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# Understanding the Factors Behind Crude Oil Price Changes

## A Time-varying Model Approach

Master's thesis

Trondheim, June 2010

Norwegian University of Science and Technology
Social Science and Technology Management
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# MASTER THESIS

**for**

**STUD.TECHN TORE MALO ØDEGÅRD AND MATS OLIMB**

| | |
|---|---|
| **Field of study** | **Financial Engineering**<br>Investering, finans og økonomistyring |
| **Start date** | 15.01.2010 |
| **Title** | **Understanding the factors behind crude oil price changes**<br>Underliggende faktorer bak bevegelser i oljeprisen |
| **Purpose** | Oil price movements have been a subject of discussion for centuries. In recent years, economists and policy makers have shown increasing concerns regarding speculation and extreme oil price movements. In this thesis we indentify and evaluate main factors behind oil price changes. |

**Main contents:**

1. Description of main factors behind oil price movements
2. Develop an empirical model for oil price changes to study developments over time and their significance.

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Deputy Head of Department

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# DECLARATION

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I hereby declare that I have written the above mentioned

thesis without any kind of illegal assistance.

TRONDHEIM
Place

Date

Signature

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# Preface

This master thesis was written at the Norwegian University of Science and Technology (NTNU), department of Industrial Economics and Technology Management, during the spring of 2010. The thesis is written within the field of Financial Engineering. The idea behind the thesis stems from the Project thesis written in the autumn of 2009 (Olimb & Ødegård, 2010), and ideas and thoughts of Jussi Keppo at the University of Michigan.

We would like to thank our supervisor, professor Stein-Erik Fleten (NTNU) for constructive feedback and contributing with guidelines on academic writing. We are also grateful to Johan Magne Sollie (NTNU) for guidance on the econometric framework and methods. Finally, we would like to express our gratitude to Torbjørn Kjus (DnB NOR Markets) for providing us with useful data and insights on the crude oil market.

**Trondheim, June 4th 2010.**

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Tore Malo Ødegård

# Abstract

This thesis investigates the underlying factors behind the crude oil price changes, using a time-varying approach for the period from 1995 to 2009. The analysis is an extension of previous studies of oil market determinants, and is to our knowledge the only time-varying analysis for a broader set of explanatory variables. By allowing the parameter coefficients to vary over time, we are able to identify and describe structural changes in the crude oil market during the time period studied. Our analysis suggests that the crude oil market participants have been more focused on expectations, and draw less attention to fundamental factors, during the time period examined. We do not find that the positions of financial investors by itself cause changes in the crude oil price significantly. However, we show that the entry of new market participants have influenced changes in the process of crude oil price setting, which has become more similar to the process in financial markets. The time-varying analysis also reveals that changes in world economic activity have a particularly strong relationship with crude oil price changes during economic recessions. We find that OPEC has been an important factor in recent years, not in virtue of being a price setter, but by the organization's diminishing ability to operate as swing producer. Lack of OPEC spare capacity in the recent years caused large imbalances in the world crude oil market, as OPEC historically has represented the only major buffer on the supply side.

# Table of contents

# List of figures



# List of tables

# 1. Introduction

The purpose of this thesis is to analyze factors affecting change in the crude oil price over the period from 1995 to 2009. We apply a time-varying model to analyze how significant factors vary over time; that is, how the different underlying explanatory factors' relationship with crude oil prices behave stochastically.

Crude oil prices have been the source of discussion over the past decades. The cyclical nature of the market in times of under- and overinvestment has made it challenging for countries, industrial companies and investors to deal with the risks involved. It is believed that high oil prices can slow economic growth, cause inflationary pressures and create global imbalances. Volatile prices can also increase insecurity and discourage essential investments in the oil sector. Recent high oil prices and tight market conditions have also raised fears about oil scarcity and concerns about energy security in many oil-importing countries.

An in-depth analysis of the underlying factors can be useful to anyone dependent on or interested in investing in the crude oil market. The empirical evidence may help to improve understanding of the behavior of the underlying factors and the market dynamics. Analysis of time-varying coefficients will not only identify which factors are significant over the time period studied, but also which factors that have relatively fixed behavior and those that behave differently through different periods of an economic cycle.

## 1.1 Crude oil market characteristics

Crude oil prices should priced much like any other exhaustible commodity (Hotelling, 1931), yet there is a common belief that oil and energy prices behave differently and are more volatile than other commodities (Fleming & Ostdiek, 1999). Some observers also argue that the crude oil market has undergone structural transformations that have changed the influence of underlying factors and placed the oil price on a new path. One special point concerning price formation in the crude oil market is the Organization of the Petroleum Exporting Countries (OPEC), which operates as a cartel with the largest production capacity. Crude oil price cycles are common and may extend over several years responding to changes in demand as well as OPEC and non-OPEC supply. The underlying factors' influence on price movements will vary during the cycle depending on the position in the cycle, pace and future expectations. As an example, the pricing power of OPEC is not straightforward. The pricing power varies over time and is induced by market conditions and can be seen in both weak and tight markets (Fattouh, 2007a).

A point made by Fattouh (2007a) is with the growing importance of the futures market in the process of price discovery; it has become more difficult for producers and especially OPEC to follow set output policies. This point might be especially important as the last years have seen a strong growth in the commodity derivatives markets. The total value of the investment in commodity indexes has increased from about 15 billion in 2003 to above 200 billion US Dollars by mid-2008 (US Senate, 2009). During this period, financial institutions have heavily marketed commodity indexes as a way to diversify portfolios, and profit from rising commodity prices. About 70 percent of the commodity index investments are invested in near-term energy contracts, following a strategy of continuously rolling futures contracts to maintain the investment (Hamilton, 2008).

## 1.2 Related studies on the crude oil market

Three main approaches have been used for analyzing oil prices. First, non-structural models rely on the theory of exhaustible resources as the basis for understanding the oil market. Second a structural supply/demand framework uses behavioral equations and factors that link oil demand and supply to its various determinants. Finally, an informal approach can be studied by analyzing oil price movements within specific contexts and episodes of oil market history (Fattouh, 2007a). In this thesis we will utilize a structural framework when analyzing underlying factors behind oil price changes, and we will also seek to identify structural changes through a time-varying framework. We go through the literature of structural studies on price determinants in an econometric framework.

Kaufmann et al. have performed several econometric analyses of oil prices. In their first paper (Kaufmann R. , Dèes, Karadeloglou, & Sanchez, 2004) a linear regression model is studied to investigate OPEC's ability to influence real oil prices. Three coefficients; OPEC capacity utilization, quotas and the degree to which production exceeds these quotas are studied along with OECD stocks of crude oil, and are all found to be significant. They also show that the direction of causality generally runs from the explanatory variables to real oil prices. We will utilize the same three OPEC variables as supply variables to analyze OPEC's influence on oil prices, and also investigate the direction of causality.

Kaufmann et al. (2008) expands their previous models for crude oil prices to include refinery utilization rates, OPEC capacity utilization and contango level as explanatory variables to explain the rapid rise in crude price between 2004 and 2006. They conclude that most of the increase can be explained by concerns about future oil market conditions, represented by the future market moving from backwardation to contango. In our time-varying model we will investigate the significance of three future market variables to study this further.

Möbert (2007) replicates the OPEC model defined by Kaufmann et al. (2004) and finds that the parameters are not stable after the market turmoil seen after September 11 2001. The analysis is extended with the previous data continued to 2006. He specifies an econometric model based on a larger set of covariates, including supply and demand variables as well as futures market variables. The findings show that these variables might be better when explaining recent price movements. Current price movements are shown to be a result of scarce refinery capacity and speculators betting on higher prices. Möbert's findings support our suspicion that underlying factors are not stable during longer economic cycles. It also supports our choice of investigating a larger econometric model.

Tham (2008) is to our knowledge the only paper studying time-varying factors behind the oil price. A set of four explanatory variables are used to explain price movements, including contango/backwardation level, refinery utilization, days of stock cover and non-commercial long ratio, for the time period from 1995:5 to 2008:2. Results indicate an increasing sensitivity of the oil price to speculation since 2004. All explanatory variables show increasing explanatory power. The time period analyzed only includes one business cycle and ends close to the level where crude oil prices peaked in July 2008. Including the recent market downturn and a larger set of covariates should give us a better understanding of the dynamics in the crude oil market.

Hamilton (2008) examines factors responsible for recent changes in crude oil prices, and especially what produced the high price in the summer of 2008. The factors are not implemented in a model but discussed to get a broader understanding. Factors include commodity price speculation, strong world demand, time delays or geological limitations on increasing production, OPEC monopoly pricing, and an increasingly important contribution of the scarcity rent[1]. One conclusion is that rather to think of the individual factors as competing hypotheses when explaining recent price movements, such as the soaring prices in 2008; one possibility is that there is an element of explanation to a broader set.

## 1.3 Focus and factors

We identify and study the significant underlying factors in a state-space framework. The thesis examines the dynamics, structural breaks and the fluctuations of the underlying factors in the crude oil market. We extend the research of Möbert, Tham and Hamilton by examining demand, supply, OPEC's influence, financial factors and price speculation simultaneously for their impact on crude oil price changes in a state-space model during the time period from 1995 to 2009.

[1] The marginal opportunity cost imposed on future generations by extracting one more unit of a resource today. Scarcity rent is the cost of depleting a finite resource because benefits of the extracted resource are unavailable to future generations.

Two contributions are made to the literature. First, we expand the time-varying model set out by Tham (2008) to include a broader set of explanatory factors and the recent financial crisis. Second, we show that no single market factor can exclusively explain crude oil price changes in any of the months studied. Our results indicate that rather looking towards one cause of longer-term oil price movements there might be an explanatory effect to a broader set simultaneously.

Our model identifies eight significant factors when explaining crude oil price changes for the time period. One factor for demand; changes in world economic growth, three factors for the supply side; changes in rig utilization, days of stock cover and refinery utilization and two factors for the financial markets; changes in contango level and non-commercial open interest long ratio, are found to be significant. Finally we also found significant effects on two OPEC factors; changes in OPEC spare production capacity and production quotas.

The time-varying parameters show that crude oil price changes have become more sensitive to world economic activity during time periods of economic recessions and by future expectations to crude oil demand after 2005. Supply fundamentals in the upstream sector and spare production capacity represented by OPEC have increased their influence in the tight market conditions seen before the financial crisis. However, the other supply fundamentals have low explanatory power, especially in the time period after 2005. The futures market position has also become less important through the time period, indicating a loosening in the relationship between weak and tight supply fundamentals and the changes in crude oil price. This is also shown by the diminishing relationship between crude oil price changes and refinery utilization rates.

# 2. The Crude oil market

## 2.1 Demand

Oil prices are linked, like those of other commodities, to the level of economic activity in the industrialized countries. Demand, both from consumers and the industrial sector, increases with economic and population growth, and slow down when economic growth rates decline. The demand for oil is also affected by factors such as the exchange rate, depending on the country being a net importer or exporter of crude oil, and the rate of industrialization in developing countries.

Oil importing countries, such as the US, will increase their oil demand as a result of economic growth. In oil exporting countries it is likely that an expansion in the oil sector has led to growth in GDP, as has been the case for countries like Russia and Saudi Arabia. In these countries, high oil prices based on rising oil demand create an inflow of oil derived revenue, increasing economic growth. If oil prices stabilize at too high levels, economic growth in importing nations might decline, causing a decline in demand and prices of oil (Priog, 2005). High prices will also lead to increases in exploration and development budgets leading to new oil discoveries and increased supply which over time will cause prices to decline. High prices can also make alternative fuels more competitive; potentially reducing the demand for oil.

The United States has historically been the single biggest consumer of crude oil, consuming 22.5 percent of the world output in 2008 (BP, 2009), but consumption has shown a flat or downward development since 2005. Recent growth in world oil consumption has come from non-OECD countries, and especially China and Saudi Arabia (BP, 2009), which also display the highest economic growth.

## 2.2 Supply

The petroleum industry is divided into three sectors; the upstream, midstream and downstream sector. The upstream sector consists of the exploration and production (E&P) business. An important indicator of the activity level within the E&P sector is the oil companies' capital investment budgets. Many economists have blamed underinvestment in the sector on the tight market and price increases in the period from 2005 to 2008 (Fattouh & Mabro, 2006). The budget numbers are however complicated to use in an econometric analysis since budgets are built on other factors like complexity level (of a field development) and cost inflation within the sector, in addition to the current activity level. The E&P sector is considered to be the bottleneck in the industry, and the most important since it determines the supply of crude oil which affects prices in the downstream sector. Bottlenecks become evident in tight market conditions, which is hard to measure directly in the upstream sector. We will use rig utilization rates as an indicator of the market conditions. Rigs represent the biggest investment cost in well development. In 2008, 37 percent of the total well cost is estimated to be on rigs (Douglas & Westwood, 2009).

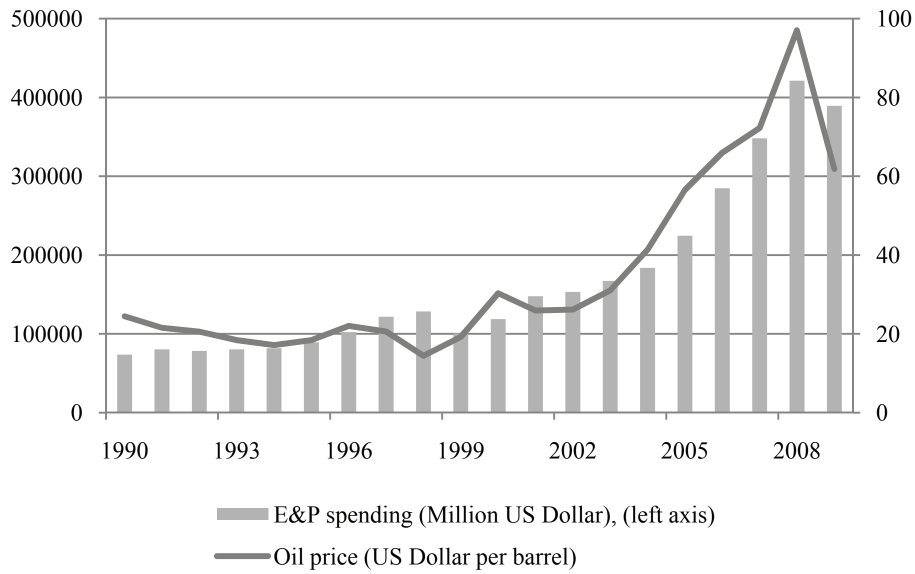


**Figure 1: Exploration and production spending**
*The figure shows the Global Exploration and Production capital investment spending by the oil companies and the yearly average crude oil price from 1990 to 2009.*

The midstream sector is primarily concerned with transportation of oil and gas from the extraction site to the refineries. Crude oil is either transported in pipelines or on tankers from offshore drilling sites. Transporting raw oil is a technical process, especially for pipeline transportation, but because of the large volumes, unit price per barrel is small compared to other parts of the value chain.

The downstream sector refers to the refining of crude oil and distribution and selling of petroleum products. Refining capacity, especially regarding distilling heavy crude to light crude, has been a topic of discussion in the recent years. The operable refinery capacity in the US has not increased since 1980. In all, the annual average refining capacity in the US was 17.6 million barrels per day in 2008 (IEA, 2009), while the annual consumption was 19.4 million barrels per day the same year. Refining of crude oil might work as a bottleneck in the industry when petroleum stocks are low and refinery utilization is high.

### 2.2.1 OPEC

The Organization of Petroleum Exporting Countries (OPEC) is a cartel of twelve countries. The purpose of the organization is to pursue ways and means of ensuring the stabilization of processes in international oil markets and safeguarding the interest of its members. In 2008 OPEC contributed to 45 percent of the world's crude oil production and held 76 percent of the total reserves (BP, 2009). Since the 1973 oil price shock, the history and behavior of OPEC has received considerable attention both in the academic literature and in the media. Conflicting academic and empirical interpretations about the influence of OPEC on the world oil markets have been proposed. OPEC is a swing producer and "sets production quotas based on its assessment of the market's call on its supply. Oil prices fluctuate in part according to how well OPEC performs this calculation. Through the process of adjusting its production quotas, OPEC can only hope to influence price movements towards a target level or target zone. In a supply-demand framework, the oil price is determined by OPEC and non-OPEC supplies as well as oil arriving to the market from OPEC members who do not abide by the assigned quotas" (Fattouh, 2007b).

## 2.3 Volatility

Oil prices are determined by market fundamentals and are affected by business cycles, which causes natural volatility in prices. However, since the oil crisis in 1973 the oil price has been considered to be more volatile than other commodities (Fleming & Ostdiek, 1999). The non-renewable and scarce nature of oil might be reasons for strong fluctuations in the crude oil market. Price spikes have historically been affected by sudden supply disruptions from wars, terrorist attacks and hurricanes. Rapid downturns in economic growth will distort future expectations on demand, which historically have caused large fluctuations in the oil price.

## 2.4 Futures market and speculators

Crude oil is the most actively traded commodity in the world. In 2008 almost 550 million barrels were on average daily traded on the NYMEX futures exchange alone, while the daily consumption was 84 million barrels (BP, 2009). The last decade has seen a considerable growth in the commodity derivatives market. Many economists have started to look at the increased volume of non-commercial traders (often referred to as speculators) to explain rapid and "unexplainable" movements in oil prices. There is however ambiguous research showing whether futures prices affect spot prices, or if it is in fact the other way around (Kesicki, 2009). The only way speculation can persistently influence oil prices is due to accumulation of the physical commodity. Futures prices above spot prices that lead to expectations of higher prices in the future can influence oil producers to sell oil later. Withholding oil from the market, thus diminishing supply, can substantially affect prices.

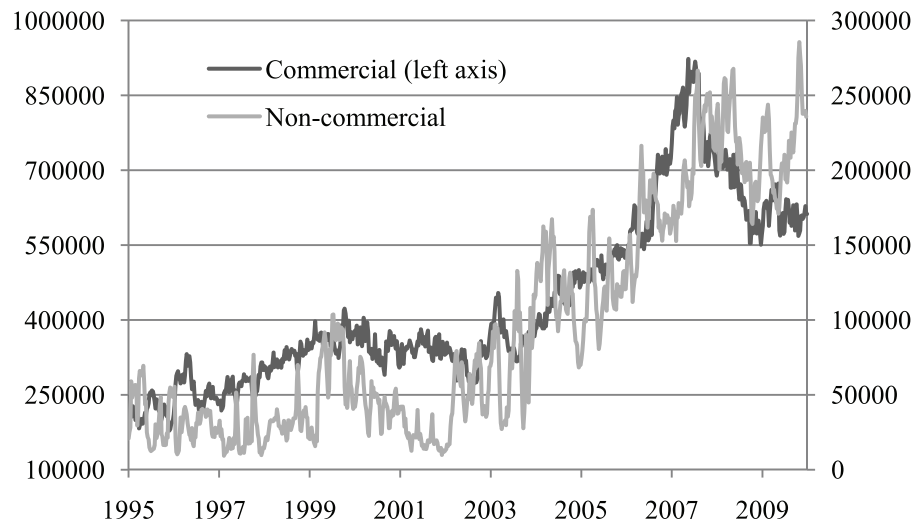


**Figure 2: Open interest**

*The figure shows the number of outstanding contracts (open interest) for all crude oil contracts traded on NYMEX. The commercial open interest is displayed on the left axis and the non-commercial open interest on the right axis. Each contract is for 1000 barrels of oil.*

## 2.5 Market factors

### 2.5.1 Demand

Unlike Möbert (2007) we will not use direct data for demand to avoid problems with simultaneity. We use the two same proxies for demand as Kaufmann (2005); gross domestic product and exchange rates. In contrast to Kaufmann (2005) we do not estimate demand equations for ten main economies, but use world economic growth and exchange rate index for the US Dollar to obtain a proxy for the global crude oil demand.

***World economic growth***

The scale and the activity level of the economy is an essential factor that affects crude oil demand. Industrialized countries have a higher demand for crude oil, while developing countries represent the biggest growth in crude oil demand. We expect economic growth to have a significant positive relationship with crude oil price changes.

***Exchange rate***

US Dollar is the currency of choice in global crude oil trade while consumers use local currencies to buy petroleum products. When the US Dollar depreciates against other currencies, countries with non-dollar appreciating currencies enjoy cheap oil, while consumers in US Dollar-pegged countries pay a higher price for the same barrel of oil. Changes in the US Dollar will therefore affect world oil demand. Depreciation (appreciation) of the US Dollar versus other currencies will decrease (increase) the cost of buying a dollar and hence also a barrel of oil. This will increase (decrease) the demand for crude oil, in other currencies than the US Dollar, and also the price. We therefore expect a negative relationship between the US Dollar exchange rate and the crude oil price changes.

### 2.5.2 Supply

The supply variables investigated are similar to Kaufmann et al. (2008), Möbert (2007) and Tham (2008), with the exception of tanker charter rates, which is included to investigate the effect any possible bottlenecks in the midstream sector might have on the crude oil price.

***Rig utilization***

To investigate the relationship between activity levels in the upstream sector, the number of active rigs utilized is used as a proxy. There is an extensive time lag (5-10 years) between exploration drilling and production, but the utilization of rigs is a good indicator of the activity level in the upstream sector and on the future expected oil supply. The relationship between the number of active rigs and the crude oil price is ambiguous. High drilling activity is a sign of increased production and supply, and should in the long-term have a negative relationship with crude oil prices. On the other side, drilling activity is also dependent on the ease of financing for oil companies and the economic activity. Drilling is capital intensive and will depend on the companies' current and expected future cash flows, which again is affected by the oil prices and economic activity. New rigs also require a lot of resources which again will have a positive impact on oil prices. We expect a positive relationship between rig utilization and crude oil price changes.

***Crude tanker charter rates***

Tanker charter rates are dependent on demand and fleet size in the tanker shipping market. The relationship between charter rates and crude oil prices is expected to be positive, but not significant since transportation costs are only a small part of total per barrel cost. Therefore, we do not expect that these factors influence the oil supply noticeably. It is more reasonable to believe that the supply bottleneck is in the upstream- or downstream sector. However, we choose to include this variable in the analysis before reaching any conclusion, and charter rates are depicted as the best indicator on the midstream sector.

***Refinery Utilization***

Refinery utilization rates affect crude oil prices based on the ability of refineries to convert crude oil to final products. High refinery utilization rates can be taken as a sign of shortages in the supply of petroleum products. This will increase prices on petroleum products, such as gasoline, and again increase crude oil prices. From theory the relationship can also be negative. High utilization rates might indicate that too much petroleum products are flowing into the market, causing prices to decrease. We therefore expect that utilization rates have both a positive and negative relationship with crude oil prices during the time period studied.

***Crude oil Stocks (Days of stock cover)***

Stocks are held as a buffer against disruptions in the supply and demand balance. Changes in crude oil stocks can influence prices in two ways. If a nation starts drawing on its crude oil stocks, it is a sign of higher domestic demand or lower domestic production or imports. It is also expected that they will replace this stock draw by e.g. buying crude oil in the market. Hence, the effect is expected to be negative.

During some periods the relationship might also be positive. If stocks are being strategically filled, to meet higher expected demand, it increases the demand for crude oil in the market and prices might rise. If futures prices are trading above the spot price, and above the cost-of-carry model[2], producers and investors might be tempted to store some of their oil and sell it in the futures market, causing prices to increase further as some supply is held back. Therefore we expect crude stocks to influence oil price both negatively and positively.

### 2.5.3 OPEC

We specify the same set of OPEC variables as Kaufmann et al. (2004) and later by Möbert (2007). The hypotheses are also in line those outlined by Kaufmann et al. (2004) and Möbert (2007).

***OPEC spare production capacity***

OPEC spare production capacity is expected to have a negative effect on oil prices. OPEC is the dominant producer in the world and the only producing entity with significant spare capacity. Being the biggest buffer on the supply side, demand shocks or temporary non-availability of non-OPEC production capacities, increase the risk of global supply shortages (Möbert, 2007).

***OPEC production quotas***

OPEC is organized with a mission to ensure the stabilization of oil markets and adjust their production quotas accordingly. If oil prices are at insufficient levels quotas are adjusted. We expect oil prices to have a negative relationship with OPEC production quotas. As OPEC increases the production quotas, more crude oil will flow into the market, creating a greater supply and decrease prices.

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[2] The cost-of-carry model is a representation of the link between spot prices and futures prices. A more detailed description of the model is given in Appendix A.5.

***OPEC cheat on production quotas***

The OPEC member countries will always have an incentive to sell more oil than agreed among OPEC members. Each country gains at the expense of the other OPEC members, since selling larger amounts of crude oil reduces the market price and harms the other OPEC members. We expect OPEC cheat to have a negative relationship with crude oil prices as more oil is supplied to the market than the communicated quotas set by OPEC.

### 2.5.4 Futures Market

Like Kaufmann et al. (2008), Möbert (2007) and Tham (2008) we investigate the futures market positions as an explanatory variable. To gain some more insight on the futures markets role in the process of price setting we study long minus short positions held by non-commercials like Möbert (2007) and the non-commercial long open interest like Tham (2008).

***Futures market position (Contango level)***

The slope of the crude oil forward curve is in theory determined by fundamental factors such as interest rates, convenience yield and storage costs. A tight crude oil market is associated with a weakening in contango or stronger backwardation and a weakening in the market is associated with market movements towards contango. Contango markets coincide with high and rising stock levels in a weak market, as demand/supply balance is too weak to push spot prices above futures prices. This concept is connected to the cost of carry model which is explained in more detail in the Appendix A.5. When inventories are high, the expected scarcity of the commodity today is low compared to some future time, that is; the convenience yield is low. Otherwise there would be no benefit to holding the inventory, and the market should be in contango. The same reasoning holds when inventories are low, which suggest that the scarcity now is greater than in the future and the convenience yield is higher than the interest rate. The market is now in backwardation and consumers prefer to have the product sooner than later. Contango level is measured as the spread between the futures contract with longer maturity and the futures contract closest to delivery. We will study two relationships between crude oil prices and the futures market position.

First, we inspect the relationship between changes in the contango level and the changes in oil prices. We expect a negative relationship between changes in the contango level and oil prices since a weakening in market fundamentals is associated with a weaker backwardation or stronger contango. This is also explained by the nature of the data since we expect price movements to occur in the closest to delivery contract first and the contract to be more volatile than the futures contract with longer maturity. This will create a negative relationship between change in crude oil prices and change in the contango level, since the futures contract with the longest maturity will display less fluctuation as the spread between the two contracts will display opposing signs compared to changes in the crude oil price. Second, we study the relationship between crude oil price changes, and whether the futures market is in contango or backwardation. As explained above we expect spot prices to decline in market contango and increase in backwardation, hence a negative relationship.

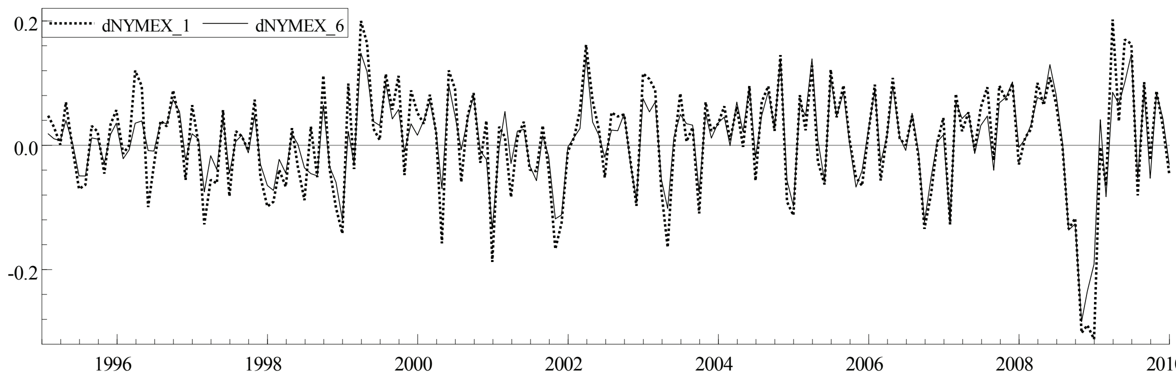


**Figure 3: Changes in NYMEX futures contracts**
*The figure shows monthly changes in prices for NYMEX traded WTI crude oil futures contract with one month (1-pos) and six months (6-pos) to maturity as the dotted and solid line respectively. The first month contract displays larger fluctuations than the six month contract.*

***Non-commercial long ratio***

The enhanced activity in the crude oil futures market has led to the suspicion that financial investors might influence the crude oil price. Demand for futures contracts can only come from two sources: Physical commodity consumers and speculators (Masters, 2008). Non-commercial[3] positions are used as a proxy for speculative activity in a commodity. We anticipate that the increased activity by non-hedgers have put an upward pressure on prices and expect that non-commercial long ratio has a positive relationship with crude oil price changes.

***Net positions non-commercials (Net length)***

Future expectations to movements in the oil price can be realized by financial investors via the futures market. These expectations are among others expressed in net non-commercial length in the future market. In theory, if investors were risk neutral and equally informed, we would not expect change in volumes and positions on the buy or short side to have an effect on the price. In a risk neutral world there should be an unlimited potential volume of investors willing to take the other side of any bets if the purchases were to result in prices above or below market fundamentals. In a real market with differing information and opinions along with risk-averse investors the picture is different. An investor might read

[3] The US Commodity Futures Trading Commission (CFTC) classifies a trader as non-commercial if the trader uses the futures contracts in a particular commodity for other purposes than hedging (CFTC, 2010).

the other investor's willingness to buy a large volume of contracts as a possible signal that they know something she does not. Financial micro-structure theory (Dufour & Engle, 2000) predicts that a large volume of purchases (sells) may well cause the price to increase (decrease), at least temporarily, until the investor can verify the fundamentals.

We will investigate two relationships between net positions and crude oil prices. First we study the relationship between changes in net positions versus changes in the crude oil price. We expect that changes in net positions will affect oil prices positively, since an increased number of long positions will increase demand for crude oil. Second we inspect the relationship between oil price changes and the actual net position held by non-commercial traders each month. We expect that when the market is net long this will put an upward pressure on prices. Hence, we expect a positive relationship between net positions and crude prices.

## 2.6 Summary of hypotheses

Table 1 summarizes all variables, variable names, their meaning, and expected signs of corresponding coefficients discussed in this section. The discussion of hypotheses for the different variables show that it is difficult to draw conclusions based on their signs and values. This is the first justification of the state-space approach where we can identify how they behave differently over time due to the general condition in the economy.

**Table 1: Summary of hypotheses**[4]

| Category | Variable | Description | Sign |
|---|---|---|---|
| *Demand* | | | |
| D | dD_wgrowth | Change in world economic growth | + |
| | dD_exch$ | Change in the real effective exchange rate | - |
| *Supply* | | | |
| S | dS_stock | Change in days of stock cover (OECD) | +/- |
| | dS_rigu | Change in world rig utilization excl. Jack-ups Gulf of Mexico | + |
| | dS_rigu_GoM | Change in rig utilization Jack-ups Gulf of Mexico | + |
| | dS_vlcc | Change in world Tanker charter rates | (+) |
| | dS_refu | Change in refinery utilization | +/- |
| OPEC | dOPEC_sparecap | Change in OPEC spare capacity level | - |
| | dOPEC_quota | Change in OPEC production quotas | - |
| | dOPEC_cheat | Change in OPEC cheat on production quoats | - |
| *Futures Market Variables* | | | |
| F | F_cont(level) | Market Contango/Backwardation level | - |
| | dF_cont | Change in market Contango/Backwardation level | - |
| | dF_oi | Change in non-commercial long ratio | + |
| | F_netl(level) | Net length for non-commercial positions | + |
| | dF_netl | Change in net length for non-commercial positions | + |
| *Dummy Variables (Special events)* | | | |
| D | Dumm_event(+) | Dummy for positive events affecting demand and negative for supply, such as hurricanes. | + |
| | Dumm_event(-) | Dummy for negative events affecting demand and positive for supply, such as terrorist attacks and financial crisis. | - |

*The table lists all variables, notation and description used to describe crude oil prices, as well as their hypothetical impact. Signs in parentheses are variables not expected to be significant during the whole time period (as explained above). dSrigu_GoM is described in the Data description in the next section..*

[4] The reason for utilizing transformed data series is argued in section 3.2.

# 3. Data

## 3.1 Data description

We collect monthly or monthly average data for each of the factors outlined in the previous section for the time period from January 1995 to December 2009. The choice of sample period is determined by economic considerations and data constraints. The data are collected from various sources and transformed to give the most efficient and correct picture to each of the hypothesis. Figure 4 plots the selected data series.

### 3.1.1 Dependent variable

The dependent variable is the world crude price. To avoid local differences in the United States WTI and European Brent market we use the average price between the two markers, traded in US Dollar per barrel, to construct a basket price, *P_crude.* The two markers are chosen since they represent the most common benchmarks and are the two most traded crudes on the future exchanges.

### 3.1.2 Explanatory variables

***Demand***

The weighted world production index, *D_wgrowth,* by the Netherlands Bureau for Economic Policy Analysis (CPB) gathered from Reuters Ecowin is utilized as a proxy for world economic growth, in the same manner as Williams (2008). There is no reliable data available on world GDP, and the country specific data are only reported quarterly.

By utilizing the US Dollar/OECD real exchange rate, *D_Exch$*, two desirable properties arise. First, the real exchange rate adjusts for inflation and second, the US Dollar is compared against a pool of OECD currencies, thus encompassing a clearer picture of the US Dollar value relative to the rest of the industrial world's currencies. The OECD countries constitute the biggest part of the world economy and other large influential economies like China have their currencies pegged to the US Dollar. We thereby consider *D_Exch$* to be a satisfying measure on the total currency effects in the crude oil market. Figure 4 shows a depreciation of the dollar since 2002.

***Supply***

Days of stock cover, *S_Stock*, is calculated utilizing monthly stock data and consumption data for the OECD countries from Energy Information Administration (EIA).

$$S\_Stock_t = \frac{OECD\_Stock_t}{OECD\_Production_t}$$

The OECD countries consume over 50 percent of the crude oil produced (EIA), and should work as a desirable proxy for the total stock cover worldwide. Figure 4 indicates seasonality in the *S_Stock* data, with low levels around January, and high levels around June each year. This seasonality stems from natural cycles in the world oil demand. We choose not to adjust for seasonality in our data as there are a number of issues with doing so, including loss of explanatory power.

Rig utilization, *S_rigu*, is gathered from ODS-Petrodata for jack-up rigs and floaters (semi-submersibles and drill ships). We have split the utilization rates for jack-ups positioned in the US Gulf of Mexico and those elsewhere. This is done because this market is more mature and based on spot prices, which should react and reflect market conditions and reactions to crude prices stronger than other markets.

World tanker rates, *F_vlcc,* are collected from Reuters EcoWin. The rates are measured in thousand US Dollars per day. The crude tanker market consists of many ship types, however the largest segment is the Very Large Crude Carriers (VLLC), and we will use these rates. Figure 4 shows that the VLCC rates are considerably more volatile in the latter half of the sample, which reflects uncertainty and periodically imbalance in the global tanker market.

To evaluate the effect of conditions in the refining sector on crude oil prices, we collect data on US refinery utilization rates, *S_refu*, in the same manner as Dèes et al. (2008). We collect 4 week averages from the EIA. Global data would be preferred, but only US data are available. Nonetheless, US refinery utilization should be satisfactory since it represents about 20 percent of world capacity in 2006 (Kaufmann R. , Dèes, Gasteuil, & Mann, 2008). The market for refined petroleum products is global and it is unlikely that utilization rates in one part of the world will differ dramatically from other parts. As long as one can transport refined petroleum products, it is improbable that US refinery utilization rates will increase while other countries' rates will decline significantly. If the greatest shortage of refining capacity occurs in the US, then US refinery rates are the relevant measure because it would reflect conditions at the margin, which by definition, determine prices (Kaufmann, Dees, Gasteuil, & Mann, 2008). The last notion is based on results which indicate that the price crude oil produced in geographical different parts of the world co-integrate (Bacheimer & Griffin, 2006).

OPEC data on production, capacity and quota is gathered from the EIA and PIRA Energy Group (PIRA). *OPEC_quota* is the OPEC production quota in million barrels per day (mbd).

The OPEC spare capacity, *OPEC_sparecap,* and is collected from the EIA. It is calculated as the difference between capacity and production, measured in mbd;

$$OPEC\_sparecap_t = OPEC\_capacity_t - OPEC\_production_t$$

OPEC production quotas, *OPEC_quota*, are collected from PIRA. The extent to which the OPEC countries cheat on their production quotas, *OPEC_cheat,* is calculated as the difference between production quota and actual production (measured in mbd);

$$OPEC\_cheat_t = OPEC\_quota_t - OPEC\_production_t$$

***Futures market***

The contango and backwardation market condition is measured by compiling monthly averages on the near month (1-pos) contract and the six month (6-pos) contract for WTI traded on NYMEX. The spread between the two price series is then used to determine the market position, *F_cont*; that is if the slope of the forward curve.

$$F\_cont_t = NYMEX(6 - pos)_t - NYMEX(1 - pos)_t$$

Figure 4 shows that prior to 2005 the market was mainly in backwardation, which agrees with Litzenberger & Rabinowitz's studies (1995). However, after 2005 the market has mainly been in contango. According to our hypothesis, this implies that the market has had an optimistic outlook on the future crude oil price over the last 5 years.

The percentage of non-commercial open interest, *F_oi,* is collected from the Commitments of Traders (COT) report reported by the CFTC. It is calculated as the proportion of long positions held by non-commercial traders and is calculated as:

$$F\_oi_t = \frac{NCL_t + NCSP_t}{OI_t - NRLP_t}$$

where, $NCL_t$ is the non-commercial long positions, $NCSP_t$ the non-commercial spread positions, $OI_t$ the total positions of all traders and $NRLP_t$ the Non-reportable long positions for every month, *t*. We subtract the non-reportable positions since the numbers consists of smaller positions held by both commercial and non-commercial traders. Figure 4 shows that the percentage of non-commercial open interest has increased considerably during the sample period. An interesting observation is that the ratio did not decrease in connection with the financial crisis.

The net positions of non-commercial traders, *F_netl,* is the spread between the average long and short position held by non-commercials in each month. Positions gathered from the COT report made public by the CFTC.

$$F\_netl_t = NCL_t - NCS_t$$

Where, $NCL_t$ and $NCS_t$ are the non-commercial long and short positions respectively.

***Special events***

Because of the scarce production capacity, events that directly affect the supply and demand of crude oil will cause price movements. We include dummies for events such as wars, hurricanes and stock market crashes or financial crisis.

**Table 2: Dummy variables**

| **Dummy** | **Event** | **Time period** |
|---|---|---|
| *Dumm_2000* | The stock market crash after the burst of the “dot-com bubble”. | 2000:12 |
| *Dumm_9/11* | Terrorist attack on the world trade center. | 2001:9-2001:10 |
| *Dumm_iraq* | The invasion of Iraq, caused fears of supply disruptions in one of the world’s leading crude oil producing countries. | 2003:4 |
| *Dumm_katarina* | The Katarina and Rita hurricanes forced the evacuation of many oil platforms in the US Gulf of Mexico. | 2005:8 |
| *Dumm_2008* | The financial crisis in 2008 | 2008:9-2008:10 |

*The table describes the dummy variables explaining market movements not explainable by other underlying factors.*

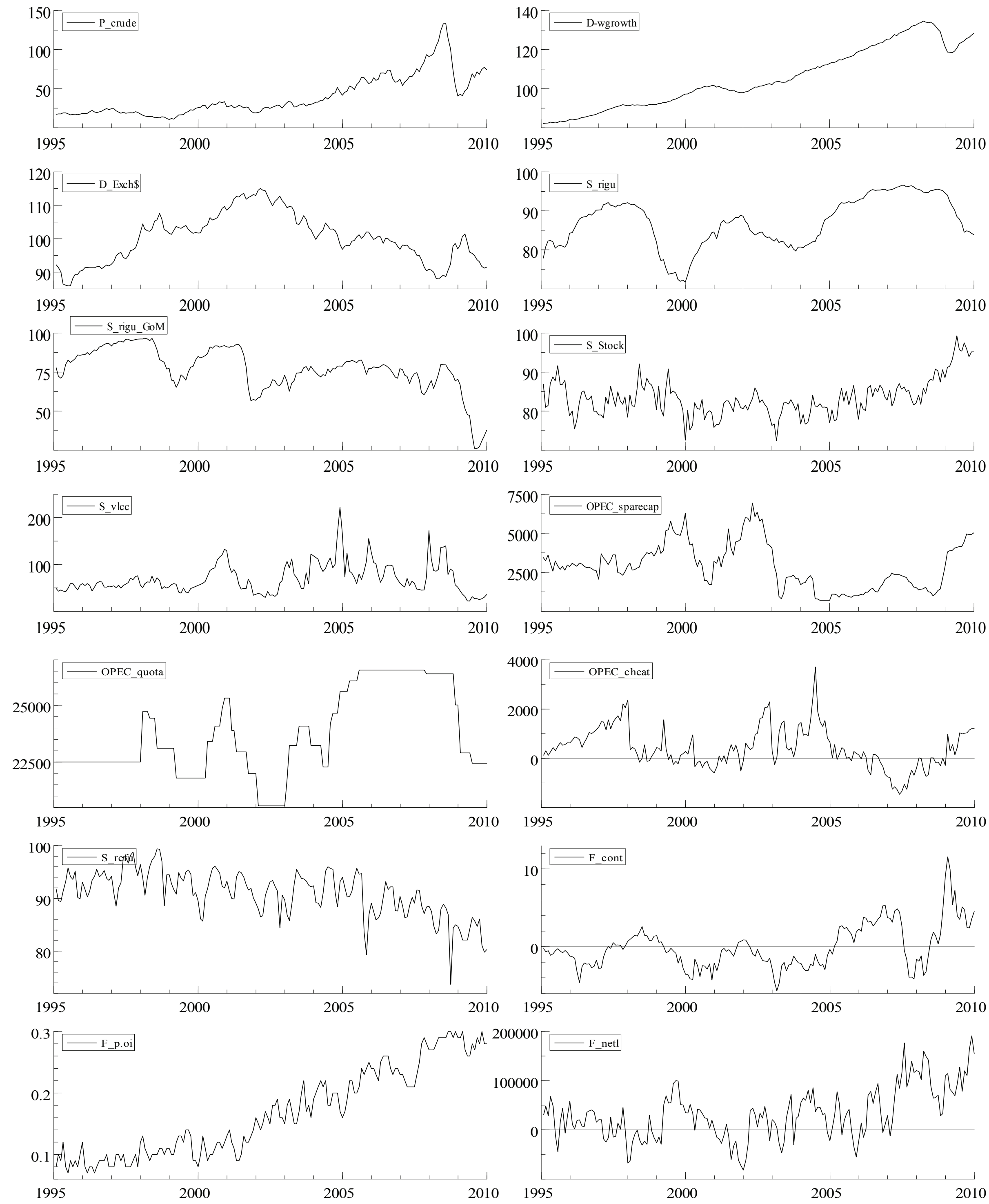


**Figure 4: Time series plot**

*Development of all time series from 1995:1 to 2009:12, Crude oil price basket price is listed in US Dollars per barrel. World growth is a weighted production index (2000=100). The US Dollar real effective exchange rate is an index describing the dollar cost of buying a unit of an index composed of an index of a pool of OECD currencies, adjusted for inflation. Rig utilization for the world and for jack-ups in the US Gulf of Mexico is the ratio of working rigs versus the total available market. Days of stock cover is the number of days available in OECD crude stocks. World tanker rates are given in USD. OPEC spare production capacity, quota, and cheat on quotas are given in thousand barrels per day. Refinery utilization is the ratio of occupied versus available capacity in the US refinery sector. Contango/Backwardation is the spread between the 6 month and first delivery month contract on NYMEX in US Dollars per barrel. Non-commercial long ratio of open interest is given as a ratio. Non-commercial net length is the spread between long and short positions given in number of contracts on NYMEX.*

## 3.2 Descriptive statistics

Descriptive statistics for the data series is presented in Table 3. The table shows the basic features of the series, and presents test results for normality and stationarity. The explanatory variables are also checked for multicollinearity. For a description of the statistical concepts used we refer to Appendix A.4.

The Jarque-Bera test reveals that the data series are generally non-normally distributed, as most of the series are skewed to the right and have low kurtosis. The Augmented Dickey-Fuller (ADF) test is used to test the data series for stationarity at 5 and 1 percent significance level. State-space modeling in itself does not require stationary time series, but since our model selection process is based on ordinary linear regression we need to fulfill this assumption. In ordinary linear regression use of non-stationary series strongly influence the behavior and properties of the final state-space model. Potential hazards with use of non-stationary series could, in our case, be infinite persistence of shocks and spurious relationships. Thereby, we would not be able to draw any valid inferences. The ADF-procedure tests the null hypothesis that the data series is non-stationary against the alternative hypothesis that the data series is stationary. As shown in Table 3, most of the time series are found to be non-stationary, as the test statistic fails to reject the null hypothesis. This is not surprising, since real prices and levels often contain a stochastic trend.

The correlation-matrix for the explanatory variables, attached in Appendix A.2, indicates that the problem of multicollinearity is present for some of the variables in the data series and should be taken into account.

The presence of non-stationarity and multicollinearity in our variables indicates a need to consider either the data or the method we intend to use further. A possible solution to the non-stationary problem is based on co-integrated relationships among the variables, as applied by Kaufmann et al. (2004) and Möbert (2007). Engle & Granger's (1987) two-step method is applied to determine if two (or more) variables co-integrate, but due to our large number of non-stationary explanatory variables the approach fails to supply an adequate specification. Instead of estimating an Error Correction Model (ECM), we transform the data series by differentiation. One issue with differentiating the data is that some long-term statistical equilibrium relations between the variables will be lost. Another solution to the problem is to study a State-Space Error Correction Model (SSECM) (Ribarits & Hanzon, 2009), but the methodology is new and is to our knowledge not utilized in the literature.

The data are transformed by the natural logarithm and calculate the first order difference (denoted log_diff) to avoid problems with non-stationary means and level differences.

$$log\_diff = ln\frac{P_t}{P_{t-1}}$$

Descriptive statistics for log_diff series are represented in Table 3. All of the log_diff series reject the null hypothesis that the data are non-stationary at 1 percent significance level, implying that that all series are stationary. The correlation-matrix (Table 9 in appendix) of the transformed data shows no signs of having potentially harmful correlations. These findings are desirable for the later model specification. Time plots of the log_diff data for the time period from January 1st 1995 to December 31st 2009 are presented in Figure 5.

The purpose of this paper is to study the time-varying coefficients affecting the crude oil market. Correlation matrices are studied with the purpose of study possible problems with multicollinearity, but we also want to study how the factors correlate with the crude oil price during the time period. Figure 13 in Appendix A.3 shows the 24 month rolling correlation between the crude oil price and each of the explanatory variables during the time period. We observe that the relationship varies throughout the time period studied and supports our reasoning for applying a time-varying model to study the dynamic effects in the crude oil market. We will refer back to Figure 13 when analyzing the results from our model.

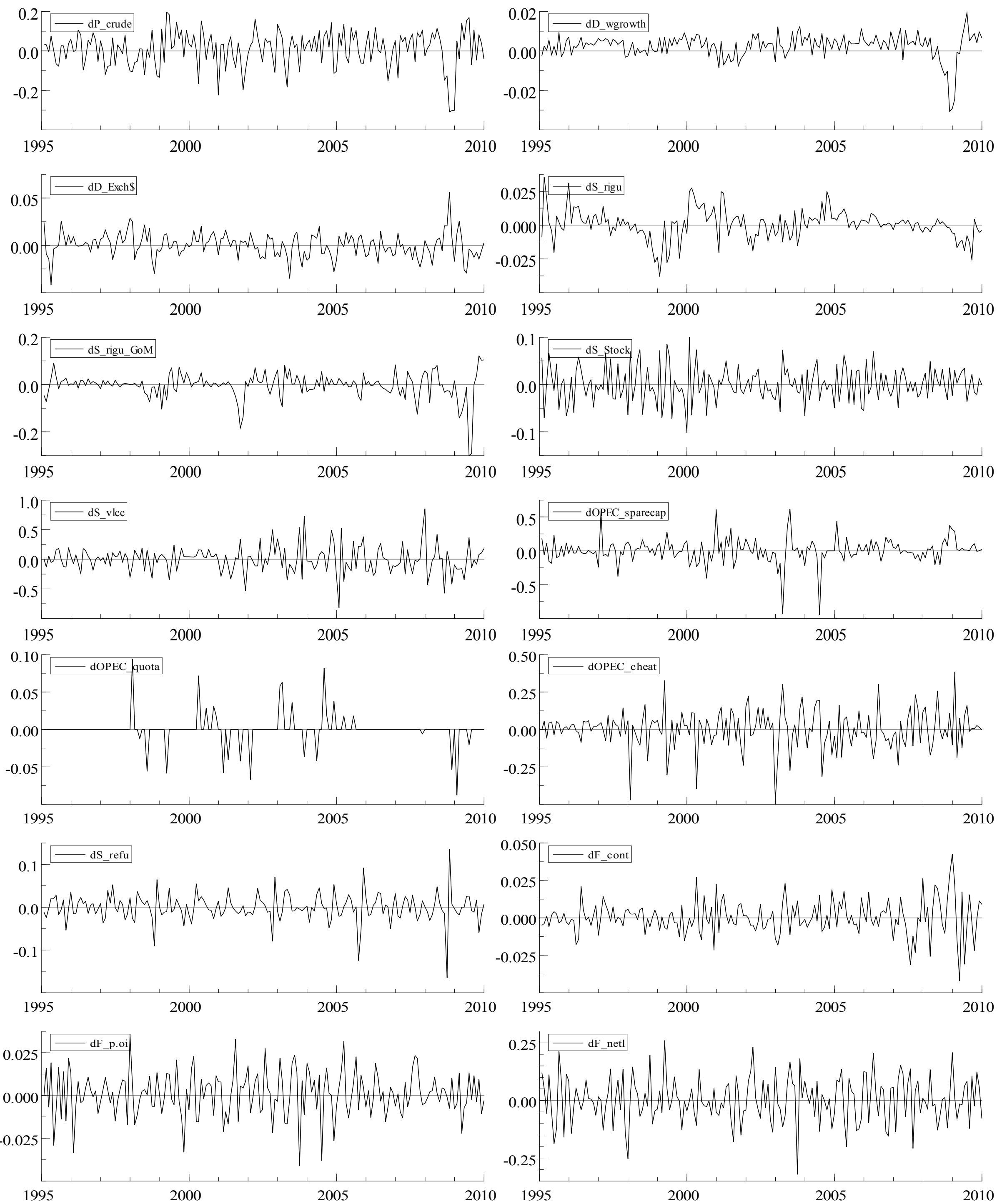


**Figure 5: Plot of transformed data**

*Logarthmic differences of the data series from 1995:1 to 2009:12. P_crude is the change in the crude oil basket price listed in US Dollars per barrel. World growth is a weighted production index (2000=100). The US Dollar real effective exchange rate is an index describing the dollar cost of buying a unit of an index composed of an index of a pool of OECD currencies, adjusted for inflation. Rig utilization for the world and for jack-ups in the US Gulf of Mexico is the ratio of working rigs versus the total available market. Days of stock cover is the number of days available in OECD crude stocks. World tanker rates are given in USD. OPEC spare production capacity, quota, and cheat on quotas are given in thousand barrels per day. Refinery utilization is the ratio of occupied versus available capacity in the US refinery sector. Contango/Backwardation is the spread between the 6 month and first delivery month contract on NYMEX in US Dollars per barrel. Non-commercial long ratio of open interest is given as a ratio. Non-commercial net length is the spread between long and short positions given in number of contracts on NYMEX.*

**Table 3: Descriptive statisitcs**

| | *P_crude* | *D-wgrowth* | *D_exch$* | *S_rigu* | *S_rigu_GoM* | *S_stock* | *S_vlcc* | *OPEC_ sparecap* | *OPEC_quota* | *OPEC_cheat* | *S_refu* | *F_cont* | *F_p.oi* | *F_netl* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Mean* | 39.611 | 105.447 | 100.187 | 87.101 | 76.771 | 83.406 | 70.160 | 2895.667 | 23728.783 | 420.611 | 90.903 | -0.047 | 0.168 | 32613.760 |
| *Standard Error* | 1.941 | 1.149 | 0.544 | 0.471 | 1.054 | 0.354 | 2.385 | 108.785 | 140.008 | 60.828 | 0.322 | 0.211 | 0.005 | 3905.066 |
| *Median* | 28.593 | 101.520 | 100.620 | 87.838 | 77.805 | 82.613 | 60.348 | 2830.000 | 23107.000 | 304.459 | 91.550 | -0.497 | 0.156 | 29390.625 |
| *Standard Deviation* | 26.036 | 15.422 | 7.298 | 6.318 | 14.135 | 4.754 | 31.999 | 1459.509 | 1878.401 | 816.093 | 4.318 | 2.833 | 0.071 | 52391.959 |
| *Kurtosis* | 1.659 | -1.107 | -0.758 | -0.630 | 2.584 | 1.053 | 2.960 | -0.440 | -1.143 | 1.042 | 0.834 | 1.743 | -1.209 | 0.171 |
| *Skewness* | 1.384 | 0.313 | 0.112 | -0.368 | -1.269 | 0.790 | 1.420 | 0.497 | 0.306 | 0.555 | -0.736 | 1.012 | 0.394 | 0.489 |
| *Range* | 122.815 | 52.560 | 29.080 | 24.770 | 70.580 | 26.847 | 200.290 | 6230.000 | 5974.000 | 5174.000 | 25.700 | 17.225 | 0.230 | 272635.250 |
| *Minimum* | 10.528 | 82.140 | 85.940 | 71.800 | 26.130 | 72.433 | 21.869 | 710.000 | 20575.000 | -1461.000 | 73.700 | -5.651 | 0.072 | -81445.750 |
| *Maximum* | 133.343 | 134.700 | 115.020 | 96.570 | 96.710 | 99.281 | 222.159 | 6940.000 | 26549.000 | 3713.000 | 99.400 | 11.574 | 0.302 | 191189.500 |
| *Jarque-Bera* | 75.270 | 12.116 | 4.8151 | 7.1182 | 93.570 | 25.747 | 120.20 | 8.8840 | 12.590 | 16.305 | 20.507 | 50.882 | 15.443 | 7.1937 |
| | [0.0000]** | [0.0023]** | [0.0900] | [0.0285]* | [0.0000]** | [0.0000]** | [0.0000]** | [0.0118]* | [0.0018]** | [0.0003]** | [0.0000]** | [0.0000]** | [0.0004]** | [0.0274]* |
| *ADF* | -1.221 | -0.680 | -1.416 | -2.457 | -1.448 | 0.342 | -4.225** | -1.8 | -1.931 | -3.751** | 0.902 | -2.859 | -0.409 | -3.605** |
| *Count* | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 |

| | *dP_crude* | *dD-wgrowth* | *dD_exch$* | *dS_rigu* | *S_rigu_GoM* | *dS_stock* | *dS_vlcc* | *dOPEC_ sparecap* | *dOPEC_quota* | *dOPEC_cheat* | *dS_refu* | *dF_cont* | *dF_p.oi* | *dF_netl* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Mean* | 0.0083 | 0.0025 | 0.0001 | 0.0004 | -0.0043 | 0.0008 | -0.0017 | 0.0031 | 0.0000 | 0.0016 | -0.0008 | 0.0002 | 0.0009 | 0.0024 |
| *Standard Error* | 0.0067 | 0.0005 | 0.0009 | 0.0008 | 0.0041 | 0.0027 | 0.0164 | 0.0135 | 0.0014 | 0.0095 | 0.0023 | 0.0008 | 0.0010 | 0.0073 |
| *Median* | 0.0230 | 0.0036 | 0.0000 | 0.0011 | 0.0003 | -0.0004 | -0.0082 | 0.0000 | 0.0000 | 0.0084 | -0.0011 | -0.0005 | 0.0013 | 0.0014 |
| *Standard Deviation* | 0.0897 | 0.0062 | 0.0127 | 0.0109 | 0.0544 | 0.0360 | 0.2198 | 0.1816 | 0.0192 | 0.1272 | 0.0315 | 0.0113 | 0.0129 | 0.0978 |
| *Kurtosis* | 1.3262 | 9.1745 | 2.0626 | 1.6473 | 8.9029 | -0.0530 | 2.3707 | 8.5260 | 10.3230 | 2.3231 | 6.6722 | 2.0468 | 0.7242 | 0.1799 |
| *Skewness* | -0.8392 | -2.0951 | 0.1456 | -0.1366 | -1.9946 | 0.0688 | 0.3261 | -0.8951 | 0.3340 | -0.5472 | -0.5761 | 0.0314 | -0.2568 | -0.1175 |
| *Range* | 0.5058 | 0.0502 | 0.0979 | 0.0734 | 0.4219 | 0.2014 | 1.6717 | 1.5608 | 0.1821 | 0.8584 | 0.3003 | 0.0846 | 0.0765 | 0.5800 |
| *Minimum* | -0.3093 | -0.0307 | -0.0416 | -0.0380 | -0.3000 | -0.1015 | -0.8165 | -0.9431 | -0.0877 | -0.4757 | -0.1648 | -0.0421 | -0.0409 | -0.3202 |
| *Maximum* | 0.1965 | 0.0194 | 0.0563 | 0.0354 | 0.1219 | 0.0999 | 0.8552 | 0.6177 | 0.0943 | 0.3827 | 0.1356 | 0.0426 | 0.0356 | 0.2598 |
| *Jarque-Bera* | 32.629 | 718.16 | 29.861 | 19.020 | 675.46 | 0.19398 | 41.866 | 489.08 | 753.06 | 46.002 | 322.63 | 28.969 | 5.3624 | 0.55702 |
| | [0.0000]** | [0.0000]** | [0.0000]** | [0.0001]** | [0.0000]** | [0.9076] | [0.0000]** | [0.0000]** | [0.0000]** | [0.0000]** | [0.0000]** | [0.0000]** | [0.0685] | [0.7569] |
| *ADF* | -10.14** | -4.867** | -8.718** | -3.751** | -7.924** | -3.847** | -13.40** | -10.91** | -11.75** | -9.680** | -4.987** | -11.47** | -9.810** | -6.984** |
| *Count* | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 |

*The top table shows the descriptive statistics for the individual time series and bottom table for the transformed data series (log_diff). The Jarque-Bera test statistic is the test for normality, and ADF is the Augmented Dickey Fuller unit root test. ** and * indicates statistical significance at the 1 percent and 5 percent significance level respectively.*

# 4. Methodology

The empirical methodology aims to determine significant factors influencing the oil price and to investigate their change over time. To identify the factors we want to include in the time-varying model, we employ a classical linear regression model (CLRM) with oil price return as the dependent variable and the discussed factors as explanatory variables. The following specification applies;

$$y_t = \alpha + \sum_{i=1}^{k} \beta_i X_{i,t} + \varepsilon_t \qquad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2) \qquad (1)$$

where $\alpha$ is a constant, $X_i$ is the data series of the explanatory variable $i$, $\beta_i$ is the beta coefficient for the explanatory variable *i,* including dummies, and the residuals $\varepsilon_t$ are Gaussian white noise.

The general unrestricted model (GUM) gives an unlimited number of combinations of variables and lags. Therefore several techniques are applied to indentify the most efficient and parsimonious model. The Autometrics function in the Oxmetrics software, economic theory and related research are utilized to identify the significant variables and most significant lags. Diagnostic tests are performed to reveal whether the models fulfill the assumptions related to an Ordinary Least Squares (OLS) regression model. Detailed descriptions of the software and statistical tests used are attached in Appendix A.4.

**4.1 Parameter stability of the linear regression**

To evaluate the stability of the parameters in the model we employ a Chow test. The test splits the data into two sub-periods and estimate the regression over the whole period (restricted regression) and then for the two sub-periods separately (unrestricted regressions). Residual sum of squares (RSS) is obtained for each regression, and thereof it is performed an F-test based on the test statistic;

$$test\_statistic = \frac{RSS - (RSS_1 + RSS_2)}{RSS_1 + RSS_2} \times \frac{T - 2k}{k}$$

where T is the number of observations and k is the number of independent variables in each unrestricted regression. Hence, the test checks whether the residual sum of squares for the whole sample (RSS) is larger than the sums of squares for the two sub-samples ( $RSS_1 + RSS_2$ ). As usual with an F-test, if the value of the test-statistics is greater than the critical value from the F-distribution, which is F(k, T-2k), we reject the null hypothesis that the parameters are stable over time.

**4.2 Estimate model with time-varying parameters**

To investigate further how the different factor coefficients behave over time we will apply a state space approach. We will base our theoretical framework on Commandeur & Koopman (2007) and Tsay (2005), with Wei (2006) and Hamilton (1994) as supporting literature. The deterministic regression model (1) is expanded to a state space model by introducing a level component, $\mu_t$, which is allowed to vary over time. The level component can be conceived of as an equivalent of the intercept in the ordinary linear regression, but in contrast this component applies only locally at each time point (Commandeur & Koopman, 2007). To model the level component we are adding an equation representing the state of the level component in the model. Similarly, we let the beta values, $\beta_t$, for each of the explanatory variables vary over time. The modeling of *k* explanatory variables requires *k* additional state equations. We then have the following linear Gaussian local level state space model, consisting of an observation equation (2) and several state equations (3), (4).

$$y_t = \mu_t + \sum_{i=1}^{k} \beta_{i,t} X_{i,t} + \varepsilon_t \qquad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2) \qquad (2)$$

$$\mu_{t+1} = A\mu_t + \eta_t \qquad \eta_t \sim NID(0, \sigma_\eta^2) \qquad (3)$$

$$\beta_{i,t+1} = \beta_{i,t} + \tau_t \qquad \tau_t \sim NID(0, \sigma_\tau^2) \qquad (4)$$

We let $\varepsilon_t$, $\eta_t$, $\tau_t$ be independent Gaussian white noise series. The variables $\mu_t$ and $\beta_{i,t}$ are the state of the system at time t and are not directly observed, while $y_t$ is the observed version of $\mu_t$ and $\beta_t$ with added noise. The first equation (2), known as the observation equation, therefore provides a link between the data $y_t$ and the state. The latter equations (3), (4), the state equations, govern the time evolution of the state variables. Hence, we have one equation which relates the crude oil price to the changes in the driving factors, while the other equations model the effects dynamically. The model shows the unobserved dynamic process at different points in time, and we can observe the stochastic behavior of the level and the slopes of the model.

The time-varying coefficients are estimated using Kalman filtering (Kalman, 1960). This technique lets the model update the state variables recursively by Bayesian optimization as we work through the time series data. We let $F_t = \{y_1, \ldots, y_t\}$ be the information available at time t. Knowing the conditional distribution of the state variables given $F_{t-1}$ and the new data $y_t$, we can obtain the conditional distribution of state variables given $F_t$. Recursive estimates of the state variables and their variance are made by the observation equations. Starting from the initial estimates, the observation equation updates to prior values of the variables are updated in each time step. Once the new data $y_{t+1}$ is included, the procedure is repeated to update knowledge of next observation of the state variables (Tsay, 2005).

We can expand the derived model further by adding trend- and seasonality components. Thus, we obtain the following final state space model;

$$y_t = \mu_t + \gamma_t + \sum_{i=1}^{k} \beta_{i,t} X_{i,t} + \varepsilon_t \qquad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2) \qquad (5)$$

$$\mu_{t+1} = A\mu_t + \upsilon_t + \eta_t \qquad \eta_t \sim NID(0, \sigma_\eta^2) \qquad (6)$$

$$\beta_{i,t+1} = \beta_{i,t} + \tau_t \qquad \tau_t \sim NID(0, \sigma_\tau^2) \qquad (4)$$

$$\upsilon_{t+1} = \upsilon_{i,t} + \zeta_t \qquad \zeta_t \sim NID(0, \sigma_\zeta^2) \qquad (7)$$

$$\gamma_{i,t+1} = \gamma_{i,t} + \varphi_t \qquad \varphi_t \sim NID(0, \sigma_\varphi^2) \qquad (8)$$

The level-, slope- and seasonal components can be set to be fixed, stochastic or omitted. Each of the regression coefficients, the betas, can be set to be fixed, random walk (Markov process) or smoothing spline. By allowing the regression coefficients to vary over time in a random walk specification, we can observe how they behave in accordance to market fundamentals. Smoothing spline is a method of fitting a smooth curve to a set of noisy observations, and is useful to illustrate the overall development of the coefficients over time. The random walk specification (4) is defined in the model above, while the alternative smoothing spline (9) specification is defined as:

$$\Delta\beta_{i,t} = \Delta\beta_{i,t-1} + \tau_t \qquad \tau_t \sim NID(0, \sigma_\tau^2) \qquad (9)$$

To determine which factors of the regression that show a significant influence on the crude oil price, we test different versions of state space model in Oxmetric STAMP (*Structural Time Series Analyser, Modeller and Predictor*). We set all the regression coefficients fixed, whilst testing for the different specifications for the level-, slope- and seasonal components. Subsequently we perform tests where we let the regression coefficients fluctuate over time as a random walk process, first one coefficient at a time and finally all the coefficients simultaneously.

We evaluate the different models by using the Akaike Information Criterion (AIC) (Akaike, 1973). The criterion compensates for the number of estimated parameters, thus allowing for a fair comparison between models involving different number of parameters. The AIC is described further in Appendix A.4. Additionally, several diagnostic tests are performed to reveal whether the residuals of the model fulfill the requirements of a linear Gaussian model, which is no signs of heteroscedasticity, autocorrelation, non-normality, or other biasing signs. The property of no autocorrelation is particular important. The test descriptions are attached in the Appendix A.4. Performing these tests are crucial in order to validate whether our conclusions are statistical adequate.

# 5. Empirical results

## 5.1 Model selection

From a general unrestricted model, including all explanatory variables and lagged variables, we revealed the most significant factors and appropriate lags in the OxMetrics 6.0 software. We intended to avoid high lags, if not there were clear and reasonable economic reasons for including them. The final model selection is based on a number of criteria described in the theoretical framework and Appendix A.4. To avoid problems with misspecifications, large outliers and heteroscedasticity in the residuals we add the dummies found significant at the 1 percent significance level. The dummies represent special events during the time period that have affected price movements. One event during the time period is found to be significant. The financial crisis in 2008 and the market crash that followed caused crude oil price movements that are not explainable by any of our covariates.

Following the steps presented in the theoretical framework, the best model was identified by fixing the coefficients of the explanatory variables, and evaluate different models based on their AIC. We tested 18 different models by allowing the level-, slope- and seasonal components to be fixed, stochastic or omitted. The model with a fixed level and slope, and an omitted seasonal component gave us the best goodness of fit by evaluating AIC. Based on our model selection process we are left with our final model shown in Table 4.

**Table 4: Linear regression model**

| Variable | Coefficient | Std.Error | t-value | t-prob |
|---|---|---|---|---|
| *dD_wgrowth* | 3.5754 | 0.7777 | 4.600 | 0.0000*** |
| *dS_rigu_1* | 0.7040 | 0.3951 | 1.780 | 0.0766* |
| *dS_Stock* | 0.2161 | 0.1192 | 1.810 | 0.0717* |
| *dOPEC_sparecap* | -0.0386 | 0.0239 | -1.690 | 0.0922* |
| *dOPEC_quota* | -0.6424 | 0.2334 | -2.750 | 0.0066*** |
| *dS_refu_2* | 0.2396 | 0.1354 | 1.770 | 0.0787* |
| *dF_cont* | -3.3457 | 0.4048 | -8.270 | 0.0000*** |
| *dF_netl* | 0.3530 | 0.0453 | 7.800 | 0.0000*** |
| *dumm_2008* | -0.1542 | 0.0414 | -3.720 | 0.0003*** |
| $R^2$ | 0.6604 | *H-test(55)* | | 1.5643 |
| *DW* | 1.6064 | *RESET23* | | 1.8718 |
| *Normality(2)* | 9.0082** | *RSS* | | 0.4556 |
| *AIC* | -5.7644 | | | |

*The table shows the final model with each variable and its significant lag. ***, **, * indicates that the factors are significant at 1 percent, 5 percent and 10 percent significance level respectively.*

Changes in economic growth, OPEC production quotas, contango level and net length positions held by non-commercials are all significant at a 1 percent significance level. Rig utilization at the first lag, days of stock cover, OPEC spare production capacity and refinery utilization at the second lag are significant at the 10 percent significance level[5]. The test summary in Table 4 shows that the goodness of fit ($R^2$) is 66 percent, which is about the same result achieved by Möbert's (2007) various linear regression models.

The H-test for heteroscedasticity does not reject the null hypothesis that the residuals are homoscedastic and the RESET23 test shows no signs of misspecification and non-linearities in the model. The Durbin – Watson DW statistic does indicate some signs of positive serial correlation, but the test-statistic is not significantly different from 2 to reject the null hypothesis. Finally, the Jarque-Bera Normality test rejects the null hypothesis that the residuals are normally distributed. This could be caused by outliers, but we choose not to correct for this by adding dummies and loose the explanatory power of the covariates in the state-space model. This should be solved by the state-space model specifications and we will study this closely in the residuals from our time-varying model.

### 5.1.1 Parameter stability

To evaluate the parameter stability we employed the Chow test described in the theoretical framework. As a simple test we divided our dataset into two periods, first period from 1995 to 2003 and second period from 2004 to 2009. The division point is based on the large increase in crude oil price from 2004. Using the linear regression model defined above we obtain the residual sum of squares for both time periods. The test statistic is above the critical value at 1 percent significance level in the F-distribution, and we reject the null hypothesis that the parameters are stable over time. To fully evaluate the stability of the parameters, and identify possible break-points, we employ the recursive tests offered by the Oxmetrics software. The 1-step (1up CHOWs) in Figure 6 shows the parameter stability test for each time step. There are some serious outliers from the critical value at 1 percent significance level, and we observe that the outliers are more frequent after 2005. This is in accordance with the simple two-period Chow test we performed above. The break-point (Ndn CHOWs) test rejects the null hypothesis that the parameters are stable for almost the whole sample. In Figure 6 the parameters seem to be stable during the financial crisis, but this is actually caused by the dummy which is included in the regression to fulfill the assumptions for the regression. The 1-step residual plot (Res1 Step) shows some outliers from the 2 standard-error region, which could be associated with coefficient changes. We also observe that the 2 standard-error region become wider during the sample, indicating more instability. The parameter

[5] We choose to include variables found significant at the 10 percent significance level since the linear model is a selection process for the time-varying model, and the significance of each coefficient will vary through time.

instability suggests that there are some structural breaks during the period and to explore these a model with time-varying parameters is more appropriate than a linear model.

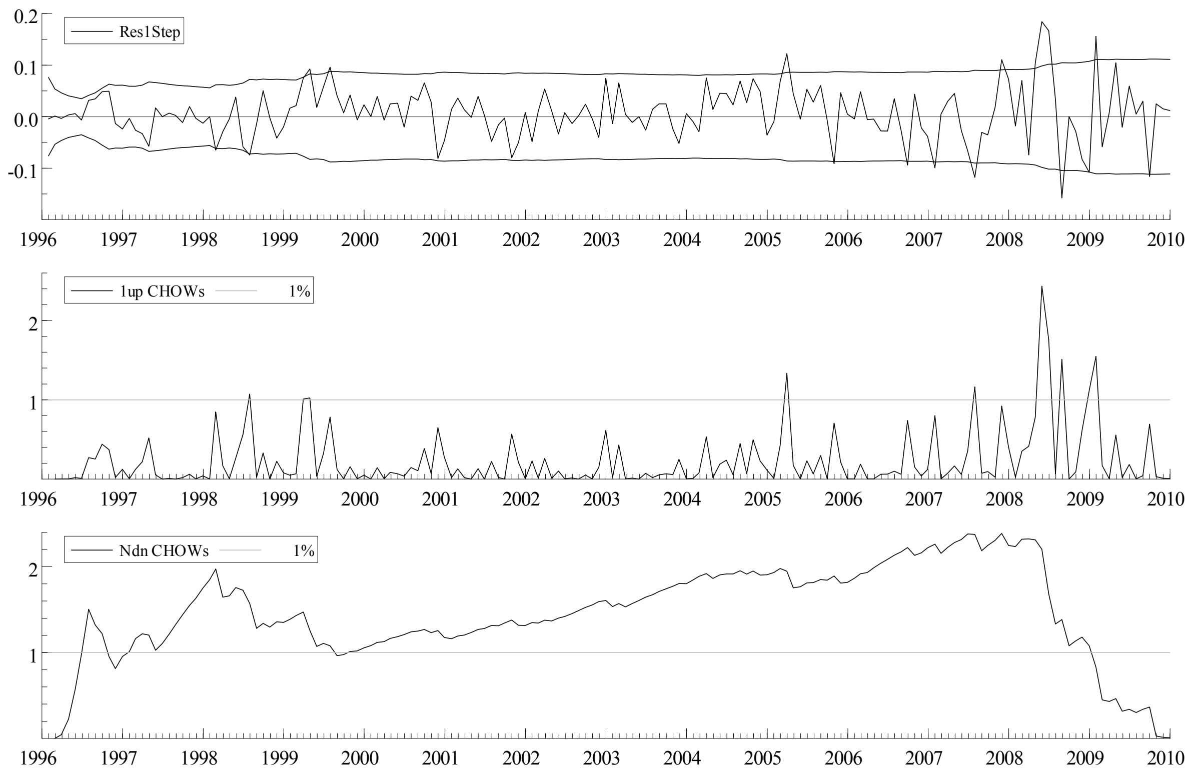


**Figure 6: Chow test graphics**

*Residual 1-step plot, 1-step Chow test and break-point Chow test for the final linear regression. The tests indicate unstable parameters.*

## 5.2 Time-varying coefficients

Figure 7 illustrates each of the significant factors' time varying influence on the crude oil price changes. The model where the beta coefficients follow a random walk performed better than the smoothing spline alternative, when evaluating the models by the AIC. When the coefficients follow a random walk over the period we can examine the unobserved dynamics in the linear regression model. It should be noted that the behavior of each coefficient is determined given the presence of the remaining time varying coefficients at any given time. As a comparison we refer to the Appendix A.1 where each explanatory factor's time varying influence on the crude oil price is illustrated, independent of the other factors.

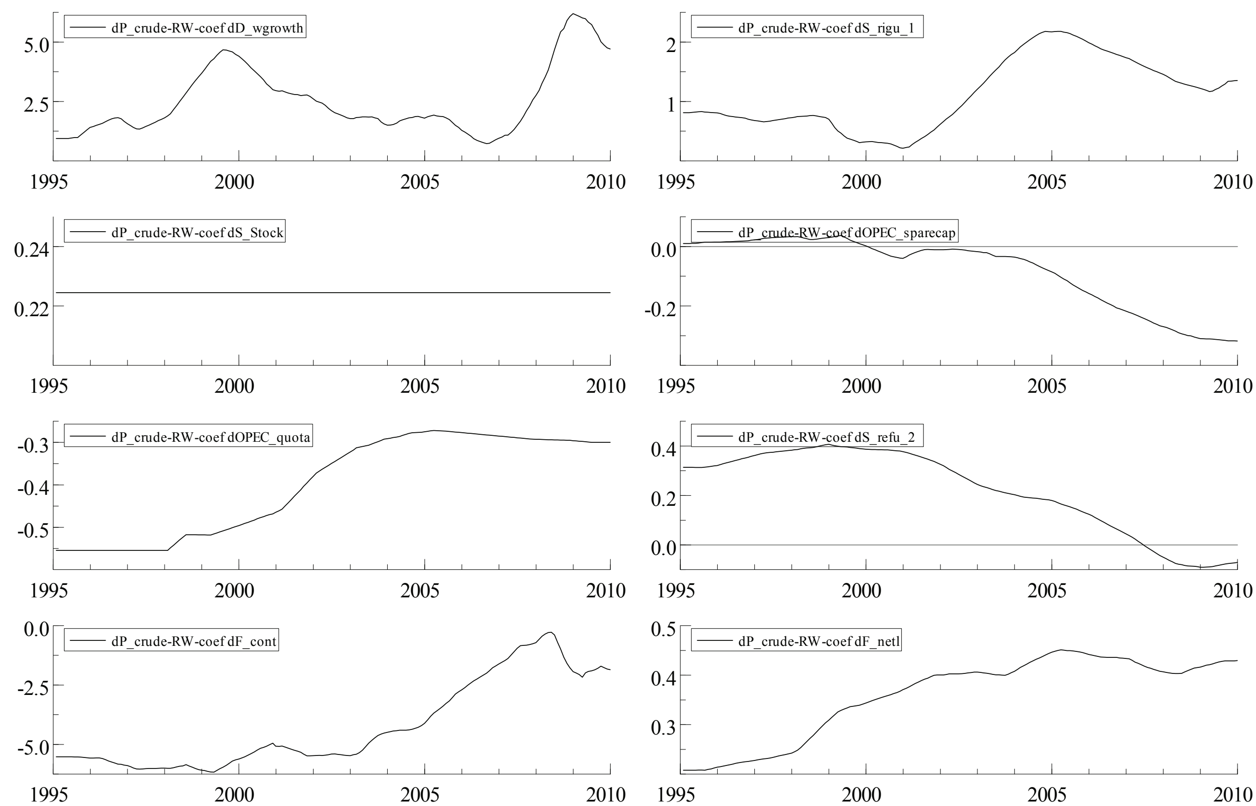


**Figure 7: Time-varying beta coefficients**

*The figure shows the random-walk time plots for the coefficients of each of the significant underlying factors in the model in the time period from 1995 to 2009.*

**Table 5: Summary of test statistics for the state-space model**

| Test summary | | | |
|---|---|---|---|
| *DW* | 1.6972 | *Ljung-Box Q(11)* | 16.025 |
| *H-test(55)* | 1.6456 | *Normality(2)* | 2.5124 |

*The Durbin-Watson test for residual autocorrelation, the Ljung-Box test statistic for residual autocorrelation, the Heteroscedastic test statistic and the Jarque-Bera Normality test statistic. ***, ** indicates that the factors are significant at 1 percent amd 5 percent significance level respectively.*

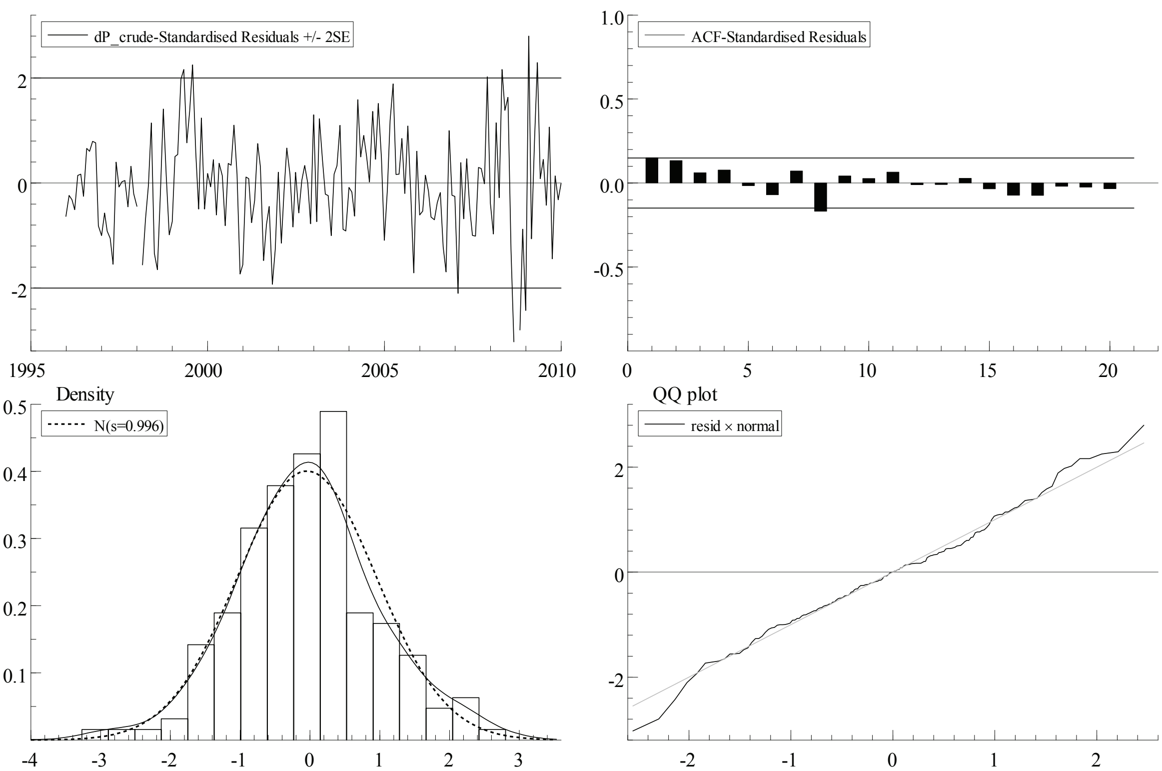


**Figure 8: Residual graphics for the state space model**
*The figure shows the standardized residuals within two standard error lines, an ACF plot of the residuals, the density plot with a dotted normality reference line and finally a QQ-plot with a dotted, grey normality reference line.*

Table 5 displays the test statistics from the state-space model. The Durbin-Watson and Ljung Box test does not reject the null hypothesis of no autocorrelation in the residuals. The Durbin-Watson test statistic indicates signs of positive autocorrelation, but this is not significant and can be verified further by studying the autocorrelation plot in Figure 8. There are still some outliers in the model, and these could be adjusted further for by adding more dummy variables to the model. This is not desirable as both information and explanatory power is lost. However, the Jarque-Bera Normalilty test does not reject the null hypothesis that the residuals are normally distributed, so no further correction is needed. Finally, the Heteroscedasticity test show that the residuals are homoscedastic.

***Economic growth***

The empirical results show that the change in economic activity has a positive relationship with the change in crude oil price in the preferred model. This is in accordance with our hypothesis. A raise in economic activity implies an increase in prosperity and hence demand for energy. Figure 7 indicates that the relationship has increased in conjunction with economic recessions[6], such as during the Asian/Russian financial crisis in 1998 and during the financial crisis at the end of 2008. This implies that investors have drawn special attention to economic activity when the economy is tense. Weakened economic activity causes large uncertainty about the future, and brings along sharp price declines in both spot and futures markets. The relationship weakens after the recession in 2001/2002 and also shows a declining relationship with changes in the crude oil price in 2009. These time periods represent economic recoveries and a continuous growth in the global economy from 2002 to 2008. Economic growth is the expected nature of the world and does not display any considerable relationship with crude oil prices in these time periods.

***Rig utilization***

Changes in the lagged rig utilization rate have had a positive relationship with the change in crude oil price, and indicate the importance of the upstream sector. From Figure 7, we observe that the influence increased considerably in the period from 2001 to 2005. This coincides with a period of a loosening in the market, and where oil prices decreased or remained relatively stable until 2004. After 2004 the rig market capacity became scarce, along with the whole oil service sector, and utilization rates settled above 90 percent for several years. The tight market put pressure on the supply side, and seems to have affected the crude oil price. This shows the effect of the upstream sector as a bottleneck in the business in the time period around 2005, and thereby being a contributing factor to the sharp rise in oil prices at the time.

After 2005, the relationship shows a flat or downward trend. This is unexpected, given the high utilization rates in the period. Even though the relationship is sustained at high levels, it is halved during the next four years, and implies that the upstream sector did not continue to affect the oil price as much as we anticipated.

***OPEC spare capacity***

The relationship between the change in OPEC spare production capacity and crude oil prices was weak from 1995 to 2004. The beta coefficient has an increasingly negative value after 2004, meaning that the factor is negatively influencing changes in the oil price to a larger degree through the period. The negative relationship is in accordance with our hypothesis. In the period before 2004, OPEC had sufficient spare capacity to ramp up production if oil prices increased above desired price ranges. However, after 2004 the spare production capacity fell below 1 million barrels per day, which made it difficult to increase production levels further when oil prices continued to increase after 2004.

[6] Definition of recession is here based on International Monetary Fund's (IMF) statement that a global recession takes place when global growth is less than three percent. By this measure three periods since 1995 qualify: 1998, 2001-2002 and 2008-2009.

As OPEC reduced its production in the beginning of 2009, and hence increased spare capacity levels, this becomes visible in the random-walk beta coefficient. It seems as the relationship between OPEC spare capacity and crude oil price changes is mainly significant in times of low capacity. Since OPEC is seen as the only production entity with any considerable spare production capacity, this represents the only supply buffer in the world crude oil market and supply shortages do become visible here.

***Days of stock cover***

The empirical results from our model show that the change in stock level has had a positive relationship with changes in the crude oil price. This is not in conformity with earlier research and the common perception that stock changes influence prices negatively (Möbert, 2007). The constant positive coefficient in the model contradicts the common notion that an increase in stock levels will always cause negative price changes. As we argued in our hypothesis we can experience positive price changes and stock increases if the futures prices trade above the cost-of-carry model (see Appendix A.5 for a description of the model). This might cause physical hoarding, since it is profitable, and be taken as a sign of increased demand for crude oil.

***OPEC production quota***

The changes in OPEC quotas have had a negative effect on the changes in crude oil price. This is in accordance with our hypothesis. As OPEC increases the production quotas, more crude oil will flow into the market, creating greater supply and decrease prices. The relationship has diminished through the time period, indicating that price changes have become less influenced by the change in OPEC production quotas. Viewing this with respect to the price rise after 2004, with prices well above any ranges set by OPEC, indicates that the pricing power held by OPEC has been moderate during parts of the time period.

Even though the coefficient never displays a zero value relationship, we found earlier that changes in OPEC spare capacity is also significant and exhibits an increasing relationship with the crude oil price after 2005. This coincides with the same time period when the coefficient for change in production quotas settles at a lower level, and we wish to study the relationship between OPEC and crude oil prices further. We will do this by replicating the model set out by Kaufmann et al. (1995), (2004) using more recent data, which incorporates the recent market downturn. This is done in the next section.

***Refinery utilization***

Our empirical results show that change in refinery utilization, lagged two months back, has had a positive relationship with change in crude oil prices throughout the majority of the time period examined. High refinery utilization rates indicate shortages in the supply of crude oil and that a bottleneck might have existed in the downstream sector, which put upward pressure on the crude oil price. The time-varying beta coefficient in Figure 7 has a decreasing trend after 2000 which indicates that the refining sector made little contribution to the increase in the crude price after 2004. The weak relationship is not surprising, as earlier research on the relationship is ambiguous. Möbert (2007) found a positive relationship, while Kaufmann et al. (2005) found a negative relationship. We also see from the rolling correlation in Figure 13 that the correlation varies throughout the time period with a negative trend.

***Contango level***

Changes in contango level is in our linear regression model the factor with most explanatory power. As we expected, the relationship is negative, however the explanatory effect is decreasing almost continuously through the sample period. This indicates that the futures market position has become less important, which is especially visible after 2005, as the coefficient moves towards zero in 2008. This coincides with the first long period of continuous price rise in a contango market between 2005 and late 2007. After this the futures market returns to backwardation, reflecting the tight market conditions at the time and the crude oil price soars from 70 to 145 US Dollar per barrel, which is reflected by the increasingly negative beta coefficient in Figure 7.

In the beginning of 2009 traders experienced the highest contango spread in history when the oil market bottomed out. This was not sustainable situation, since the market had reached a point where either the back end of the futures curve had to adjust downward or the front end of the curve had to adjust upwards to avert an oil crisis in the medium term. As the recovery started, it was the front of the curve that moved up, and the contango level weakened (Fattouh, 2010).

The results from Figure 7 indicate that the futures market position offers less contribution to explaining recent price changes, especially after 2005. As argued earlier, the factor serves as an indicator for fundamentally weak and tight market conditions. This might explain the decreasing and low explanatory power of fundamental supply factors, such as changes in stock level and refinery utilization in the latter part of our sample period.

***Net positions non-commercials***

The net length of non-commercial position has had a positive relationship with the change in crude oil price. This is in accordance with our hypothesis as we expect an upward (downward) pressure on prices when the non-commercials increase (decrease) their net long positions.

Figure 7 shows that the relation has become more important during the time period studied. The beta coefficient more than doubled from 1995 to 2005, and remained at this level for the rest of the time period examined. We expect the strengthened relation could be related with the increased inflow of money into the crude oil futures market. In the last decade there has been a considerable growth in the commodity derivative markets, and financial institutions have heavily marketed commodity indexes as a way to diversify portfolios, and profit from the rising commodity prices. About 70 percent of the commodity index investments are invested in energy (of which mostly crude oil) contracts, following a strategy of continuously rolling long futures contract to maintain the investment (Hamilton, 2008). These new market participants have a different way of assessing asset prices and are more concerned with expectations about future fundamentals than the current market balance. Trades are executed in the futures market and may affect crude oil spot prices through, among other factors and links, the cost-of-carry model.

Change in non-commercials' net positions is together with change in contango level the variable with most explanatory power in our preferred model. This underscores the importance of considering the futures market when analyzing the crude oil price. The weakening in the explanatory power of supply variables and the reduced negative relationship between change in contago level and change in crude oil price, indicates that market current fundamentals on the supply side have become less important when determining crude oil prices, especially after 2005. The increased relationship between change in net length of non-commercial positions and change in crude oil price implies an increased role of the financial investors and traders in oil price movements. These results shows that new market participants have entered the crude oil market, and may have altered the traditional way in which crude oil prices are set.

Next in this thesis, we will investigate the causal relationship between the significant factors and crude oil price changes. Then we will, as mentioned, study the influence of OPEC further and finally investigate if the introduction of financial investors may have altered the price changes in the crude oil market.

## 5.3 Granger-causality

We employ a Granger-causality test to investigate the causal relationship between changes in the crude oil price and the explanatory variables (Granger, 1969). The variable $X$ is said to Granger-cause $Y$ if $Y$ can be better predicted using the histories of both $X$ and $Y$ than it can by using the history of $Y$ alone. Thus Granger-causality means that there is a correlation between the current value of one variable and the past values of another variable, but does not necessarily mean that movements in one variable directly cause movements in another. Hence, Granger-causality should not be interpreted as cause and effect, but rather as a lead and lag relationship between the variables.

The test is implemented by regressing equation (10) against equation (11), where an F-test (appendix A.4.6) is used to examine the null hypothesis of no causality. We perform the test in context of the fullyspecified model to avoid spurious interpretations. To determine direction of causality, the reverse model is estimated, as presented by equation (12) and (13).

$$Y_t = \alpha + \sum_{k=1}^{K} \beta_k Y_{t-k} + \sum_{k=1}^{K} \gamma_k X_{i,t-k} + \sum_{j=1}^{J} \lambda_j C_{j,t} + \sum_{s=1}^{S} \varphi_s \zeta_s + \mu_t \qquad \mu_t \sim NID(0, \sigma_\mu^2) \qquad (10)$$

$$Y_t = \alpha + \sum_{k=1}^{K} \beta_k Y_{t-k} + \sum_{j=1}^{J} \lambda_j C_{j,t} + \sum_{s=1}^{S} \varphi_s \zeta_s + \upsilon_t \qquad \upsilon_t \sim NID(0, \sigma_\upsilon^2) \qquad (11)$$

$$X_t = \beta_0 + \sum_{k=1}^{K} \beta_k X_{t-k} + \sum_{k=1}^{K} \gamma_k Y_{t-k} + \sum_{j=1}^{J} \lambda_j C_{j,t} + \sum_{s=1}^{S} \varphi_s \zeta_s + \mu_t \qquad \mu_t \sim NID(0, \sigma_\mu^2) \qquad (12)$$

$$X_t = \beta_0 + \sum_{k=1}^{K} \beta_k X_{t-k} + \sum_{j=1}^{J} \lambda_j C_{j,t} + \sum_{s=1}^{S} \varphi_s \zeta_s + \upsilon_t \qquad \upsilon_t \sim NID(0, \sigma_\upsilon^2) \qquad (13)$$

$Y$ is the dependent variable, change in crude oil price, and $X$ is the explanatory variable we intend to test against $Y$. $C$ represent the other explanatory variables in the model, $\zeta$ represent the included dummies, and $\mu$ and $\upsilon$ are error terms. As before, the error terms are assumed to be independent and normally distributed with mean zero and constant variance. $K$ is chosen as the minimum number of lags which avoid the problem of autocorrelation in the regression, and is found by using AIC. $J$ equals the number of explanatory variables in the model, subtracted the variable which are tested, and is therefore equal seven. $S$ represents the number of dummies found significant at 1 percent significance level. The test is implemented by using exclusion restrictions and F-tests[7] in the PcGive OxMetrics 6.0 software. Table 6 summarizes our findings. Two of the explanatory variables in the model are found to have a bi-directional (feedback) relationship with crude oil changes at 5 percent significance level; world growth and contango level. The bi-directional causal relationship between change in the variables and change in the crude oil price, indicate that they have influenced each other simultaneously through the time period studied. Further, we find strong statistical evidence of causality from change in crude oil price to change in stock level, with a weak feedback in the reverse direction. The causality from change in crude oil stock to change in crude oil price is surprising, as we not expect the crude oil price to influence the stock level. This finding is at odd with Kaufmann et al. (2004) which found no causality from stock level to crude oil price.

[7] The tests are performed with robust Heteroscedasticity and Autocorrelation Consistent Standard Errors (HACSE), which rest on a method presented in Andrews (1991) and are shown to perform well as long as the degree of autocorrelation is not large.

**Table 6: Granger-causality test**

| | **Oil price change Granger-cause variable change** | | **Variable change Granger-cause oil price change** | |
|---|---|---|---|---|
| | *Significant* | *P-value* | *Significant* | *P-value* |
| *World growth* | Yes | 0.0270** | Yes | 0.0354** |
| *Stock* | Yes | 0.0091*** | Yes | 0.0887* |
| *Rig utilization* | No | 0.2257 | No | 0.5656 |
| *OPEC sparecap* | No | 0.2044 | Yes | 0.0937* |
| *OPEC quota* | No | 0.3520 | No | 0.4641 |
| *Refinery utilization* | No | 0.6499 | No | 0.1826 |
| *Contango level* | Yes | 0.0192** | Yes | 0.0495** |
| *Net length* | Yes | 0.0016*** | No | 0.3185 |

*The table describes the results from Granger-causality tests between changes in crude oil price and changes in the significant variables. The test finds a bi-directional relationship for two of the variables at 5 percent significance level, and strong statistical evidence of causality from changes in stock level and changes in net length positions to changes in crude oil price. ***, **, * indicates that the relationships are significant at 1 percent, 5 percent and 10 percent significance level respectively.*

Change in OPEC spare capacity is the only explanatory variable which is found to have a unidirectional causality to change in crude oil, but the causality is only significant at 10 percent level. There is no statistical evidence of causal relationship between change in crude oil and change in rig utilization, refinery utilization, or OPEC quota. The lack of significant causal relationship between these variables may be due to their differing explanatory power in the selected model.

The Granger-causality test fails to indentify causality from change in non-commercial trader positions to change in crude oil price. Our results suggest that crude oil price changes influence changes in net positions of non-commercial traders, with no feedback in the reverse direction. The finding is congruent with Büyükşahin & Harris (2009) which investigated the role of the speculators in the crude oil futures market using non-public disaggregated data from CFTC. The unidirectional causality indicates that non-commercial traders are generally trend followers, which is an interesting finding concerning the question whether the non-commercial traders' net positions (length) in crude oil futures market have had an impact on market prices.

Summarized, the Granger-causality test supports our arguments that it is difficult to establish an adequate oil price model, especially for the purpose of forecasting. The presence of simultaneity, and the lack of causal relationships from explanatory variables to crude oil price, demonstrates that it is problematic to identify direction of influences in the crude oil market. We generally struggle to indentify significant causality from the explanatory variables to oil price. We think that this to some extent could be related to our low-frequency data.

## 5.4 OPEC's influence on crude oil prices

OPEC's influence on crude oil prices and their pricing power has been the source of various research and studies. OPEC should affect crude oil prices as the biggest organized oil producer and controlling over 2/3 of the world crude oil reserves. We replicate the structural model parameter specification set out by Kaufmann (1995), (2004) and later by Möbert (2007):

$$P\_crude = \alpha + \beta_1 S\_stock + \beta_2 OPEC\_quota + \beta_3 OPEC\_cheat + \beta_4 OPEC\_sparecap + \beta_5 Q1 + \beta_6 Q2 + \beta_7 Q3 + \sum_{i=8}^{I} \beta_i D_i \tag{14}$$

*P_crude* is the crude oil price, *OPEC_qouta* is the production last set before each month and *OPEC_cheat* and *OPEC_sparecap* are the magnitude in which the countries cheat on their production quotas and spare production capacity respectively. *Q1, Q2* and *Q3* are dummy variables for the first, second and third quarters respectively and *D* is the dummies for any events affecting oil supply during the sample period, identified in earlier, found significant at the 1 percent significance level.

We study the model given by (14) in the state-space framework described in the previous section. Earlier methods applied are the Dynamic Ordinary Least Squares (DOLS) developed by Stock and Watson (1993) and the Full Information Maximum Likelihood (FIML) of a Vector Error Correction Model (VECM) developed by Johansen (1988) and Johansen & Juselius (1990). Möbert (2007) found no cointegrating relations on a sample extending to 2006. Möbert's analysis also indicates structural breaks and high instability in the crude oil price model. This indicates that the mentioned methods above might not be appropriate when studying the relationship described in equation (14). We therefore utilize the time-varying model, which might contribute to a better understanding of how this relationship has changed during the sample period.

Model selection is again based on the AIC, but we only test models for level and slope, as seasonal components are already implemented by the quarterly dummy variables in equation (14). The model with fixed level and omitted slope gave us the best model fit.

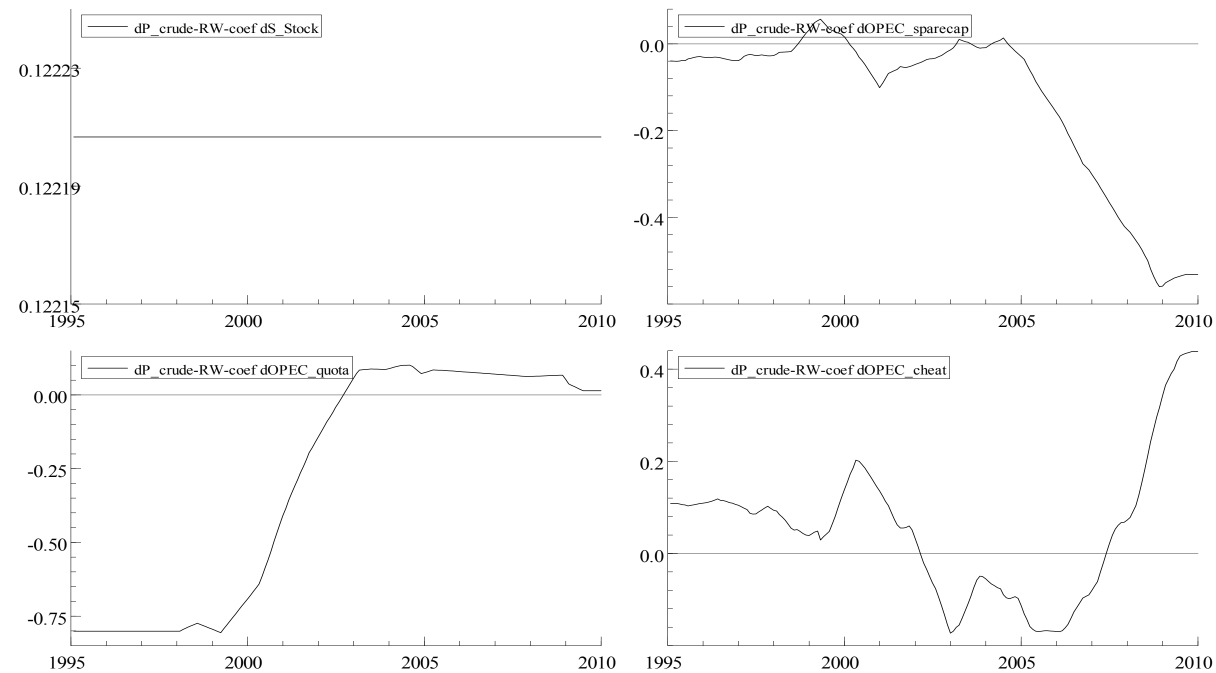


**Figure 9: Time varying beta coefficients for the OPEC model**

*The figure shows the random-walk time plots for each of the coefficients in the OPEC model in the sample period from 1995-2009.*

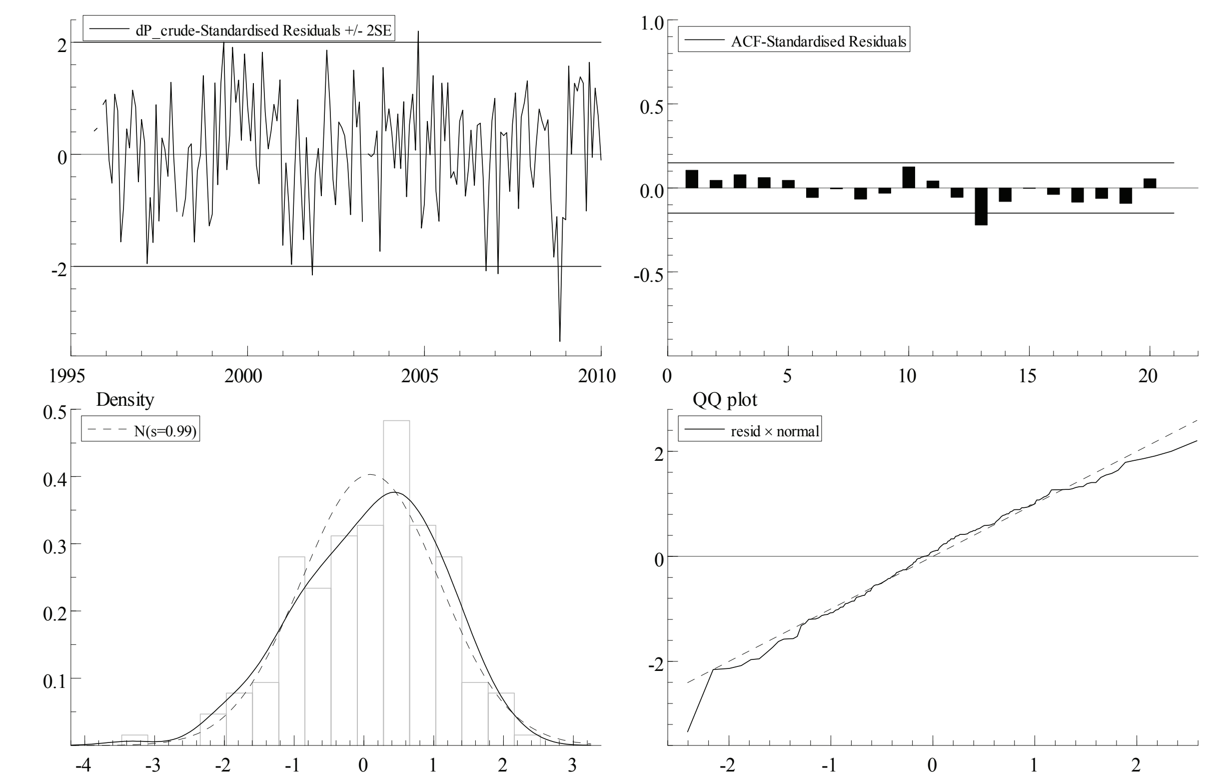


**Figure 10: Residual graphics for the OPEC model**

**Table 7: Summary of test statistics for the OPEC model**

| | | | |
|---|---|---|---|
| $R^2$ | 0.1089 | *H-test(56)* | 1.0990 |
| *DW* | 1.7758 | *Ljung-Box* | 19.532 |
| *Normality(2)* | 6.3747** | *AIC* | -4.5674 |

*$R^2$ is the goodness of fit, the Durbin-Watson test for residual autocorrelation, the Ljung-Box test statistic for residual autocorrelation, the Heteroscedastic test statistic and the Jarque-Bera Normality test statistic. ***, **, * indicates that the factors are significant at 1 percent, 5 percent and 10 percent significance level respectively.*

Examining model diagnostics in Figure 10 the null hypothesis of no autocorrelation is not rejected and there is no clear signs heteroscedasticity in the residuals. There are however some large negative outliers causing the null hypothesis of normal residuals to be rejected.

Figure 9 shows the random-walk process for the OPEC variables. Again the OECD days of stock cover is found to be stable during the whole sample period. OPEC spare production capacity shows the same increasingly negative relationship with crude oil prices after 2005 and seems to display a low degree of influence before this. Studying OPEC production quotas does however show some surprising results. The relationship is not only decreased, but it seems to be almost insignificant in the years after 2002. The relationship between crude oil prices and OPEC cheat is unstable and hard to determine during the time period, however it appears to mainly positive. This is surprising since we expect cheating on production quotas by OPEC member countries to cause an increase in supply and a negative influence on crude prices.

It seems as the OPEC factors' influence on crude oil price changes is not caused by OPEC's pricing power or their behavior as a cartel. OPEC's pricing power comes from setting production quotas. In particular, quota decisions can be viewed as signals to the market about OPEC's preferred crude oil price range. This signaling mechanism may or may not succeed depending on whether the market believes that OPEC is able to undertake the necessary output adjustment in different market conditions. OPEC has on many occasions succeeded in defending or controlling oil prices, but adjusting output downwards has sometimes proven to be unsuccessful. Because of different features between the OPEC countries agreements are hard to reach, and each country has an incentive cheat on the designated quotas (Fattouh, 2007b), especially in times of high oil prices.

Oil prices are determined largely by OPEC production capacity, which reflects the balance between the demand for oil from OPEC and additions to OPEC capacity. This implies that OPEC can influence oil prices by changing the rate at which it adds capacity, through quota decisions. But this is only possible when capacity can be adjusted both upwards and downwards. The point is particularly visible in the time period between 2003 and 2008 when crude oil prices rose well above price ranges set by OPEC, but the organization failed to increase quotas due to very low spare production capacity levels during the same time period. It seems that the underlying fundamentals of supply shortages, represented by the OPEC spare capacity, might have influenced crude oil prices more than the actual decision made on production quotas by the OPEC members.

## 5.5 Future expectations affecting crude oil prices

Our results indicate that there has been a structural break around 2005 in many of the significant factors explaining price changes in the sample period. A loss of explanatory power is especially visible for the contango level coefficient, which indicates that fundamental variables on the supply side have lost some of their explanatory power. We have also shown that economic growth only offers real explanatory power in times of economic declines. In addition, the entry of financial investors seems to have affected the crude oil price, if not by their positions then by their relative size and different mindset towards how prices of financial assets are set. This has led to a notion that there might be some other explanatory variables that have become significant during the sample period, and especially after 2005.

One explanation is the dual nature of crude oil as a physical commodity and a financial asset. Fattouh (2010), among others, highlights the increased importance of the role of future expectations, new market participants and the interactions between these. Financial assets are priced almost solely on the expectations of future earnings and cash flows, which is associated with future fundamentals, and especially future economic growth.

We use the Morgan Stanley Capital International World Index (MSCI) to see how future expectations on market fundamentals on the demand side and the risk willingness of financial investors have affected crude oil price changes through our period. The factor will also let us investigate if the dual nature of crude oil is a recent phenomenon. To do this we utilize the same time-varying model investigated earlier in section 5.2, only adding MSCI as an additional explanatory variable[8]. The factor is not found to be significant through the whole time period, however it is found to be significant between 2006 and 2009. The time-varying coefficient of MSCI variable is shown in Figure 11.[9]

[8] We back-tested our initial model selection process including the MSCI variable in the GUM. The factor was not chosen by our selection process; that is it is not found to be significant during the whole time period. Another point we stress is that the factor is not a fundamental factor that should be confused with the other defined variables, but is the best proxy for expectations in the financial market and willingness to take on risk by financial investors.
[9] The factor does not affect the other factors considerably and the model still passes the test diagnostics. All factors with the included MSCI variable is presented in Appendix A.6.

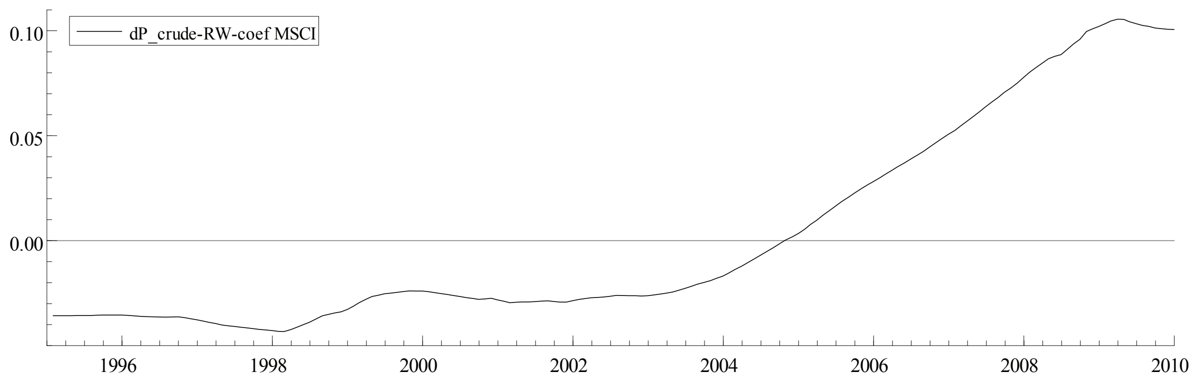


**Figure 11: Time-varying coefficient for the MSCI factor**

From Figure 11 we note that the relationship between changes in the global stock market and changes in the crude oil price is negligible before 2005. After this the relationship increases considerably and confirms the theory that oil prices have been more affected by future expectations like other financial assets after the structural changes in 2005.

## 5.6 Model weaknesses and alternative approaches

We have in this thesis chosen to utilize logarithmic differentiated data series. As discussed in the methodology section, we regard this to be an appropriate method in our case. However, even though the approach is statistically valid, it is not without weaknesses. A disadvantage is the loss of information about long-term relationships. This is particularly a problem for the change in OPEC quota variable, where the number of non-zero observations is small. Further, modeling with differentiated data series, we are not able to capture all potential bottlenecks. For instance, rig utilization rate is above 90 percent in the period 2005-2008, which means almost maximum utilization. The persisting high utilization rate contributes to an upward pressure in prices for oil services, and thereof on the production cost for each barrel of oil produced. But our model approach is not able to capture this fact, as it only considers change in the data series. This may explain the decreasing relation between crude oil price changes and change in rig utilization between 2005 and 2008 in Figure 7. The same problem also applies to refinery utilization.

A possible solution to the problems with differentiated data would have been to employ an ECM (using non-transformed data), as carried out by (Kaufmann R. , Dèes, Karadeloglou, & Sànchez, Modelling the world oil market: Assesment of a quarterly econmetric model, 2005) and (Möbert, 2007). This approach, however, does not facilitate examination of time-varying coefficients without further adjustments. In order to investigate time-varying relation a State-Space Error Correction Model (SPECM) could be used, but this methodology is new and is to our knowledge not utilized in existing literature.

The linear model selection process identifies some explanatory factors significant at the 10 percent significance level and others that are highly significant, higher than the 1 percent level. The significance of each explanatory variable is likely to vary throughout the time period, and this is why the selection criteria is set so wide. However, in the state-space model the statistical significance of each variable is not tracked through time and the method might award too much influence on some variables in certain time periods.

The results from the Granger-causality tests indicate that the explanatory variables used in the selected model are not strictly exogenous. However, the problem of simultaneity is fairly common in regression models, and does not necessarily have serious consequences for the results of the model. We consider the consequences of omitting affected variables as more disadvantageous for the results than some simultaneity in the data. Further, we note that the low frequency of the data may affect the results of the causality-testing. Hence, use of monthly data may conceal causality or the true lead-lag relationship between variables.

# 6. Conclusions

We develop and study a state-space model for the underlying factors affecting monthly crude oil price changes for the time period from 1995 to 2009. This is to our knowledge the first time-varying approach on a broad set of crude oil determinants. A set of eight explanatory variables is found to be significant over the whole sample. The evaluated factors are shown to behave mainly in accordance with our hypothesis, and we argue that the dynamics of most factors could be explained with changes in market conditions and in a macroeconomic picture. The methodology enabled us to explore and identify dynamics and structural shifts in the underlying factors. We illustrate that there seems to be a structural break in many of the factors, and hence in the price determination, before and after 2005.

Our analysis show that crude oil price changes over the time period cannot be attributed to one single market factor, or a subset of factors, alone. This indicates that rather looking for explanations in a subset of explanatory variables it is useful to study a broader set when explaining price changes. We show that price changes can be explained by several factors, including demand fundamentals in times of economic distress, bottlenecks in the upstream sector and OPEC spare capacity, as well as developments in the futures market, in related time periods. The state-space model approach also illustrates that the relative strength between the variables vary through the sample.

Earlier research shows that the decisions made by OPEC are still influential (Masters, 2008). In the time period before 2005 we partly confirm these results. However, the empirical studies identify a structural break around after this. It seems that the increased influence from OPEC after 2005 stem from the lack of spare capacity on the supply side and not from increased pricing power by adjusting production quotas. OPEC acts as a swing producer in the world oil market and with production capacity pushed to the limit, there was little supply buffers left in the market between 2004 and 2008 to control the rapid increase in crude oil prices.

The empirical results show that futures market variables have the highest explanatory power through the time period. The analysis indicates that the influence of the futures market increases almost continuously through our sample period. Our findings suggest that the market current fundamentals on the supply side have become less important for price determination, and that the increased participation of financial investors in the crude oil futures market may have altered the traditional way in which crude oil prices are set. We suspect that crude oil prices have become more affected by future expectations, similar to financial assets.

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# Appendix

## A.1 Individual time-varying coefficient plots

Figure 12 shows the additional graphical analysis of the different coefficient's time-varying relationship with changes in the crude oil price, independent of the other factors. Hence, we obtain independent models for each explanatory variable are obtained, and ideally these models should not differ extensively from the joint model presented in the earlier section.

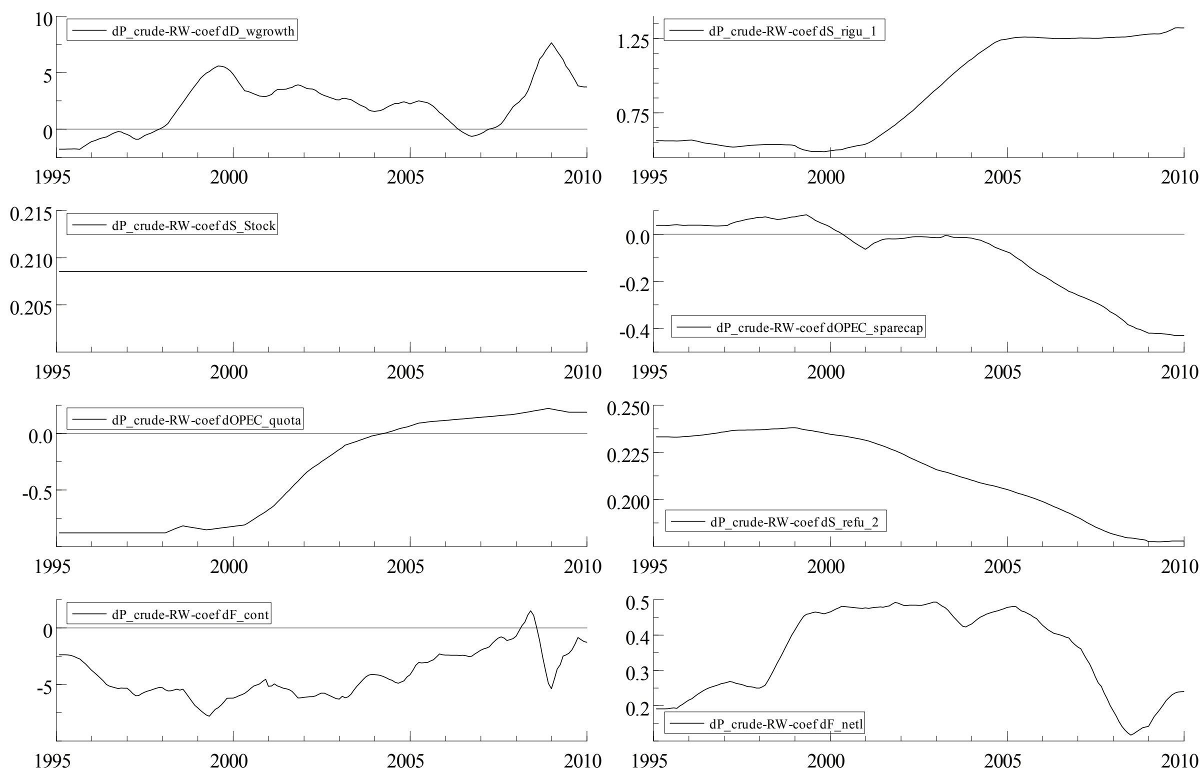


**Figure 12: Time-varying beta coefficients for the state-space model, analyzed individually**

We note there is not any harmful changes affecting our conclusion from the independent model. The plot shows that most coefficients display similar paths as those obtained in our main model previous in the paper. The factor explaining net length of non-commercial traders have changed in the last years of our sample period. This can most likely be attributed to the fact that the non-commercials traders kept their long positions through the financial crisis of 2008, and did not go net short. The results do however not question our main results, as this is proven to the most explanatory and efficient model given the influence of all eight factors simulatenously.

## A.2 Correlation-matrices

**Table 8: Correlation matrix, time series**

| | *D-wgrowth* | *D_exch$* | *S_rigu* | *S_rigu_GoM* | *S_stock* | *S_vlcc* | *OPEC_sparecap* | *OPEC_quota* | *OPEC_cheat* | *S_refu* | *F_cont* | *F_p.oi* | *F_netl* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *D-wgrowth* | 1 | | | | | | | | | | | | |
| *D_exch$* | -0.13 | 1 | | | | | | | | | | | |
| *S_rigu* | 0.55 | -0.29 | 1 | | | | | | | | | | |
| *S_rigu_GoM* | -0.51 | 0.00 | 0.03 | 1 | | | | | | | | | |
| *S_stock* | 0.31 | -0.36 | 0.23 | -0.50 | 1 | | | | | | | | |
| *S_vlcc* | 0.29 | 0.01 | 0.16 | 0.28 | -0.37 | 1 | | | | | | | |
| *OPEC_sparecap* | -0.41 | 0.35 | -0.49 | -0.28 | 0.14 | -0.67 | 1 | | | | | | |
| *OPEC_quota* | 0.69 | -0.29 | 0.67 | 0.10 | 0.06 | 0.50 | **-0.78** | 1 | | | | | |
| *OPEC_cheat* | -0.37 | 0.05 | -0.28 | 0.02 | -0.10 | -0.05 | 0.13 | -0.58 | 1 | | | | |
| *S_refu* | -0.60 | 0.17 | -0.24 | 0.61 | -0.28 | 0.03 | 0.01 | -0.22 | 0.22 | 1 | | | |
| *F_cont* | 0.39 | -0.12 | 0.47 | -0.34 | 0.61 | -0.23 | 0.00 | 0.28 | -0.19 | -0.32 | 1 | | |
| *F_p.oi* | **0.94** | -0.17 | 0.50 | -0.62 | 0.41 | 0.18 | -0.34 | 0.57 | -0.25 | -0.67 | 0.45 | 1 | |
| *F_netl* | 0.55 | -0.45 | 0.10 | -0.46 | 0.42 | -0.08 | -0.05 | 0.20 | -0.17 | -0.40 | 0.12 | 0.58 | 1 |

*Correlation coefficients above the absolute value of 0.8 might cause problems with mulicollinearity and are marked.*

**Table 9: Correlation matrix, transformed data**

| | *dD_wgrowth* | *dD_exch$* | *dS_rigu* | *dS_rigu_GoM* | *dS_stock* | *dS_vlcc* | *dOPEC_sparecap* | *dOPEC_quota* | *dOPEC_cheat* | *dS_refu* | *dF_cont* | *F_cont(level)* | *dF_p.oi* | *dF_netl* | *F_netl(level)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *dD_wgrowth* | 1 | | | | | | | | | | | | | | |
| *dD_exch$* | -0.25 | 1 | | | | | | | | | | | | | |
| *dS_rigu* | 0.05 | 0.11 | 1 | | | | | | | | | | | | |
| *dS_rigu_GoM* | 0.05 | -0.10 | 0.08 | 1 | | | | | | | | | | | |
| *dS_stock* | -0.13 | -0.01 | -0.11 | 0.06 | 1 | | | | | | | | | | |
| *dS_vlcc* | 0.21 | -0.05 | 0.03 | 0.11 | -0.07 | 1 | | | | | | | | | |
| *dOPEC_sparecap* | -0.24 | 0.05 | -0.11 | -0.09 | 0.01 | -0.25 | 1 | | | | | | | | |
| *dOPEC_quota* | 0.24 | -0.07 | 0.07 | 0.07 | 0.01 | 0.01 | -0.19 | 1 | | | | | | | |
| *dOPEC_cheat* | -0.02 | 0.05 | 0.06 | -0.06 | -0.17 | 0.16 | -0.16 | -0.56 | 1 | | | | | | |
| *dS_refu* | 0.04 | 0.00 | 0.01 | 0.13 | 0.05 | -0.03 | -0.03 | -0.05 | 0.03 | 1 | | | | | |
| *dF_cont* | -0.31 | 0.08 | 0.09 | 0.07 | 0.03 | 0.10 | 0.00 | -0.09 | 0.02 | 0.14 | 1 | | | | |
| *F_cont(level)* | -0.23 | 0.03 | -0.27 | -0.23 | 0.05 | -0.16 | 0.23 | -0.24 | -0.03 | 0.01 | 0.22 | 1 | | | |
| *dF_p.oi* | -0.01 | 0.10 | 0.13 | -0.15 | -0.07 | -0.17 | 0.07 | 0.08 | -0.04 | 0.02 | -0.21 | -0.07 | 1 | | |
| *dF_netl* | 0.11 | -0.16 | 0.02 | 0.06 | 0.02 | -0.13 | 0.09 | -0.09 | -0.04 | 0.00 | -0.28 | 0.03 | 0.24 | 1 | |
| *F_netl(level)* | 0.06 | -0.10 | -0.05 | 0.06 | 0.04 | 0.13 | -0.08 | 0.00 | 0.10 | -0.02 | 0.01 | 0.11 | -0.10 | -0.29 | 1 |

*Correlation coefficients above the absolute value of 0.7 might cause problems with mulicollinearity and are marked. There are no problems with multicollinearity in the transformed data.*

## A.3 Rolling correlation plots

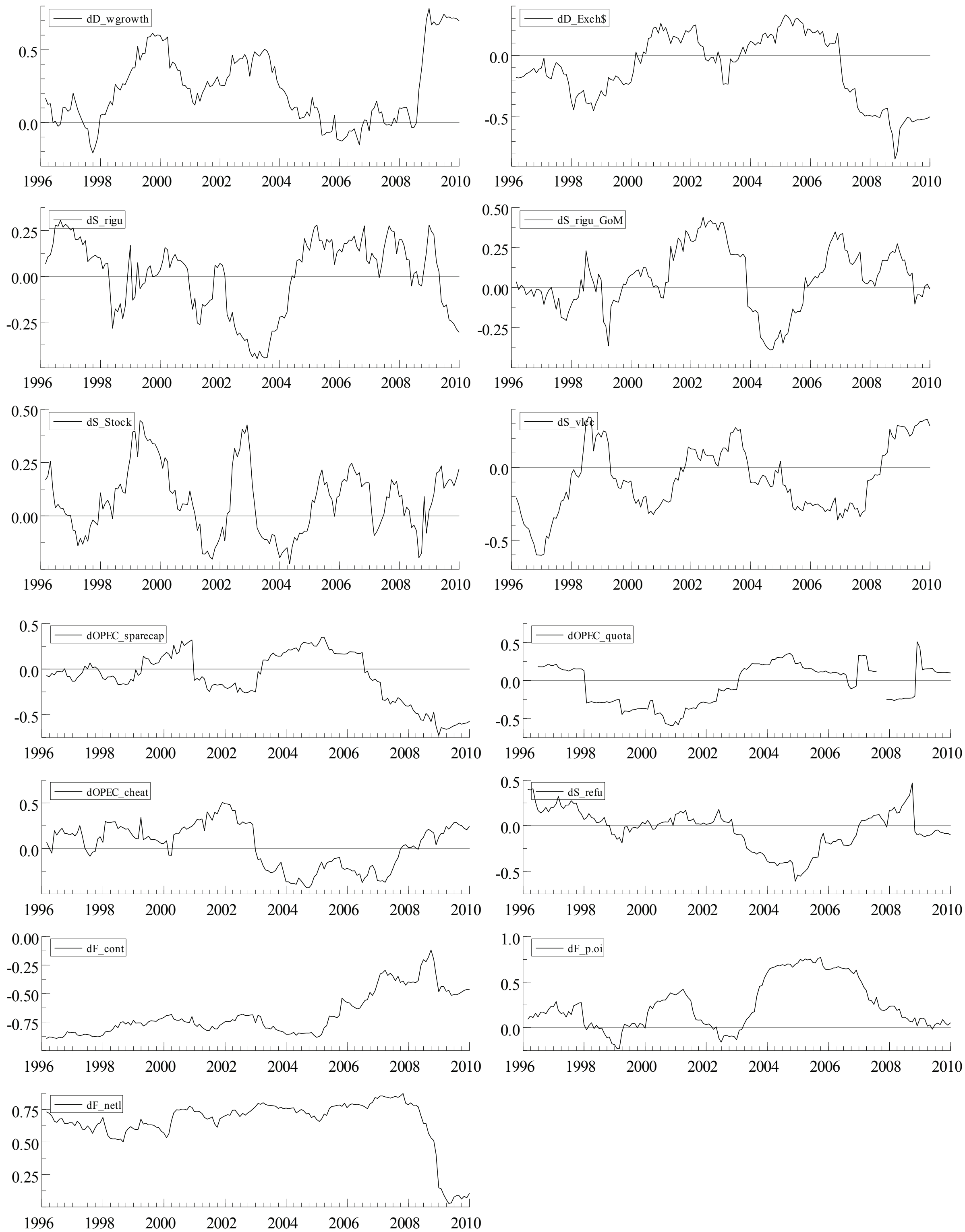


**Figure 13: Rolling correlations**

*The figure shows the 24 month rolling correlation plots between changes in the crude oil prices versus the changes in each of the explanatory variables from 1996 to 2009. One year is omitted in the calculation due to data constraints.*

## A.4 Statistical concepts used

### *A.4.1 Test for stationarity: ADF*

The foundation of ordinary linear time series regression is stationary processes. If any of the time series are non-stationary, this can strongly influence the behavior and properties of our regression. For instance will persistence of shocks be infinite for non-stationary series, while for stationary processes they will gradually die away. Another serious problem is that in case of non-stationary processes the t-ratios will not follow a t-distribution, so we cannot validity undertaken hypothesis about the regression parameters.

A time series is stationary if the following is true for all variables.

$$E(y_t) = \mu$$
$$E(y_t - \mu)(y_t - \mu) = Var(y_t) = \sigma^2$$
$$E(y_{t_1} - \mu)(y_{t_2} - \mu) = Cov(y_{t_1}, y_{t_2}) = \gamma_{t_2 - t_1}$$

That is constant mean, constant variance and constant autocovariance structure, respectively. A non-stationary series must be differenced d times before it becomes stationary. So an I(0) series is stationary, while an I(1) series contains one unit root.

To test for unit roots, we use the augmented Dickey-Fuller (ADF) test statistics. The objective for the test is to examine the null hypothesis that $\psi$=0 (series contains a unit root) in the model;

$$\Delta y_t = \psi y_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta y_{t-i} + u_t$$

The model correct for potential autocorrelation in $u_t$ by using $p$ lags of the dependent variable. The Akaike information criterion (Appendix A.3.9) is used to determine the optimal number of lags of the dependent variable. The test statistic follows a non-standard distribution and is defined as;

$$test\_statistic = \frac{\hat{\psi}}{S\hat{E}(\hat{\psi})}$$

Critical values are derived from simulation experiments. If the test statistic is greater than the critical value the null hypothesis of non-stationarity is rejected.

### *A.4.2 Goodness of fit statistic: $R^2$*

The most common goodness of fit statistic is known as $R^2$ (Brooks, 2002). $R^2$ is a measure of the proportion of variability explained by the fitted regression model. This can be calculated from the total sum of squares (*TSS*) and the residual sum of squares (*RSS*). The *TSS* is the total variation across all observations about its mean value, while the *RSS* is the part of the *TSS* which is not explained by the regression model. The expression for $R^2$ can be derived as;

$$R^2 = 1 - \frac{RSS}{TSS} \qquad TSS = \sum_{i=1}^{n} (y_i - \bar{y})^2 \qquad RSS = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

Hence, the value of $R^2$ is within zero and one. The higher the value of $R^2$, the more variability is explained by the regression model.

***A.4.3 OLS-assumptions***

Linear Gaussian regression models are based on three assumptions concerning the residuals of the analysis. In order to be a white noise process the residuals should satisfy three important properties, namely independence, homoscedasticity and normality. That is zero autocovariance, except at lag 0, and constant variance and mean.

$$\gamma_{t-r} = \begin{cases} \sigma^2 & \text{if t=r} \\ 0 & \text{otherwise} \end{cases}$$
$$Var(\varepsilon_t) = \sigma^2 < \infty$$
$$E(\varepsilon_t) = \mu$$

Tests performed to check these assumptions are described in appendix A.4.4 – A.4.6

***A.4.4 Test for autocorrelation: Ljung-Box portmanteau test***

Autocorrelation exist when the errors are correlated with each other, and is a serious problem in regression analysis. Consequences of ignoring autocorrelation if its present is that the coefficient estimates derived using OLS are inefficient, even though they are still unbiased. So if the standard error estimates are inappropriate, there exists a possibility that we could make wrong inferences. The problem of autocorrelation could often be solved by extending the model from static to dynamic by including lags of the dependent variable. However, inclusion of lagged values of the dependent variable is not without problems. For instance will inclusion of lagged values of the dependent variable violated the assumption that the right hand side (RHS) variables are non-stochastic (Brooks, 2002).

To test for autocorrelation we observe the autocorrelation-plot and employ the Ljung-Box portmanteau test of linear dependence (Ljung & Box, 1978), with the following test statistic;

$$LB(s) = T^2 \sum_{k=1}^{m} \frac{\hat{\tau}_k^2}{T-k} \sim \chi_m^2(s-n)$$

The test statistic corresponds to Box and Pierce (1970) Q-statistic, but with a degrees of freedom correction for better small sample properties. Under the assumptions of the test, LB(s) is asymptotically distributed as $\chi_m^2(s-n)$ after fitting an AR(n) model. The null hypothesis is that the autocorrelation coefficients are jointly zero, while the alternative hypothesis is that they are not random.

***A.4.5 Test for heterocedasticity: White's test***

Heteroscedasticity means that the variance of the residuals in the regression is not constant, and violates the assumptions for linear regression. In the case of heteroscedasticity the least squares estimator is still a linear and unbiased estimator, but it is no longer the best linear unbiased estimator. So the standard errors computed for the least squares estimator are incorrect. This implies that other than the least squares estimators should be applied. To test for heteroscedasticity we employ the Oxmetrics' version of the White test (White, 1980).

The test is based on an auxiliary regression of the squared residuals on all the squares and cross-products of the original independent variables, and with a normally distributed disturbance term independent of the original error term. Redundant variables like squares of dummy variables are omitted from the regression (Doornik & Hendry, 2009).

*Original regression:* $y_t = x_{i,t}\beta_i + \varepsilon_t$

*Auxiliary regression:* $\hat{u}_t^2 = \alpha_i x_{i,t} + \gamma_i x_{i,t}^2 + \varsigma_i x_{i,t} x_{i+1,t} + v_t$

Lagrange Multiplier approach is adopted to evaluate the regression, and take use of the $R^2$ –value (Appendix A.3.2) of the auxiliary regression. If one or more coefficients in the auxiliary regression is statistically significant, the value of $R^2$ will be relatively high. Likewise, if none of the variables is significant $R^2$ will be relatively low. The test would thus operate by obtaining $R^2$ from the auxiliary regression and multiplying it by the number of observations, *T*. So

$$T \times R^2 \sim \chi^2(m)$$

Where m is the degrees of freedom for the chi-square distribution and equals the numbers of regressors in the auxiliary regression. The null hypothesis is that $\alpha_i, \gamma_i, \varsigma_i$ are jointly zero. If the test statistic is greater than the critical value then reject the null hypothesis that the errors are homoscedastic, so the model has heteroscedastic regression errors.

### *A.4.6 Test for normality: Jarque-Bera test*

To test for normality we apply the Jarque-Bera test (1981), which is also known as the Bowman-Shenton test. The test uses the property of a normally distributed random variable that the entire distribution is characterized by the first two moments; the mean and the variance (Brooks, 2002). The third and fourth moments of a distribution are the skewness and kurtosis. The Jarque-Bera tests whether the coefficient of skewness and coefficient of excess kurtosis are jointly zero, with the following test statistic;

$$JB = \frac{T}{6}(skewness^2 + \frac{(excess\_kurtosis)^2}{4}) \sim \chi^2(2)$$

where $T$ is the sample size. The test statistic asymptotically follows a chi-square distribution with two degrees of freedom under the null hypothesis that the residuals are normally distributed. If the test statistic is lower than the critical value the null hypothesis of normality is not rejected.

### *A.4.7 Test for misspecification: RESET-test*

To test for misspecification of the functional form of the linear regression, we employ the Ramsey's RESET (Regression specification test) test (Ramsey, 1969). The method works by adding higher order terms of the fitted values into an auxiliary regression, so that the residuals from the original regression are regressed on powers from of the fitted values.

*Auxiliary regression:* $\hat{u}_t = \beta_1 + \beta_2 \hat{y}_t^2 + ... + \beta_p \hat{y}_t^p + v_t$

The value of $R^2$ (appendix A.3.2) is obtained from the auxiliary regression, and set into the following test statistic;

$$T \times R^2 \sim \chi^2(p-1)$$

The test statistic is asymptotically distributed as a chi-square distribution with *p - 1* degrees of freedom, where *p* is the highest order term in the fitted values used in the auxiliary regression and *T* is the number of observations (Brooks, 2002). RESET23 which is the version of the test employed in the Oxmetrics software uses power up to three by including squares and cubes (Doornik & Hendry, 2009). If the value of the test statistic is greater than the chi-squared critical value, we reject the null hypothesis that the functional form was correct.

### *A.4.8 Testing multiple hypotheses: the F-test*

The f-test is used to test hypotheses which involve more than one coefficient simultaneously (Brooks, 2002). Under the framework, two regressions are required; the unrestricted and the restricted regressions. The unrestricted regression is the one in which the coefficients are freely determined by the data, while the restrictions are imposed on some betas for the restricted regression. The residual sums of squares from each regression are determined, and two residual sums of squares are compared in the test statistic;

$$test\_statistic = \frac{RRSS}{URSS} \times \frac{T-k}{m}$$

Where $T$ is the number of observations, $m$ is the number of restrictions and $k$ is the number of regressors in the unrestricted regression. *RRSS* and *URSS* are the residual sum of squares from the restricted and unrestricted regressions, respectively. The null hypothesis of equal betas is rejected if the test statistic exceeds the critical F-value.

### *A.4.9 Multicollinearity*

Multicollineariy describes the situation where the explanatory variables are very close correlated with each other (Brooks, 2002). In this case there is no guarantee that there will be possible to isolate the parameters of interest, and due to large standard errors the model will be very sensitive to small changes in the specification. There is no clear limit value for multicollinearity, but Tabachnick and Fidell (1989) states that a correlation coefficient between two explanatory variables greater than 0.7 in absolute value indicates a collinear relationship which is potentially harmful.

### *A.4.10 Information criteria*

Information criteria consist of two factors, a term which is a function of the residual sum of squares (RSS), and some penalty for the loss of degrees of freedom from adding extra parameters. The object is to choose the number of parameters which minimizes the value of the information criteria. We are using two different criteria in this thesis. Akaike's information criterion (AIC) is used to evaluate the state space model, while Schwarz's Bayesian information criterion (SBIC) is used in the OxMetrics Autometrics function (appendix A.7). These are defined as;

$$AIC = \ln(\hat{\sigma}^2) + \frac{2k}{T}$$

$$SBIC = \ln(\hat{\sigma}^2) + \frac{k}{T}\ln T$$

Where $\hat{\sigma}^2$ is the residual variance, k=p+q+1 is the total number of parameters estimated and T is the sample size. As seen from the formula above, SBIC embodies a much stiffer penalty term for adding extra parameters than AIC.

### *A.4.11 The Autometrics function in PcGive OxMetrics software*

Autometrics is an automatic model selection program, created by Jurgen Doornik (2009). The program starts with a general unrestricted model (GUM), covering the entire initial dataset. The GUM must provide sufficient information on the process being modeled, and has to be statistically well-behaved. Hence, we need to check all the data series using diagnostic tests (as described in the theoretical framework). Autometrics' next step is to perform a multiple path search. For each insignificant variable the GUM defines a path, the program deletes that variable and continues with backward deletion, one variable at time. Each path is followed until termination, leaving only significant variables. The program then tests the resultant path with respect to the GUM to prevent too great a loss of information. This terminal is also subjected to diagnostic tests and if rejected, the path is followed in the reverse direction until a suitable model is found (Schipperhein, 2008). Usually several terminal models are selected by the program. In this case the Autometrics combines the elements of the selected terminals and creates a new GUM, after which the procedure starts all over again. When the next GUM equals the former one, and still several models remain, an information criterion is applied to choose among them. The Autometrics use the Schwarz information criterion (see appendix A.3.8).

## A.5 Cost-of-carry model

The cost-of-carry model states that the futures price should equal the spot price plus the cost of carrying or holding the position, which is also referred to as the basis or contango level in this thesis. The cost of carry for storable commodities, such as crude oil, refers to the risk-free rate that could be earned by investing in a risk-free asset. The cost of storage is added to the cost of carry, to compensate for costs regarding this. There is also a convenience yield associated with benefits of physically holding the asset and not the contract for future delivery.

$$F_{t,T} = S_t e^{(r+s-c)(T-t)}$$

Where, $F_{t,T}$ is the futures price at time $t$ with delivery at time $T$, $S_t$ is the spot price at time $t$, r is the risk-free rate, s is the storage cost and c is the convenience yield (given in percent).

Arbitrage constriction makes this relationship hold. If the futures price is higher than the spot price plus the cost of carry, then arbitrageurs will buy the spot asset and sell the futures contract and make a riskless profit. The cost-of-carry model illustrates that the futures market cannot drift too far into contango over long periods of time. The same argument holds for backwardation. If futures prices are less than the spot price plus the cost of carry, owners of the physical asset will choose to sell the commodity in the spot market and buy a contract for future delivery. This creates a risk-free profit from the basis and the fact that the arbitrageur avoids storage cost (Chance & Brooks, 2010).

The model is useful when studying contango levels in the crude oil market. When the market is in contango the convenience yield is low, indicating less benefits of holding the physical asset and little expectations of sudden supply shortages. Backwardation markets are associated with high convenience yields and fears of supply shortages in the near term.

## A.6 Time-varying coefficient plots including MSCI factor

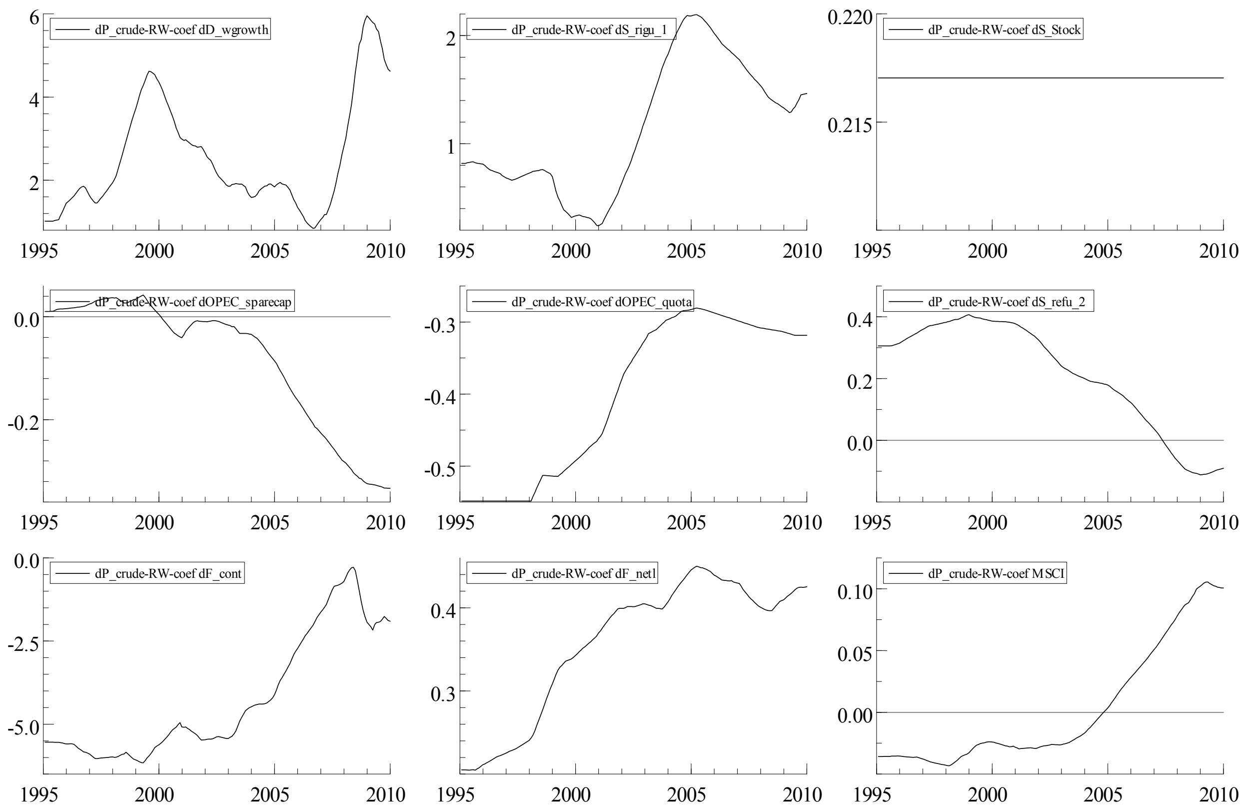


**Figure 14: Time-varying coefficients including the MSCI factor**

We note the addition of the MSCI factor does not change the other coefficients considerably as the factor is only significant from the time period from 2006 to 2009. The relationship between changes in the global stock market index and changes in the crude oil price is only significant in the period from 2005 and 2009.