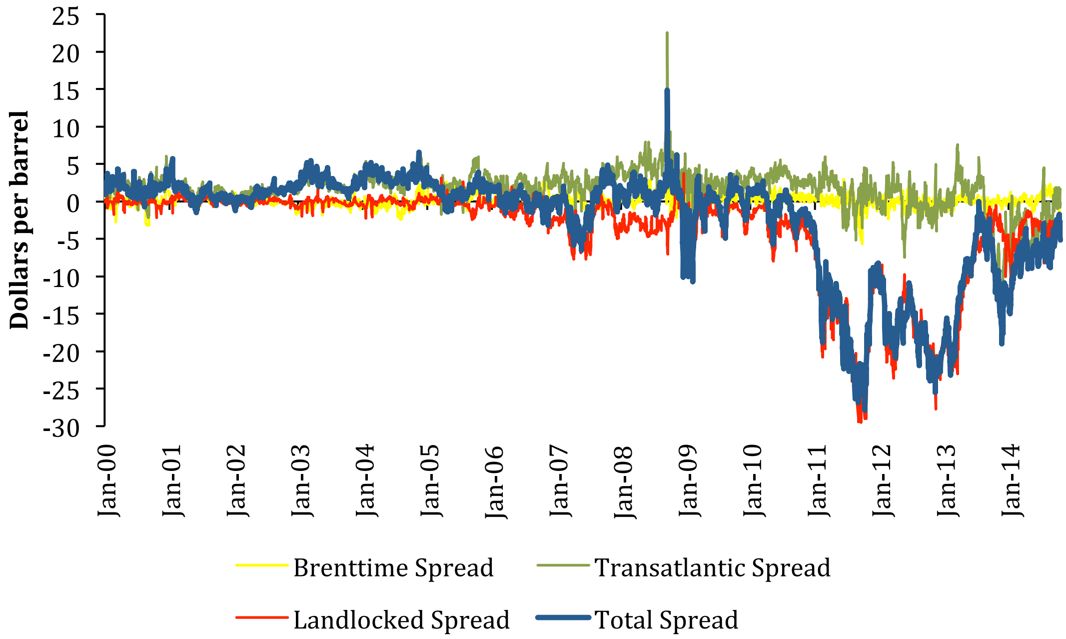

Figure 10 - Spread Decomposition 2000-2014

Prior to the financial crisis all spreads fluctuated around zero, with the first major spikes emerging around the time of the financial crisis. That major variations occurred during the financial crisis is not unexpected, as crude oil prices plummeted, with Brent being traded at a 60% discount during the crisis relative to pre-crisis levels (Bolton, 2014). However, the financial crisis is not a period of special interest to us, as it was a period with extreme volatility in commodity prices.

After the financial crisis, the first fluctuations in the spread decompositions appeared early 2010. Both the WTI-Brent spread and the landlocked commodity spread experienced adverse development from their previous movements. To further study the spread we depict the period following the financial crisis in figure 11.

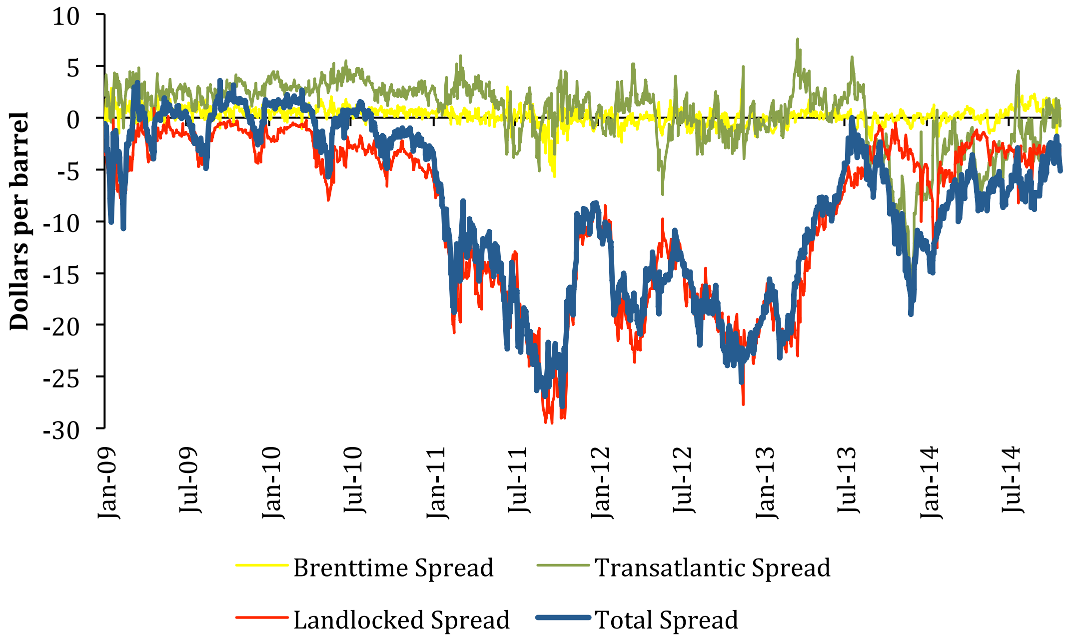

Figure 11 - Spread Decomposition 2010-2014

Depicting the time period after the financial crisis gives a clearer picture of the spread decompositions' divergence from previous trends. As noted, the WTI-Brent spread and the landlocked commodity spread are closely correlated. This could imply that the inability for crude to be sent out of Cushing has had a negative effect on the WTI-Brent spread. In late 2013 the transatlantic commodity spread fell around the same time as the landlocked commodity spread rose. This might explain why the spread continued its negative development before returning to more normal levels.

To further analyze the decomposed spreads, we examine summary statistics, presented in section 10.1.5 in the appendix. The mean of the WTI-Brent spread falls almost $12 per barrel in the period after 2010, indicating that some significant factor or factors have affected it.

One of these factors could be the landlocked commodity spread, with its mean decreasing $10 after the break in the relationship. The spread was negative, both prior to, and after the break. This could be due to pipeline issues at Cushing, depressing the WTI price as competition increased among suppliers, as shown in our theoretical analysis in section 6. In addition, LLS is a seaborne crude, and thus experienced no such constraints. The bottleneck could have distorted demand for WTI in favor other sweet crudes, increasing the price of LLS.

After the new relationship was established in 2014, the mean increases by $8, but still has a negative sign. As explained earlier, both storage capacity and pipeline infrastructure at Cushing were expanded, easing the pressure on Cushing's ability to shift oil out to the market. We believe this had an impact on the spread, as more crude could now be transported out to the U.S. market.

The transatlantic commodity spread also falls after 2010. Prior to the break there was a higher cost of transportation, as can be seen from the Baltic Dry Index in section 10.1.6 of the appendix. The intuition is that increased demand for shipping will lead transportation costs to rise. Consequently, all else equal, Brent as a seaborne crude faces higher transportation costs to foreign markets, leading refineries and other consumers of crude in the U.S. to prefer geographically closer crudes. The high transportation costs made LLS trade at a premium relative to Brent.

After the financial crisis, shipping costs were reduced and stayed low for the whole sample period. This implies a lower cost of transportation for Brent, making it a more viable crude for producers of finished petroleum products in the U.S. This could have extended the unusual spread between WTI and Brent. We see a further reduction in the transatlantic commodity spread after the new relationship is established. This would imply, all else equal, that the cost of shipping was further reduced, increasing the demand for Brent. The Baltic Dry Index has fallen throughout 2014, which supports this theory. But the fall in the transatlantic commodity spread is less significant than the increased landlocked commodity spread, indicating that the reduced pressure at Cushing had a greater effect than the reduced cost of shipping. This can be inferred from the values of the means, where the reduction in the transatlantic commodity spread is $6 lower than the increase in the landlocked commodity spread.

The Brent nearby time spread does not change sign or strength across the sub-samples. This is somewhat surprising, as factors such as the Arab Spring should have had an effect on Brent prices. However, demand for Brent has not changed significantly during the sample period, which leads us to surmise that there must be other factors that have kept the demand for Brent at a stable level. The fact that Brent has not experienced changes in demand strengthens the evidence for landlocked conditions and transportation costs being the major drivers behind the WTI-Brent spread.

We continue our analysis of the decomposed spreads by examining the correlations between the spread and decompositions, shown in table 10.

Table 10 - Spread Correlations

Spread	2000-2010	2010-2014	2014
Total Spread	1.000	1.000	1.000
Landlocked	0.647	0.911	0.498
Transatlantic	0.349	0.361	0.584
Brenttime	-0.118	0.217	0.116

The correlation between the WTI-Brent spread and the landlocked commodity spread is 0.911 between 2010 and 2014. While it is not sufficient to state that there is a causal relationship, the correlation coefficient does indicate that there is a strong relationship between them. We hypothesized that supply side issues stemming from pipeline infrastructure at Cushing has had a significant impact on the spread, and the correlation coefficient supports our theory. We know from previous literature, as explained in section 4, that the landlocked problems facing WTI were apparent before our postulated break, and this is supported by the correlation coefficient between 2000 and 2010. After the new relationship was established, the correlation coefficient decreases significantly. We surmise this to stem from the new pipelines out of Cushing that helped alleviate some of the pipeline pressure that was present between 2010 and 2014.

The correlation between the Brent nearby time spread and the WTI-Brent spread is positive both during and after the break, but decreases somewhat in value. We postulate this decrease to stem from a greater effect on WTI from global demand after the pipeline bottleneck in Cushing eased. In the period leading up to the break the correlation coefficient is negative. This stems from growing demand for crude in emerging markets, which had a large impact on Brent, as explained in section 5.1.3.

It is also apparent that the correlation coefficient for the transatlantic commodity spread increases after the revival of the spread relationship. A cause for this increase could be that after the capacity issues have subsided and the new relationship established, the relative effect of transportation costs increases, as the landlocked effects have been reduced. This implies that as more oil can be supplied from Cushing, other effects might have had a relatively larger impact on the spread.

7.3.5 The West Texas Crude Quality Spread

The West Texas crude quality spread, $(WTI_0 - WTS_0)$, is not a part of the spread itself. It is, however, included to examine if constraints in supply and demand that affect the WTI-Brent spread has had spillover effects on the prices of other crudes, like WTS. Both crudes are delivered at Cushing with WTI being priced at a premium due to its higher quality. This quality spread has historically been at an almost constant level.

From figure 12 we can infer that the quality spread is no longer at a constant differential. The increasing differential comes from the fact that lighter products are in higher demand than heavier products, and that not all refineries can handle the heavier crude, as explained in section 5.1.1. With the bottleneck in Cushing leading to increased competition amongst WTI suppliers and increased imports of other light crudes, it leads to a depreciation of the WTS price. As seen in the transatlantic commodity spread, the cost of carry by sea has fallen, which could, all else equal, increase import of light sweet crudes. In addition, refiners want to sell refined products from lighter crudes first as they can gain a premium compared to refined products from the lower quality WTS, which carry a higher refinery cost. All of these factors could have led to the further depreciation of the WTS price, with the WTI-WTS spread only returning to normal levels when supply conditions at Cushing have improved.

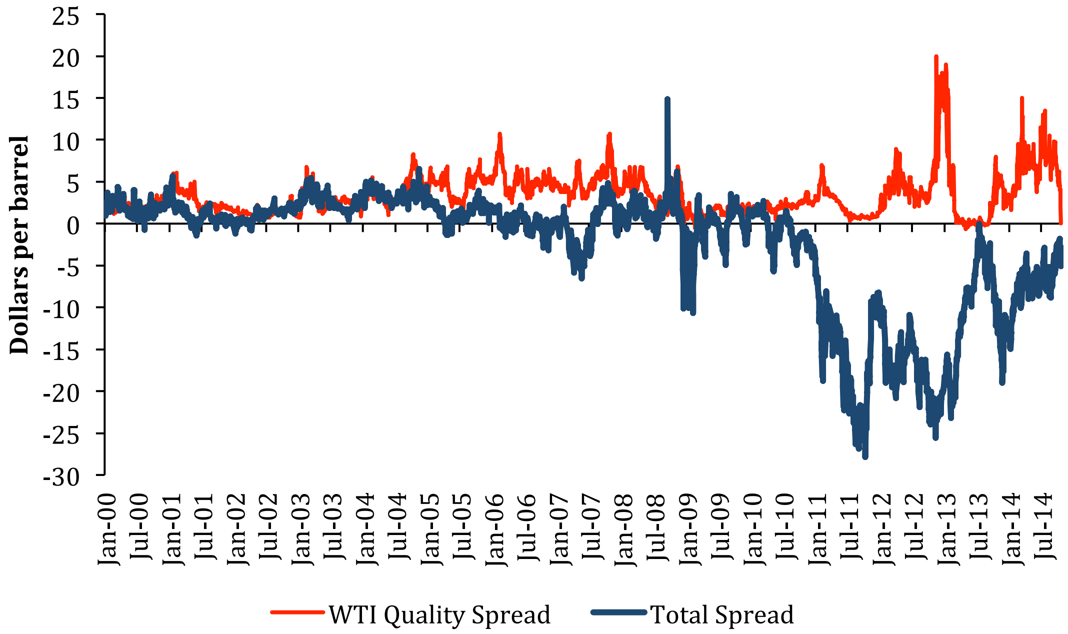

Figure 12 - Total and West Texas Crude Quality Spread

As more premium crudes are made available the lesser quality WTS is squeezed out of the market. The mean for the quality spread in the sample period from 2014 confirms this, with the spread increasing from $3.12 to $6.92 as seen in section 10.1.5 in the appendix. What is also interesting is that the volatility of the spread has increased between 2010 and 2014. This implies that after the ending of the long-term relationship between WTI and Brent, short-term changes in demand and supply affected the spread to a greater degree than before. The volatility decreases in 2014, signaling that the fluctuations in the WTI-WTS spread decreases as infrastructure issues are resolved and the volatility of the total spread is reduced.

From these findings we can deduce that there have been spillover effects related to the unusual behavior in the WTI-Brent spread. These spillover effects have increased the spread between WTI and WTS, which historically has been traded at a near constant rate.

7.4 Summing Up: Cointegration and Decomposition

We wished to examine if the long-term relationship between WTI and Brent had ended. Through a recursive analysis with the Engle-Granger two-step test for cointegration we could no longer reject our null hypothesis, at a 90% level of significance, at the start of 2010. This implies that the times series were not cointegrated from this period. Our robustness test on spot prices for the same sample period supported our initial findings.

We also examined if the spread had converged and were back in a new cointegrated relationship. Several factors, like pipeline expansions out of Cushing, pointed to this. By using the same recursive technique as when establishing the break, we could reject our null hypothesis at the 95% level of significance, and infer that the crudes had moved back into a cointegrated relationship at the beginning of January 2014.

We were interested in uncovering why the spread had diverged, and utilized the crudes LLS and WTS to decompose the spread into time and commodity spreads. We know from our stylized theoretical analysis in section 6 that a capacity constraint can have the effect of diverging crude prices. Our study of the decomposed spreads implied that this was the case, and that supply side factors at Cushing could have caused the spread's divergence. In addition, we also found evidence for the transatlantic commodity spread, a proxy for shipping costs, to have prolonged the divergence between the WTI and Brent.

7.5 Empirical Findings

In our cointegration analysis in section 7.2, we put forth evidence that the long-term relationship between WTI and Brent temporarily ended through the use of an Engle-Granger test. Now we extend our analysis to examine if there is statistical evidence for our physical and financial factors of interest to have impacted the WTI-Brent spread. We build an empirical model to test and quantify our findings from the spread decomposition.

7.5.1 Assumptions

Before we can perform an empirical analysis there are certain assumptions that must be in place. Our empirical model must fulfill the Gauss-Markov assumptions to produce the best linear unbiased estimators of the population parameters (Wooldridge, 2012). These assumptions are explained in detail in section 10.1.7 of the appendix. Due to our large sample data, from 2000 to mid-2014, we rely on the central limit theorem for our normality assumption. The central limit theorem states that the mean of a large number of independent random variables will be approximately normally distributed, regardless of the underlying distribution (Stock & Watson, 2012).

To correct for potential heteroskedasticity and autocorrelation in our sample data we use Newey-West standard errors, explained in section 10.1.8 of the appendix. The Newey-West standard errors are dependent on the number of lags chosen to correct for autocorrelation. We select 4 lags, as we are using weekly data and want to capture correlation within a month.

In section 7.2, we established that futures for WTI and Brent were non-stationary. It is therefore necessary to ascertain if the spread itself is also non-stationary, as non-stationary time series can produce spurious regression results (Woolridge, 2012). We use the ADF test described in section 7.2.1.1 to check for non-stationarity. We find the spread to be non-stationary, as seen in table 11. This implies that we can obtain spurious regression results.

However, if two non-stationary time-series are cointegrated, it is possible to run regressions on them without the fear of spurious results (Woolridge, 2012). We therefore run the Engle-Granger two-step test for cointegration, explained in section 7.2.1.1, on our independent variables of interest. Based on our hypotheses and earlier findings, our independent variables of interest are the landlocked commodity spread, the transatlantic commodity spread, the Brent nearby time spread and the open interest for WTI and Brent. The results are presented in table 11.

Table 11 – Augmented Dickey-Fuller and Engle-Granger Results

	ADF		Engle-granger
Variable	Lags	T-statistic	T-statistic
Spread	21	-1.502	N/A
Landlock	39	-1.859	-10.456
Transatlantic	23	-1.978	-4.998
Brenttime	10	-7.183	-2.699
Brent Open Interest	40	0.164	-9.626
WTI Open Interest	40	-1.44	-4.75

With the exception of the Brent nearby time spread, all variables are integrated order of one I(1). The Engle-Granger test is run with the spread as the corresponding variable, so that the Engle-Granger test statistic for the WTI-Brent spread is not applicable.

We find that our variables of interest are non-stationary and cointegrated with the spread. From the results we can infer that the Brent nearby time spread and the WTI-Brent spread is not cointegrated, and thus we include it in our model for control purposes only. The fact that our variables of interest are cointegrated with the spread allows us to run a regression on these variables without fear of spurious regression results. We wish to establish to what degree the independent variables of interest have had in the development of the spread, and therefore utilize a Chow test.

A Chow test is a test of whether the coefficients in two linear regressions on different data sets are equal. We test if our two sub-samples follow the same regression function, specifically if our variables of interest change after the relationship between WTI and Brent end in 2010. We test this by creating a dummy variable equal to one after the relationship ended. We then interact the dummy with all variables of interest. Formally our empirical model becomes:

$$\begin{aligned} Spread = \; & \beta_0 + \beta_1 landlock + \beta_2 transatlantic + \beta_3 Brentopeninterest \\ & + \beta_4 WTIopeninterest + \delta_0 \, break + \delta_1 (landlock * break) \\ & + \delta_2 (transatlantic * break) + \delta_3 (Brentopeninterest * break) \\ & + \delta_4 (WTIopeninterest * break) + \sum \beta_t control \; variables + u_t \end{aligned} \tag{9}$$

Where the variable break is the indicator variable for when the cointegrated relationship between WTI and Brent ended. All variables of interest are interacted with our dummy variable to capture the effects on the spread after the break. The corresponding null and alternative hypothesis is:

$$\begin{aligned} & H_0 \colon \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0 \\ & H_a \colon \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 \neq 0 \end{aligned} \tag{10}$$

If the null hypothesis is rejected, the interaction variables have significant explanatory power on the spread.

7.5.2 Regression Results

With the necessary assumptions fulfilled, we run a regression on our sample data to uncover if our variables of interest have had significant explanatory power on the WTI-Brent spread. We run regressions with and without the control variables. The results for our variables of interest are presented in table 12, while the full regression is presented in section 10.1.11 in the appendix. We do not interpret the coefficients on our control variables, as they are not of interest in answering our hypotheses. As can be seen from the table, the coefficients change in value and level of significance when we include our control variables, which imply that Model 1 has omitted variable bias. Consequently, we use the regression results from Model 2, where all variables are included, to test our hypotheses.

Table 12 - Regression Results

Variables	Model 1	Model 2
Landlock	0.839***	0.770***
	(0.0497)	(0.0624)
Landlock Interaction	0.127**	0.197***
	(0.0514)	(0.0686)
Transatlantic	0.742***	0.599***
	(0.0668)	(0.102)
Transatlantic Interaction	0.242***	0.362***
	(0.0725)	(0.110)
Brenttime	-0.0605***	-0.0605***
	(0.0216)	(0.0222)
Brent Open Interest	0.00144	0,00214
	(0.00156)	(0.00157)
Brent Open Interest Interaction	0.00387	0,00352
	(0.00329)	(0.00232)
WTI Open Interest	0,0019	0,00169
	(0.00118)	(0.00110)
WTI Open Interest Interaction	-0,00123	-0,000999
	(0.00162)	(0.00154)
Break Dummy	-1.078*	-1.340*
	(0.608)	(0.785)

Standard errors in parentheses *p < 0.10, ** p < 0.05, *** p < 0.01

We test whether the individual coefficients and the full set of interaction terms are significant by utilizing T- and F-tests, explained in section 10.1.9 of the appendix. To test if our null hypothesis holds and the same model applies, both before and after the break, we run a Chow test on the interaction terms, as explained in section 7.5.1. Formally we examine the following null hypothesis:

$$H_0: \text{Break} = (\text{Landlock} * \text{Break}) = (\text{Transatlantic} * \text{Break}) = (\text{Brent open interest} * \text{Break}) = (\text{WTI open interest} * \text{Break}) = 0 \quad (11)$$

$$H_A: \text{Break} = (\text{Landlock} * \text{Break}) = (\text{Transatlantic} * \text{Break}) = (\text{Brent open interest} * \text{Break}) = (\text{WTI open interest} * \text{Break}) \neq 0 \quad (12)$$

From the test we retrieve an F-statistic of 3.26 with a coherent P-value of 0.0064. Based on these results we can discard the null hypothesis and infer that the same model does not apply; i.e., the coefficients change significantly after the ending of the long-term relationship.

We are also interested in testing the coefficients on our variables and interaction terms individually. From the regression results we obtain and calculate their individual t-statistics and corresponding P-values. Table 13 presents the results.

Table 13 – T-statistics and P-values

Variables	t-statistic	P-value
Landlock	12.34	0
Landlock Interaction	2.88	0.004
Transatlantic	5.85	0
Transatlantic Interaction	3.3	0.001
Brent Open Interest	1.37	0.172
Brent Open Interest Interaction	1.18	0.129
WTI Open Interest	1.54	0.125
WTI Open Interest Interaction	-0.65	0.517

We find the coefficients for the landlocked and transatlantic commodity spreads to be significant at the 99% level, whereas the coefficient for WTI and Brent open interest are not significant at the 90% level. This implies that the variables for open interest do not have a statistically significant impact on the spread, whereas the landlocked and transatlantic commodity spreads do.

7.5.3 Analysis

We now establish what effects our independent variables of interest have had on the WTI-Brent spread. As WTI and Brent prices are denoted per barrel, our results have the same interpretation. All our relationships are on level-level form, implying that a one-unit increase in our independent variable changes the dependent variable equal to the coefficient, formally:

$$\Delta Spread = \beta_t \Delta x \tag{13}$$

Here, β_t is the coefficient on the independent variables of interest, denoted x. We will analyze the coefficients and interaction terms together. For example, the coefficient on transatlantic and the transatlantic interaction term will be discussed jointly.

The capacity issue at Cushing has been widely reviewed as the main cause of the divergence between the prices of WTI and Brent. In addition, our stylized theoretical analysis demonstrated how a capacity constraint causes prices to diverge. Our empirical model confirms this, with the coefficient for landlock being significant at the 99% level. The coefficient is positive with a corresponding value of 0.770, inferring that all else equal, an increase in the landlocked commodity spread of $1 increases the spread by $0.770. This implies that for our whole sample set, the effect of the landlocked commodity spread is large and significant. After the break in the long-term relationship, the impact of the landlocked commodity spread increases further. The coefficient on landlock's interaction term is 0.197 and significant at the 99% level, increasing the total effect of the pipeline capacity constraint after the break to $0.967, all else equal.

The results confirm what we hypothesized, that pipeline capacity issues at Cushing have had a significant impact on the spread, and increased in significance between 2010 and 2014.

A less discussed issue is the influence of the transatlantic commodity spread. With capacity issues hindering the supply of crude to nearby refineries, transportation costs can be a significant factor on the spread. Our empirical model confirms this, as the transatlantic coefficient has a positive sign with a value of 0.599, significant at the 99% level. This result indicates that a \$1 increase in the transatlantic commodity spread, all else equal, increases the spread by \$0.599. The result implies that throughout our sample period a change in transportation costs across the Atlantic converts either into reduced Brent prices or increased WTI prices. The interaction term for the transatlantic commodity spread is also significant. By adding the coefficients, we find that a \$1 dollar increase in the transatlantic spread, all else equal, translates to an increase of \$0.961.

It is apparent from our results that the transportation costs across the Atlantic has had a significant impact on the spread. Low transportation costs increases demand for Brent as refineries and other consumers find it profitable to import it. It is also apparent that the transportation costs has had an increased significance on the spread after the ending of the relationship. The coefficient increased by \$0.362, signaling that changes in the cost of transportation had a larger impact on the spread after the break. As transportation costs were lower after the break, illustrated by the Baltic Dry Index in section 10.1.6 in the appendix, we can infer that the demand for Brent increased. This result sheds light on that not only infrastructure issues at Cushing has had an effect on decoupling WTI and Brent prices. Low transportation costs across the Atlantic could have lessened the pressure on expanding the infrastructure out of Cushing, and thus extended the period of the spread's unusual behavior.

From the results we can infer that both supply and demand, represented by the landlocked and transatlantic commodity spread, has had a significant effect on the spread, decoupling WTI from world prices. However, the effect of the landlocked commodity spread can be further studied. As mentioned in section 3.1.1.2, surging crude prices spurred the transformation of oil technology. Consequently, unconventional oil became economically viable. Imported shale oil from Canada and the surge of tight oil production in North Dakota increased pressure on Cushing's infrastructure. Therefore, one can advocate that the supply shock came as a consequence of high crude oil prices, caused by a prolonged period of high demand for crude.

We also hypothesized that even though we are dealing with the most traded commodities in the world, the amount of futures trading has not had an effect on the fundamental relationship between WTI and Brent. We tested this hypothesis by including the open interest of Brent and WTI in the regression. Even though the futures markets has a significant impact on WTI spot prices and the fact that Brent futures are the most traded commodity in the world, our regression results infer that neither the open interest for Brent nor WTI have a statistically significant impact on the spread throughout our sample period.

With the results from our empirical analysis we conclude that our hypotheses, outlined in section 2, could not be rejected. We hypothesized that supply conditions at Cushing has had a significant effect on the spread between WTI and Brent, which our empirical findings could not reject. In addition, our empirical results showed that transportations costs across the Atlantic had a significant impact on the spread, extending the divergence between the crudes. We also confirmed that even though the two crudes are the most traded commodities on the market, the volume of futures trading has not had an impact on the spread's divergence.

After controlling for many of the factors that can influence the prices of WTI and Brent, we can infer that a lack of pipeline infrastructure at Cushing, combined with transportation costs, is significant in explaining the divergence of the two crude oil prices between 2010 and 2014.

7.6 Limitations

In this section we highlight some of the limitations in our data and method. It is important to be aware of the limitations in our research; both for the convenience of the reader, but also for those who wish to extend our analysis.

7.6.1 Method

For our analysis of the long-term relationship we utilized the Engle-Granger two-step test for cointegration, combined with a recursive analysis. Although the Engle-

Granger test is adept at examining whether two variables are cointegrated, other tests such as a Chow test for structural breaks might be more fitting to pinpoint break dates. The Chow test searches for known break dates in a singular time series, whereas the Engle-Granger tests for cointegration between two or more time series. However, as the Chow test only searches for known break dates and our main focus was to examine whether the two crudes were in a long-term relationship, we decided that the Engle-Granger two-step test for cointegration was a more relevant statistical tool.

As pointed out by Oglend, Lindbäck & Osmundsen (2013), the test statistic in time series analysis can be sensitive to the number of lags used. The Newey-West standard errors are also sensitive to this, and thus results might be biased depending on the number of lags chosen. To find the optimal number of lags in the ADF test we employed the Akaike Information Criteria. Although it is the most suited selection method according to Stock and Watson (2012), Verbeek (2008) points out that there is no formal consensus on which method to utilize. As various methods can give different lag lengths, the choice of selection method might have implications for the results.

George Box (1979) wrote, “Essentially all models are wrong, but some are useful”. What he wanted to point out was that no model is in essence correct, but simplifications of the real world. Despite their weaknesses, econometric models can be useful in guiding the user to understand the mechanisms that affect the dependent variable. Even though our model does not capture all effects, it will give the reader an insight into what has affected the spread.

7.6.2 Data

There are a significant number of factors that affect crude oil prices. To study all these factors and their implications on the WTI-Brent spread would require a far more extensive dataset, surpassing the range of our work. Furthermore, our empirical results are based on weekly, public data. If we had access to non-disclosed data our analysis and research would have been more robust.

In our data sample, variables for Saudi Arabian production of crude and total OPEC spare capacity are included. However, we have only managed to account for monthly production and spare capacity data, having to interpolate the data in order to use them in our regression. This implies that we might incur measurement errors, although none of the variables are volatile.

Unlike earlier research, we are not able to exclude Saudi Arabian spare capacity from total OPEC spare capacity. The OPEC spare capacity is only publicly available in aggregated form and we can therefore not isolate Saudi Arabian spare capacity from that of OPEC. Büyüksahin et al. (2012) argue that the clearest indication of a significant change in the world energy fundamentals is reflected in the OPEC spare capacity, excluding Saudi Arabia. Furthermore, they argue that Saudi Arabian spare capacity is theoretical at best, and that the crude oil is not of the same quality as Brent and WTI. This means that a refinery cannot easily switch between the crudes in the short run. However, in spite of these factors, we believe the OPEC spare capacity is a variable that should be included and controlled for as it has implications on the price of Brent.

Another potential limitation in our data is the proxy for real economic activity. We are dependent on the Baltic Dry Index to pick up the wanted effects from global demand, but there is a certain fear that the index reflects information that is distinctive to the shipping market. Especially supply side factors in the shipping market can weaken the direct link between freight rates and real economic activity. However, several papers use the index to account for economic activity (see e.g. Sørensen, 2009; Bakshi, Panayotov & Skoulakis, 2011; Fan and Xu, 2011), and contrary to some conventional measures of activity, freight rates will account for effects from large economies, such as China and India, where data is difficult to obtain.

We are not able to control for BFOE crude production, as the data available only dates back to mid-2007. Before this, the aggregated production numbers for the benchmark are uncertain, as the BFOE benchmark did not exist in its present form. Because the production volume from Ekofisk is not available before 2007, the production numbers for the Brent benchmark will be artificially low. Due to this uncertainty we decided not to include this variable and is thus a limitation. In addition, the variable ADS, a variable for U.S. economic activity, is only available on a daily basis. To account for this we averaged every week, which may give some measurement errors.

Our variables on the Arab Spring and hurricane activity are dummy variables and equal to one when active. Although dummy variables are easy to interpret, we might lose some of the variation in our sample data.

7.7 Implications

This section explores some of the more important implications of our findings from the unusual behavior in the WTI-Brent spread.

The fact that infrastructure problems at Cushing led WTI to disconnect from Brent and other light sweet crudes, have implications for the non-arbitrage theory presented by Fattouh (2009), and the relationship between WTI and Brent presented in his research. Although we did not empirically test his theory, our findings suggest that the model should be extended to account for infrastructure issues at Cushing, in addition to the cost of carry for Brent and the quality discount, to fulfill the non-arbitrage condition. This has implications for arbitrageurs in the commodity market as well. In addition to the usual arbitrage conditions, they need to anticipate changes in the pipeline infrastructure at Cushing to profit from fundamental arbitrage trading between WTI and Brent.

The same infrastructure problems at Cushing led WTI to disconnect from other light sweet crudes and distillate product prices, creating historically high margins for refineries utilizing it. The implication of WTI’s divergence from other crudes can be seen in the refineries’ crack spread, an approximation of its yield. Figure 13 depicts the 3:2:1 crack spread for WTI, Brent and LLS. The 3:2:1 crack spread reflects a refinery’s revenue and cost, and therefore its profit. The intuition is that 3 barrels of crude will yield roughly 2 units of gasoil and 1 unit of diesel fuel.

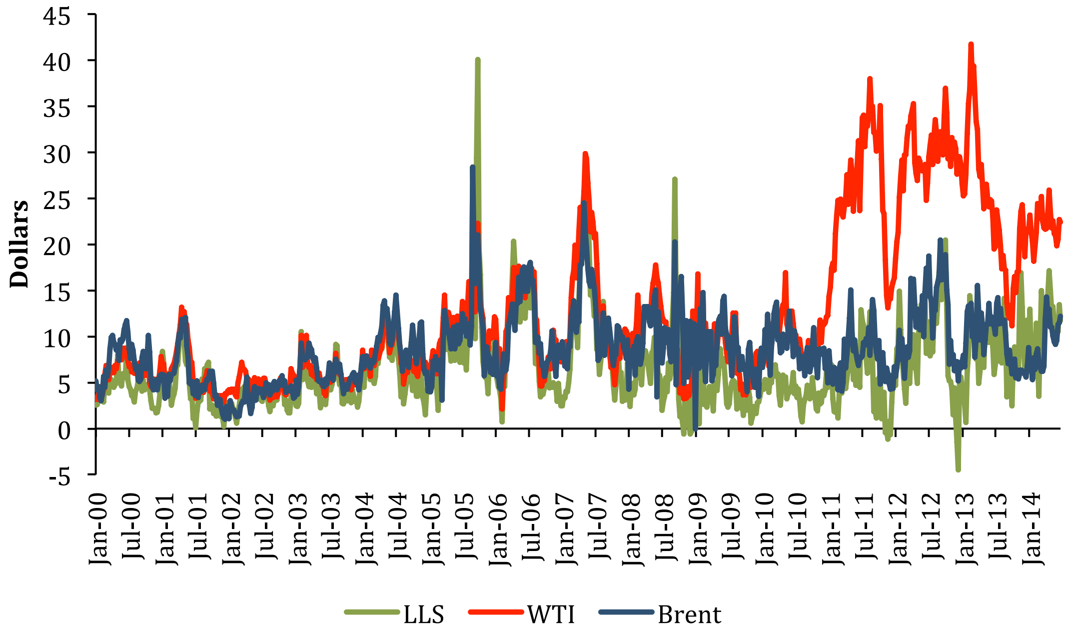

Figure 13 – 3:2:1 Crack Spreads for WTI, Brent and LLS (Bloomberg L.P., 2014b)

The crack spreads move in tandem in the period between 2000 and 2010, before the cointegrated relationship between WTI and Brent ended. As a direct consequence of the decreased WTI prices, the corresponding WTI crack spread decouples from Brent and LLS in 2010, with refineries utilizing WTI experiencing a prolonged period of abnormal margins.

The decoupling has also had implications for the end users of distillate products. U.S. airlines have historically used crude oil contracts on WTI to hedge against a price increase in jet fuels. The price divergence between WTI and jet fuel prices caused several airlines to lose millions in fuel hedging ineffectiveness, as they no longer were insulated from rising fuel costs. As a consequence, some U.S. airlines switched from derivatives on WTI to derivatives linked to Brent and LLS for their jet fuel hedging.

Due to its decoupling from light sweet crudes, the WTI benchmark faces losing its market position in the global crude market, as it may no longer be the most suitable benchmark for hedging global risk, domestic risk or both. Persistent infrastructure issues at Cushing, the fact that it only captures U.S. domestic conditions, and that an increasing amount of unconventional oil in North America is priced relative to LLS points in this direction. As a result, LLS is quickly becoming a benchmark of significance in the U.S. market and, unless pipeline issues are completely resolved, might replace WTI as a leading benchmark in North America.

8. Conclusion

In this thesis we have analyzed the relationship between WTI and Brent since 2000. For a prolonged period of time Brent traded at a premium to WTI, despite being of slightly lower quality. It is this unusual spread between the crudes that was the essence of our research.

To confirm whether the relationship between WTI and Brent had ended we utilized an Engle-Granger two-step test for cointegration. From the test results, we found that we could no longer surmise that the two crudes were in a cointegrated relationship, at the 90% level of significance, in early 2010.

We also tested whether the crude prices were in a new relationship, and found evidence for this at the beginning of 2014, being able to reject our null hypothesis at the 95% level of significance. New infrastructure came online and eased pressure at Cushing, increasing the flow of WTI to the market. However, in the new relationship, Brent trades at a premium to WTI as long as pipeline constraints in Cushing are apparent.

After finding that the crudes were no longer in a cointegrated relationship, we decomposed the spread to examine what might have caused the spread's unusual behavior. We decomposed the WTI-Brent spread into three components, a landlocked commodity spread that captures local supply conditions at Cushing, a transatlantic commodity spread that captures transportation costs across the Atlantic and a Brent nearby time spread that captures the immediate demand for Brent. Descriptive statistics on the components indicated that supply factors in Cushing, combined with transportation costs, caused the unusual behavior between 2010 and 2014. In addition, we examined the West Texas quality spread, and found it to fluctuate in the same period. We accrued this fluctuation to result from tightness in the North American oil market, which increased demand for lighter crudes and consequently depressed the price of the low quality WTS.

After decomposing the spread, we built an empirical model to test the validity of our findings and quantify the individual effects on the WTI-Brent spread. Our results supported the findings from the spread decomposition, with supply side factors in Cushing and fluctuations in transportation costs across the Atlantic having a significant effect on the spread. In addition, we tested whether open interest had an effect on the spread. Our empirical model, however, could find little evidence for this.

In accordance with previous research, we found that the divergence of the WTI-Brent spread can be accrued to Cushing's lack of infrastructure. Cushing experienced an increasing inflow of crude due to the increased unconventional oil production in North America. Production across the continent soared to record highs, incentivizing an infrastructure expansion to move this new oil to Cushing, but with little possibility of shifting the oil out.

What our research also uncovered was that transportation costs across the Atlantic have impacted and extended the price divergence between WTI and Brent. This has, to our knowledge, not been identified in earlier research. Transportation costs fell in the period after the financial crisis, making Brent a more viable crude to export to international markets. Decreasing transportation costs from 2010 could have decreased the pressure on pipeline expansion out of Cushing, as Brent was an economically viable alternative.

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10. Appendix

10.1.1 U.S Production and Import

Figure 14 illustrates the U.S. production of unconventional oil from the Bakken Field in North Dakota and imported crude oil from Canada to Cushing.

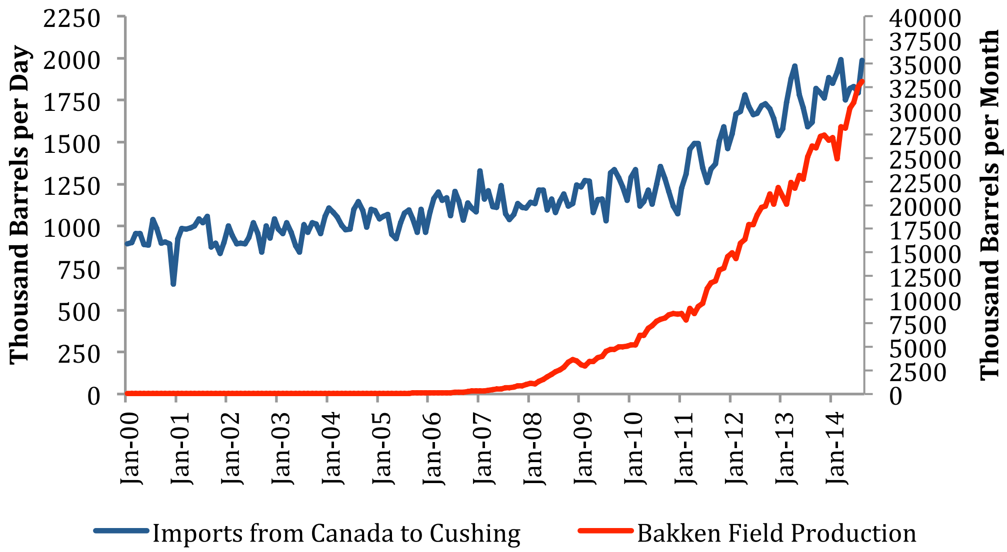

Figure 14 - U.S. Production and Import from Canada

10.1.2 Relationship Between OPEC and Brent

Figure 15 is a graphical presentation of the inverse relationship between the OPEC spare capacity and Brent crude prices.

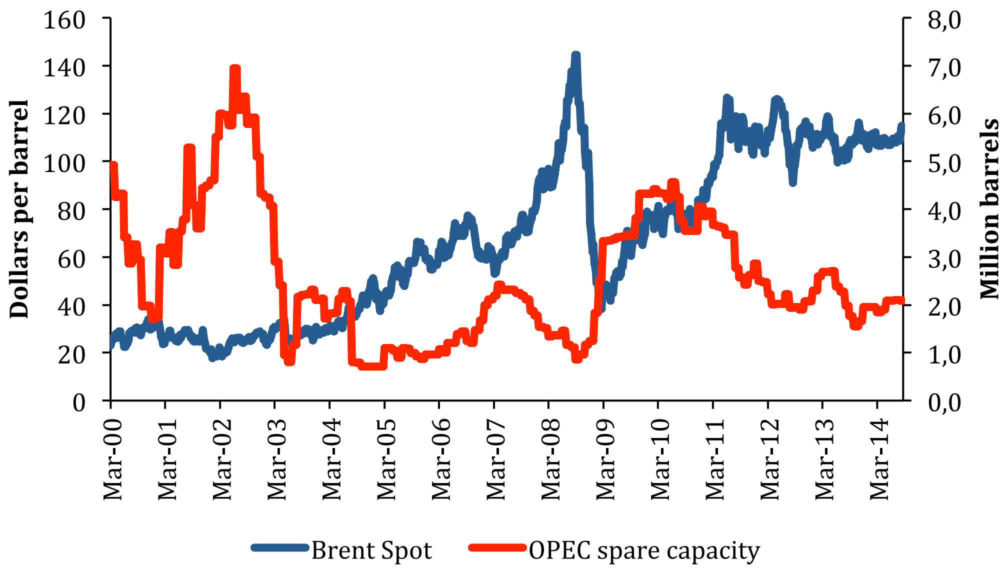

Figure 15 - Brent Spot and OPEC Spare Capacity

10.1.3 The Akaike Information Criterion

The Akaike Information Criterion (AIC) offers a choice of the number of lags one should include in a model. It deals with the goodness of fit of the model, the complexity, and the trade-off between the two. The AIC formula is:

$$AIC(p) = ln\left[\frac{SSR(p)}{T}\right] + (p+1)\frac{2}{T} \tag{14}$$

Where *SSR(P)* is the sum of squared residuals of the estimated AR*(p)*.

10.1.4 Robustness Test

10.1.4.1 Augmented Dickey-Fuller for Spot Prices

Table 14 shows the results from the robustness check on spot prices.

Table 14 - Augmented Dickey-Fuller Test Results

	Spot 2000-2014	
	WTI	**Brent**
Number of lags	6	2
Test statistic	-1.686	-1.488
Differentiated		
Number of lags	5	1
Test statistic	-25.417	-43.668
Critical values		
10%	-2.57	
5%	-2.86	
1%	-3.43	

10.1.4.2 Recursive Analysis for Spot Prices

Figure 16 shows the result from the recursive analysis on spot prices in the robustness check.

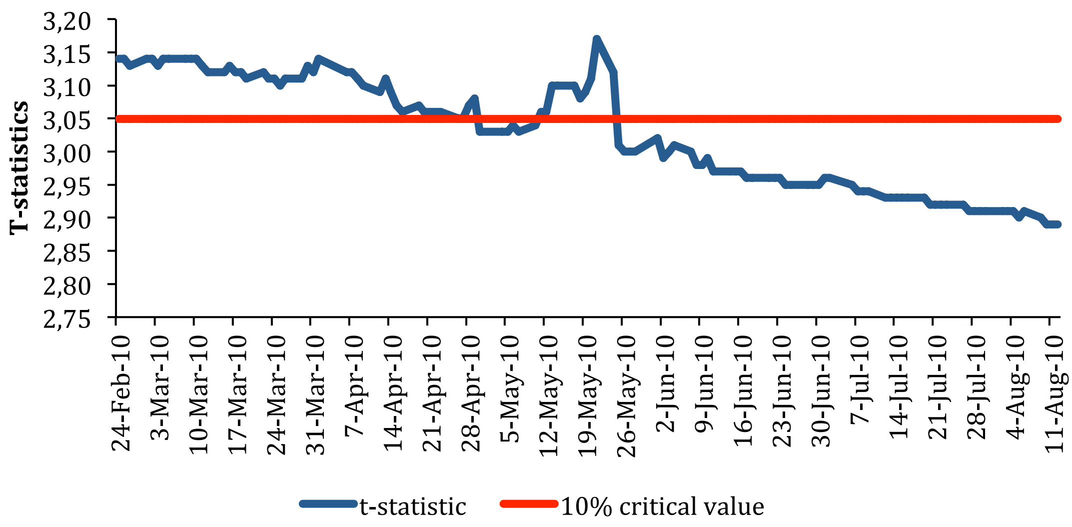

Figure 16 - Recursive Analysis for Spot Prices

10.1.5 Descriptive Statistics of the Spread Decomposition

Tables 15 to 17 are descriptive statistics for the spread decomposition presented in section 7.3.

Table 15 - Descriptive Statistics 2000-2010

Spread	Observations	Mean	Volatility
Spread	2460	1.19	1.91
Landlock	2460	-1.01	1.68
Transatlantic	2460	2.46	1.54
Brenttime	2460	0.28	1.52
WTI-Quality	2460	3.34	1.81

Table 16 - Descriptive Statistics 2010-2014

Spread	Observations	Mean	Volatility
Spread	987	-11.29	7.92
Landlock	987	-11.88	7.73
Transatlantic	987	0.63	3.33
Brenttime	987	0.05	1.72
WTI-Quality	987	3.12	3.17

Table 17 - Descriptive Statistics 2014

Spread	Observations	Mean	Volatility
Spread	197	-6.79	2.26
Landlocked	197	-3.89	2.02
Transatlantic	197	-2.48	2.39
Brenttime	197	0.37	1.19
WTI-Quality	197	6.92	2.3

10.1.6 The Baltic Dry Index

The Baltic Dry Index is issued daily by the Baltic Exchange. It is not restricted to the Baltic Sea and its surrounding countries, but provides an assessment of the price of moving the major raw materials by sea (The Baltic Exchange, 2014). Figure 17 illustrates the index between 2000 and 2014.

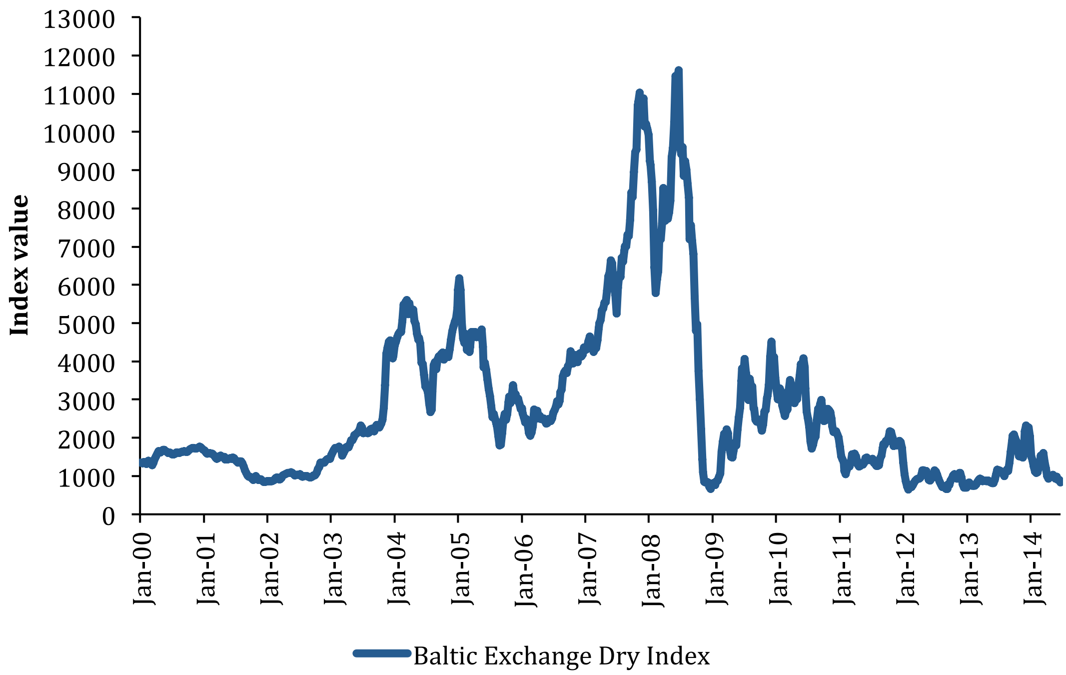

Figure 17 - The Baltic Dry Index

10.1.7 Ordinary Least Squares

Time-series data comes with temporal ordering, is not a random sample of units, and is almost always correlated over time. Due to these factors the assumptions for crosssectional assumptions must be altered. The Gauss-Markov assumptions for time-series data are:

1. The population is linear in parameters
2. There is no existence of perfect collinearity
3. Zero conditional mean
4. Homoscedasticity in the error term
5. No serial correlation
6. Normality

Assumption 1: The population is linear in parameters

It is assumed that there is a linear relationship between the dependent and independent variables, with a simple model shown as:

$$y_t = \beta_0 + \beta_1 x_{t1} + u_t \quad (15)$$

Where *t* is used to index time.

-u: error term, represents factors other than *x* that affect *y*.

-β_0: the population constant term/intercept

-β_1: population slope parameter

Assumption 2: There is no existence of perfect collinearity

This implies that each x_{tj}varies somewhat over time, and no explanatory variable is an exact linear function of the others. This rules out perfect correlation.

Assumption 3: Zero conditional mean

It is assumed that contemporaneous exogeneity holds, that is for every *t*,

$$E(u_t|x_{t1}, \dots x_{tk}) = E(u_t) = 0 \quad (16)$$

This allows for lagged dependent and explanatory variables that react to past changes in the dependent variable.

Assumption 4: Homoscedasticity

For all *t*,

$$Var(u_t|\boldsymbol{x_t}) = \sigma^2 \tag{17}$$

This is the contemporaneous form of the homoscedastic assumption.

Assumption 5: No serial correlation

The contemporaneous assumption is stated as,

$$Corr(u_t, u_s|\boldsymbol{x_t}, \boldsymbol{x_s}) = 0 \tag{18}$$

Assumption 6: Normality

$[u_t]$ is independent of the explanatory variables, x**,** and is independent and identically distributed as:

$$u_t \sim Normal(0, \sigma^2), t = 1,2, \dots n \tag{19}$$

10.1.8 Newey-West Standard Errors:

The Newey-West standard error corrects the estimated standard errors from Ordinary Least Squares by making them robust to autocorrelation and heteroskedasticity. One drawback is that Ordinary Least Squares is not efficient; there exists an unbiased linear estimator with a lower variance. However, if the fear of autocorrelation is apparent, Newey-West is an accepted way of ridding oneself of this problem.

$$Newey - West\ s.e = \sqrt{\sum_{t=1}^{T} \sum_{t'=t-L}^{t+L} \frac{x_t x_{t'}}{(\sum_{s=1}^{T} x_s^2)} g e_t e_{t'}} \tag{20}$$

10.1.9 Testing Coefficients

10.1.9.1 Testing One Coefficient

We test the coefficient on the independent variable to understand whether it has a significant effect on our dependent variable.

The null hypothesis is that the coefficient does not have a significant effect:

$H_0 = 0$ (21)

Our alternative hypothesis is based on whether we believe that our coefficient is larger/lesser than nil, or that it varies from nil.

One sided test: $H_a > or < 0$ (22)
Two sided test: $H_a \neq 0$

We chose a level of significance α, usually 5%, which gives us our Type 1 error.

Our test parameter is: $t = \frac{(\widehat{\beta_J} - B_j)}{se\ (\widehat{\beta_J})}$ where B_j is our null hypothesis.

10.1.9.2 Testing Multiple Coefficients

Here we test whether a group of variables has no effect on the dependent variable. We also test for joint significance, i.e. that the variables in combination give a significant effect on the dependent variable, even though they separately may not have any effect.

We operate with two models, one restricted and one unrestricted. The unrestricted model includes all our variables, while the restricted do not include the variables we want to test. The model, given that H_0 is true, is the restricted model.

The F-test is based on the idea of comparing SSR_{UR} and SSR_R. If the unrestricted model is "sufficiently lower" than the restricted model, we should reject our null hypothesis.

The test parameter is:

$F = \frac{(SSR_r - SSR_{UR})/q}{SSR_{UR}/(n-k-1)}$, or if we only have the R^2: $F = \frac{(R_{UR}^2 - R_R^2)/q}{(1-R_{UR}^2)/(n-k-1)}$

Where q is the number of exclusion restrictions and k is the number of parameters in the unrestricted model.

10.1.10 Open Interest for WTI and Brent

Figure 18 is a graphical illustration of the open interest for WTI and Brent.

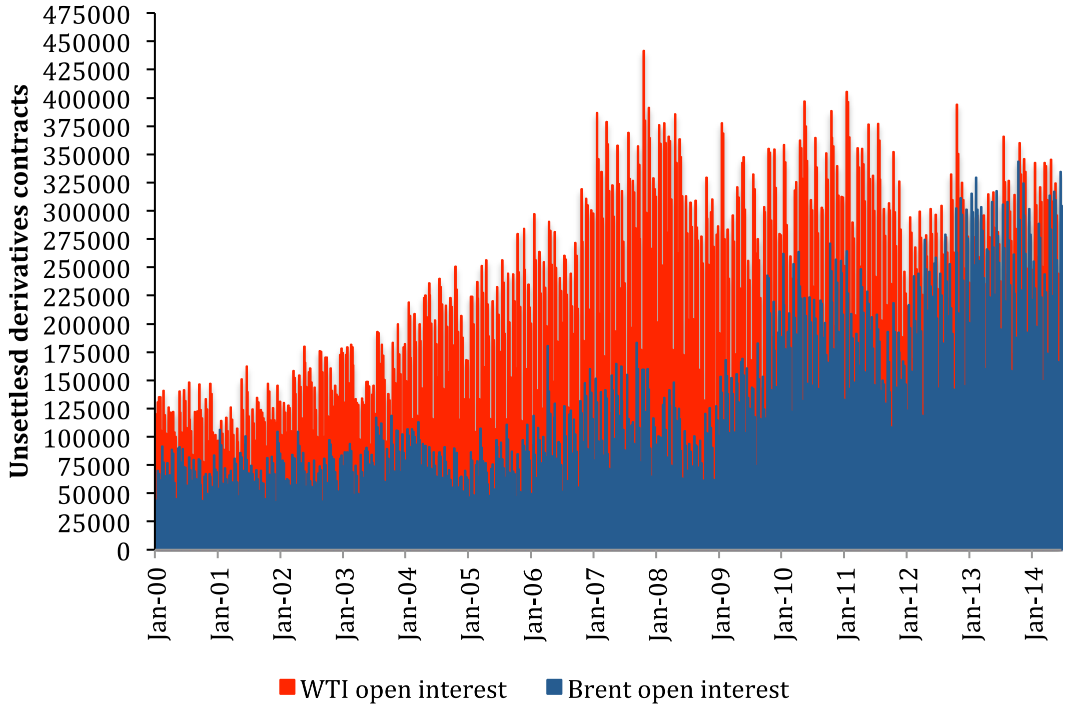

Figure 18 - Open Interest for WTI and Brent

10.1.11 Regression Results

Table 18 shows the regression results from our empirical model.

Table 18 - Regression Results

Variables	Model 1	Model 2
Intersect	0.297**	3.454
	(0.136)	(2.407)
Time	-0.00122**	-0.00228
	(0.000621)	(0.00156)
Landlock	0.839***	0.770***
	(0.0497)	(0.0624)
Landlock Interaction	0.127**	0.197***
	(0.0514)	(0.0686)

Transatlantic	0.742***	0.599***
	(0.0668)	(0.102)
Transatlantic Interaction	0.242***	0.362***
	(0.0725)	(0.110)
Brenttime	-0.0605***	-0.0605***
	(0.0216)	(0.0222)
Brent Open Interest	0.00144	0.00214
	(0.00156)	(0.00157)
Brent Open Interest Interaction	0.00387	0.00352
	(0.00429)	(0.00232)
WTI Open Interest	0.0019	0.00169
	(0.00118)	(0.00110)
WTI Open Interest Interaction	-0.00123	-0.000999
	(0.00162)	(0.00154)
Break Dummy	-1.078*	-1.340*
	(0.608)	(0.785)
Saudi Arabia Production	-	-0.00159
		(0.00217)
OPEC Spare Capacity	-	-0.162*
		(0.0890)
U.S. Rigcount	-	-0.000134
		(0.00141)
U.S. Rigcount Intersect	-	0.00113
		(0.00148)
Baltic Dry Exchange	-	0.000131**
		(0.0000528)
TED-Spread	-	0.00339*
		(0.00177)
NYSE	-	-0.000194**

		(0.0000844)
ADS	-	0.348**
		(0.150)
USD/EUR	-	0.0825
		(1.065)
Arab Spring Dummy	-	-0.311
		(0.684)
Hurricane Dummy	-	0.123
		(0.215)
N	755	755

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$