

Risk Management in the Crude Oil Market

Market efficiency and hedging strategies

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Abstract

This thesis aims to explore two main issues. First we study crude oil prices in view of weak-form efficiency. Thereupon we look into different hedging strategies that could be used to stabilize income in a market with high volatility. The data used are crude oil prices of West Texas Intermediate between 1987 and 2010. We conclude that the spot crude price and the 3 month future price for the same oil type are weak-form efficient. The two prices tend towards a long-run equilibrium and differences in prices are quickly adjusted. OPEC's role in the market is discussed as a weakness to price efficiency. Based on efficient prices, we find that the minimum variance hedging method gives the lowest risk, but a naive hedge ratio is easiest to implement in a business strategy for a risk averse management. On the other hand, a risk neutral oil company would get a higher added return by merely buy and sell in the spot market. By introducing a multiple risks hedging model consisting of price risk and exchange rate risk, we suggest that a Norwegian company could reduce its total risk of the portfolio by increasing its exposure in the currency market.

Preface

Working with the report has been a demanding, challenging and educational process. We have learned a lot regarding the oil business and the oil price. This is experience we have harvested huge benefits from and might use in future work.

We want to thank our advisor Knut Kristian Aase, who primarily has served as a source of inspiration and critics. We would also like to thank the people we interviewed in the process. They took the time and effort to provide us with interesting and useful information.

Bergen, June 20th 2010

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1 Introduction

Our motivation for writing this thesis is partly due to the recent financial crisis. The oil price has been very volatile the last years, resulting in incentives for both buyers and sellers to hedge against these fluctuations. For Norway, a net exporter of oil, a high oil price is favorable as this result in increasing revenues for the Norwegian oil companies, and the Norwegian government. We therefore focus on the supply side of the oil market in our thesis. Studies show that companies tend to use hedging in futures contracts when the outlook is poor and they tend to have no protection when the prospects are good (Knill et al, 2006). If oil prices follow a random walk, the prices cannot be predicted. If the management of oil companies is risk averse, they should perhaps have a fixed risk profile, regardless of expectations.

The efficient market hypothesis has often been attacked by experts and traders who argue that the market cannot be efficient when we experience crisis. In the highlight of this we want to investigate if the oil price is efficient. We want to look at long- and short term effects of the spot and the futures market for oil, in order to establish the relationship between these. It is interesting to see whether the physical spot market and the financial futures market differ from each other regarding the efficiency hypothesis. We would expect a financial market to be efficient. On the other hand, we will suspect that the physical market could be inefficient because of OPEC's dominant position.

The problems for the thesis boil down to two main topics: 1) Is the crude oil markets efficient? and 2) In which way should a risk averse management use hedging to face a high volatility in the oil market?

We will in this thesis start off by giving an overview of the crude oil market and underlying theories which will give a more explicit overview for the further work. In chapter three we will carry out the methodology we use. We will use West Texas Intermediate (WTI) prices in our empirical research, and the data descriptive will be presented in chapter four. In the analyze section we first test the efficient hypothesis. Previous studies done by Green and Mork(1991), Gjølberg(1985) and Gülen(1998) show that empirical studies have different

results on efficiency in the oil markets. We therefore find it interesting to include more recent observations which contain highly volatile periods to test for weak-form efficiency.

In the second part of the analyze section we study different strategies with respect to the price risk. Our main focus will be the naïve and the minimum variance hedging strategy. In the last part we will also include the exchange rate risk in our models. To finalize we will compare the models using hedging effectiveness, but also look at the added return and the portfolio's risk.

2 Theory

2.1 Overview of the oil market

To get a clearer picture of the content of this thesis, we start off by presenting the development of the crude oil price in the past and also give an overview of the situation today. This information gives a foundation for further understanding our analysis and results.

2.1.1 The oil market in a historical perspective

Before we start analyzing the oil market and the futures market for oil it can be worth mentioning some of the extraordinary periods in the oil market. The development in the oil prices from 1970 to 2010 is shown in Figure 2.1. Crude oil is traded in barrels and U.S. dollars are the main currency. One barrel of oil equals approximately 159 liters.

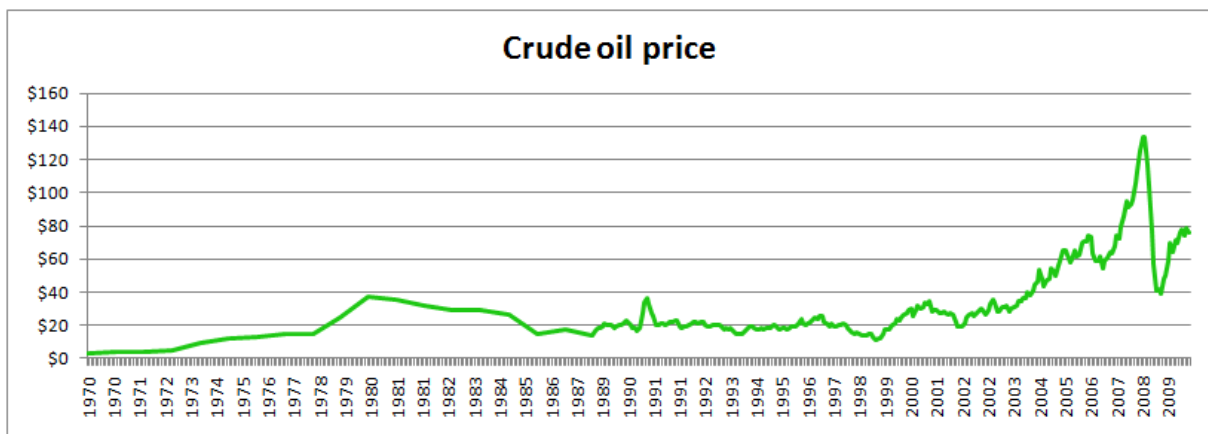


Figure 2.1: Shows historical nominal crude oil prices. Yearly prices are used from 1970 to 1987, and monthly prices from 1988 until today.

In the 1950s and 1960s the real oil price was relatively stable around \$3 dollar per barrel, but the 1970s and especially in 1973-74 marks a watershed. Since 1970 the oil price has been subject to several major breaks; it rose dramatically in 1973-75 and again in 1979-81 and fell steeply in 1986. Since the 2000 the prices has been increasing significantly, but the prices fell sharply during the financial crises.

The establishment of OPEC

The Organization of the Petroleum Exporting Countries (OPEC) was created at the Baghdad Conference in Iraq in September 1960. The organization was founded with the purpose to limit the supply in order to keep prices high. The members of OPEC meet on a regular basis to set production quotas, in order to influence the price. (Rousseau, 1998)

Yom Kippur War

In 1970 the demand for oil began to outstrip the production. As the world market for oil got tighter the Arab countries started to use the oil power to achieve economic and political objectives. This development peaked in 1973 when Egypt and Israel went to war. Saudi Arabia refused to increase production in order to halt rising prices unless the U.S. backed the Arab position. OPEC agreed to set a new and much higher price for oil amongst the member countries (from 3 dollars to 11.65 per barrel). This was a major rise in prices and affected the oil importing countries significantly. (Rousseau, 1998)

Iraq – Iran War

The second oil price shock was a fact when the outbreak of the war between Iraq and Iran started in 1980. During the war period almost 4 million barrels were removed from the world market on a daily basis. That was 15 percent of total OPEC output and 8 percent of the world market. In 1980 OPEC decided to set the oil price at a new higher level at thirty six dollar per barrel. However, the crisis did not last very long since the other oil producing countries maintained a high production during the period. (Rousseau, 1998)

High exports

In the 1980s the Saudi Arabian exports started to pick up, and so did the total supply of oil. In early 1986 the market was flooded with oil and the oil price dropped drastically and hit a low point close to \$10 per barrel in the summer of 1986, a drop by more than one half from a year earlier. (Rousseau, 1998)

The Financial Crisis

From 2003 to the middle of 2008, the prices increased approximately 450%. In the fall of 2008 the financial crisis started, which not just affected the stock market, but also the commodity market and the rest of the economy. Oil prices were quoted at \$ 146 per barrel on 3 July 2008. Oil demand and oil prices fell sharply back the same autumn in the wake of U.S. economic recession and financial crisis. On Christmas Eve in 2008, the oil price fell down to \$ 36.6 per barrel. This was one of the largest drops in the history of the oil price and resulted in huge losses for many oil companies worldwide. (IEA, 2010)

2.1.2 The oil market today

OPEC's role and position

“In accordance with its Statute, the mission of the Organization of the Petroleum Exporting Countries (OPEC) is to coordinate and unify the petroleum policies of its Member Countries and ensure the stabilization of oil markets in order to secure an efficient, economic and regular supply of petroleum to consumers, a steady income to producers and a fair return on capital for those investing in the petroleum industry”(OPECs homepage, 2010)

The member countries of OPEC meet on a regular basis to discuss the price level and production. OPEC's influence on the market as a cartel has been widely criticized, since it became effective in determining production and prices. OPEC's ability to control the price of oil has diminished somewhat, due to the subsequent discovery and development of large oil reserves in Alaska, the North Sea, Canada, the Gulf of Mexico, the opening up of Russia, and market modernization. However, OPEC has 76% of the worlds discovered oil reserves (BP, 2009).

OPEC Secretary General Abdalla S. El-Badri says that OPEC has the reserves that is needed and is further investing in new capacity. As OPEC go to 2020 they will double their investments. This will increase the production capacity by 9 million barrels a day. OPEC would like to have excess capacity on standby. This is because they want to use it as a safeguard against any disruptions according to OPECs strategy. (E&P Magazine 20/1, 2008)

OPEC has been reliable, responsible and ready to ensure the needs of the market and to react against any dangerous fluctuations of the prices. OPEC want to joint co-operation with all producers and consumers countries as well as to share the risks, but also the profit, a reasonable and fair profit with all the actors of the world economy. (Khelil, 2002)

Since the 1970s, international policy in relation to petroleum has been dominated by OPEC and the International Energy Agency, IEA. The recent developments have strengthened OPEC with high incomes and two new member states, Angola and Sudan. OPEC's success in stabilizing the oil market indicates that major exporters such as Russia, Norway and Mexico have an interest to cooperate, which has also been the case historically. (UD)

In the long term, the world will most likely switch to OPEC. In 2000, OPEC held approximately 79 per cent of the world's crude oil reserves and yet accounted for only 42 per cent of its crude production. This imbalance will after time correct itself. OPEC's World Energy Model forecasts a rise in world oil demand from around 76 million barrels per day in 2000 to 106 million barrels per day 2020. (Khelil, 2002)

Towards efficiency in the oil market

As discussed in the previous section we have established the important role and position of OPEC. When we further want to test for efficiency in the crude oil market it is necessary to accommodate that OPEC set a production quanta, which has a great influence on the crude oil price. This is a contrary to the theory of efficiency where the prices are based purely on demand and supply. Even if we find a tendency towards efficiency we should be careful in our conclusion.

The futures market is on the other hand a financial market, where most of the contracts are paper contracts with no physical delivery. Even if the underlying asset is the crude oil it will be more appropriate to run our analysis for efficiency in this market. We will however test both markets for efficiency, but accommodate for the effect of OPEC and the production setting.

2.2 Crude oil pricing theory

To understand the formation of the crude oil price, it is of importance to look at different theories that attempt to explain the price. We will derive and discuss several factors that are central to the price and price movements of crude oil.

2.2.1 Return to storage and expected prices

To derive future prices of crude oil, we will start to look at a basic approach to explain the price according to returns to storage. An investor borrows money at time t and buys Q barrels of crude oil at the price S_t . The investor has the possibility to store each barrel of oil at the price C_t . The investor then borrows totally $(S_t+C_t)Q$ from the bank, and pays back with interest the sum of $(1+i_t)(S_t+C_t)Q$, where i_t is the loan's interest rate. At time $t+1$ the investor can sell each barrel of crude oil at price S_{t+1} . The investor will profit from the investment if:

$$(S_{t+1})Q > (1+i_t)(S_t+C_t)Q \quad (2.1)$$

S_{t+1} is unknown, but the investor expects of the price to be $E_t(S_{t+1})$ at time t . The investor will buy oil and store it whenever

$$E_t(S_{t+1}) > (1 + i_t)(S_t + C_t) \quad (2.2)$$

Given the inequality above, risk neutral investors will buy physical oil today and store it because they will gain profit from this action according to their expectations of the future price. Assuming all investors have this same expectation of the future price, they will all want to buy physical oil today, and the demand for oil will increase and thereby the price at time t will also increase, $\Delta S_t > 0$. The supply of oil at time $t+1$ will increase, and the investors therefore expects a lower spot price at time $t+1$, $\Delta E_t(S_{t+1}) < 0$. This process will continue until we reach equilibrium where $E_t(S_{t+1}) = (1 + i_t)(S_t + C_t)$.

If we look at the opposite inequality, $E_t(S_{t+1}) < (1 + i_t)(S_t + C_t)$ where the right side is the greatest, the investor will lose money by storing oil. In addition to the physical storing cost, C_t , some investors find it convenient to have oil in storage. This “negative cost” must be

subtracted from the cost of carry, $CoC = i_t S_t + (1+i_t)C_t$. The net cost of carry is then $C_t^\# = i_t S_t + (1+i_t)C_t - \Psi_t$, where Ψ is the convenience yield. (Hamilton, 2008)

Convenience yield is an expression of having a commodity on hand. The reason why an investor may find it convenient to have a physical commodity, and not just as a futures contract, is in case of unforeseen events like war, politic regime shifts, natural disasters, etc. Lin and Duan (2007) found that the convenience yield of WTI crude oil is highest in the summer, while Brent crude oil is highest in the winter. The reason for this is that WTI is more sensitive to high demand in the summer months, while the convenience yield for Brent is higher in the winter because of the sensitivity of supply. Another interesting result is that the convenience yield may explain the price spread between WTI and Brent. On the other hand, it is well known that the different oil prices reflect the quality and transport costs of the crude oil.

In equilibrium of holding one unit of the crude oil one period, the following equality should hold:

$$E_t(S_{t+1}) = S_t(1+i_t) + (1+i_t)C_t - \Psi_t \quad \Leftrightarrow \quad E_t(S_{t+1}) = S_t + C_t^\# \quad (2.3)$$

The implication of this equality is that big changes in the crude oil prices should be mostly unpredictable (Hamilton, 2008). If our beliefs are that the crude oil market is unpredictable, we will expect that the prices follow a random walk process. We will discuss this further in chapter 5.1.

2.2.2 Demand for crude oil

Oil products are vital in society of the world today. Crude oil is being used for making products as gasoline, diesel fuel, asphalt, lubricant oil and petrochemicals. Demand for such products and other petroleum products stands for a huge market in the modern world.

In 2009 the demand for crude oil worldwide was 84.8 million barrels per day, according to the International Energy Agency (IEA). Demand in OECD countries declined by 4.4% from 2008 to a total demand of 45.5 million barrels per day in 2009, or 54% of the total demand.

For 2010 it is projected a total demand for crude oil to increase by 1.9% to 86.4 million barrels per day. Demand in the OECD is expected to be on the same level as in 2009, while the increase in 2010 mainly expected to come in China, the Middle East and the rest of Asia. This indicates a higher pressure on the demand side since Asia is becoming more and more oil dependent. The International Monetary Fund, IMF, expects in the World Economic Outlook (2009) that the demand of oil will increase as industrialization continues in emerging and developing economies. It is primarily the emerging economies which IMF expects will return to a robust growth, as the growth should remain subdued in advanced economies. However, to accommodate for future oil demand, a capacity expansion is needed.

2.2.3 Supply and production of crude oil

Oil reserves are generally owned by countries. Crude oil is non-renewable resource and the owners of an oil field must deal with the dilemma of extracting the oil now or later. The owner can leave the oil in the ground in the purpose of extracting it later in time, at a higher price. The marginal opportunity cost imposed on future generations by extracting one more unit of oil today is known as the scarcity rent. The Hotelling's rule, published by Harold Hotelling in 1931, gives the optimal extraction speed of a non-renewable resource. Hotelling's rule says that the scarcity rent, which is the spot price less the marginal production cost, rises at the same rate as the interest rate. (Hamilton, 2008) This could be expressed by:

$$\delta_t = P_t - MCP_t \rightarrow P_{t+1} - MPC_{t+1} = (1+i_t)(P_t - MCP_t), \quad (2.4)$$

where δ is the scarcity rent, P is the price, MCP is the marginal production cost and i is the interest rate. The principle of the theory is that the present value of extracting one unit of a non-renewable resource is the same at any given time and that at the resource is just exhausted when the time reaches infinity. (Livernois and Martin, 2001) It is important to notice that the scarcity rent changes over time as the prices and the marginal production cost changes.

The problem with theory trying to estimate producer's optimal extraction rate is that nobody know exactly how much oil there exists under the earth's surface. It is estimated that OPEC

have 76% of world’s total oil reserves in 2008. (BP, 2009) This clearly represents a market power of the OPEC countries.

The total supply of crude oil in 2009 was 86.6 million barrels per day. OPEC produced 29 million barrels per day, which stands for 33.5% of the total supply. On the other hand, OECD supplies 22.4% and are a net importer of oil.

2.2.4 The elasticity of the crude oil market

In figure 2.2 below, the production and consumption from 1998 to 2008 is presented. As we can see, the consumption has been increasing until 2008. The differences between the production and consumption are accounted for consumption of non-petroleum additives and substitute fuels, such as fuel ethanol and biodiesel. (BP, 2009) A higher demand of oil products may be an explanation for why the oil price today has increased since the millennium.

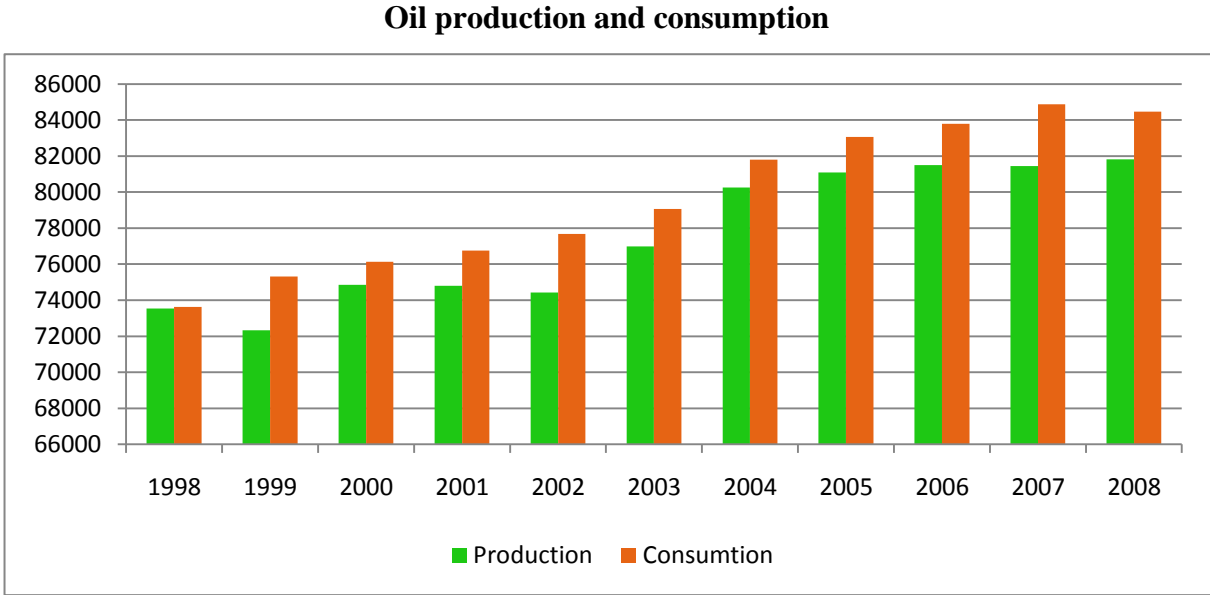


Figure 2.2: Shows the daily oil production and consumption from 1998 to 2008 in thousands of barrels oil. Source: BP statistical review 2009

Today oil is the dominant source of energy, but substitutes exist. The advantage of oil today is that it is much cheaper than alternatives such as solar power. As the earth is running out of oil, the price is likely to increase and will sooner or later reach the maximum level where oil is no

longer competitive compared to its substitutes. This price ceiling is known as the backstop price. (Hanneson, 1998)

In the short run the demand for crude oil market must be considered to be inelastic. Especially the transport industry is heavily dependent on oil products and there are limited substitutes to these. For some usages, oil can be replaced by other energy sources, but that will in most cases be a time-consuming and costly process. Renewable sources such as wind and solar power are inefficient and expensive compared to oil at the present.

Because of long lead times in developing additional production capacity, the supply side of the crude oil market is also inelastic. High investment and operations cost contributes to the inelasticity of the supply.

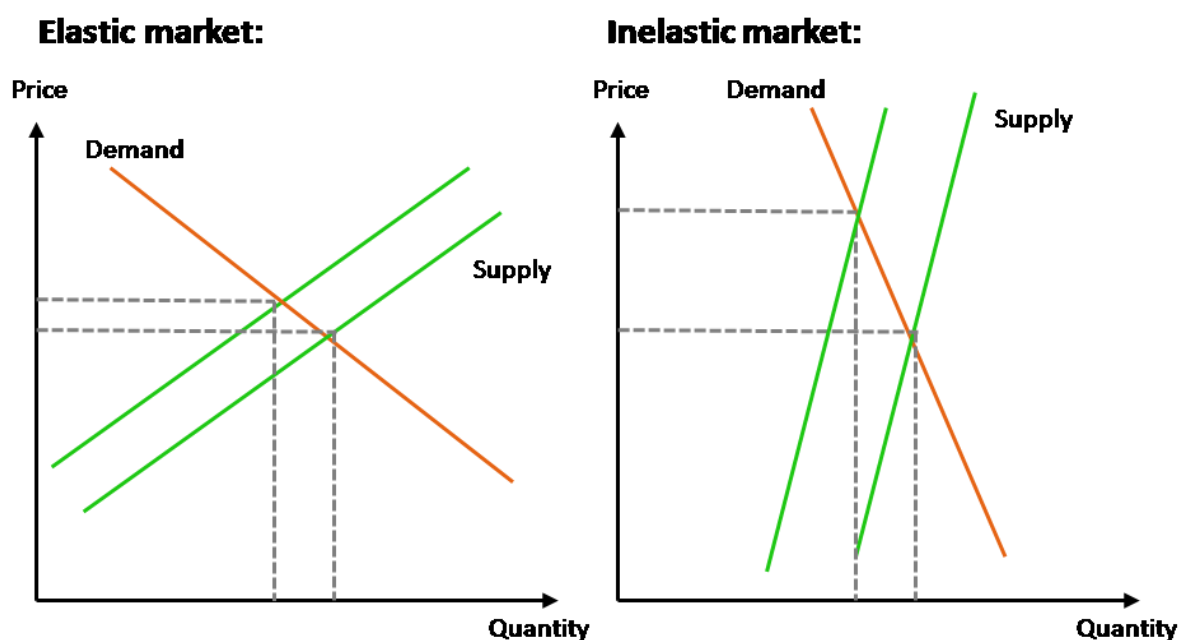


Figure 2.3: Example of elastic and inelastic market illustrated with a shift in the supply curve.

Because the market is relative inelastic in the short run, we expect a more dramatic price volatility with changes in demand or supply. This is illustrated in figure 2.3 above. In recent years the price has been more volatile, especially if we are looking at the real price of crude oil (Hamilton, 2008).

2.2.5 The crude oil price and the US dollar

The fact that the crude oil mainly is traded in US dollars makes the crude oil price sensitive for changes in the exchange rate of US dollars. Only 11% of the production of oil takes place in United States of America, and the nation stands for 25,6% of the consumption (BP statistics 2009). Although US dollars are a common used currency in the global economy, the exchange rate contributes to an increased risk for crude oil traders worldwide.

According to the IMF World Economic Outlook (2008), the US dollar contributes mainly to the crude oil price through two channels.

The first channel is the purchasing power parity (PPP) channel. Theory of PPP says that the domestic price level P_t is equal to the exchange rate S_t multiplied with the foreign price level P_t^* , $P_t = S_t P_t^*$, in terms of nominal prices. A depreciation of the US dollar makes the crude oil less expensive for consumers of other currencies. A lower price will in the next phase result in an increased demand. In the view of suppliers of oil, a depreciation of the US dollar will lead to a reduced profit in terms of other currencies. A typical Norwegian oil producer will thereby be affected in this way, because its cost will be in NOK and its income in USD.

The second channel is the asset channel, which reflects an investor risk by holding financial assets in US dollars. A depreciation of the US dollars will thereby reduce the return from these assets in another currency, and increases the risk of inflationary pressure in the United States, and may force investors to use commodities, such as crude oil, to hedge against inflation. (IMF, 2008)

2.3 The Efficient-market hypothesis

One of the most important foundations for economic theory is the efficient-market hypothesis. An efficient market is a market in which prices always fully reflect all available information. This means that it is never possible to beat the market by making analysis based on the information available, and there is no information not known to everyone in the market. If there had been information that was not priced into the share, market participants would have immediately seen the opportunity and gained advantage of this until it was no longer profitable.

It is common to distinguish between three main forms of market efficiency: weak form, semi-strong form and strong form. (Bodie et al, 2008)

Weak-form efficiency

Market efficiency in weak form implies that prices reflect all information stored in historical data. The prices are changing randomly, regardless of the price of the preceding days. This is called a random walk. At weak efficiency it will not be possible for an investor to find shares that are under-or over-valued by analyzing historical data. Technical analysis will therefore be a waste of time.

Semi-strong-form efficiency

Market efficiency in the semi strong form includes all the characteristics of weak form, in addition, prices reflect all available public information. This means that investors know everything about the company's values and future earnings. As soon as new information is published, this will immediately be integrated in the stock price, so it will never be possible to make money based on the stock price deviates from the correct price for the stock. In such a market fundamental analysis will be redundant, since the results of this will already be calculated into the share price.

Strong-form efficiency

The final form of market efficiency is considered to be very extreme, and seems more like a utopia than something that is possible to achieve in reality. At strong efficiency the market is

both efficient in weak form and semi-strong form, in addition all private information is also priced in. Thus, all the relevant information has already been taken into account, including the information that has not been published yet. No one can thus profit by trading on inside information. It can be debated whether this form of market efficiency can be achieved, since private information is not widely available. However, there exist strict rules for insider trading, so the possibility of making use of private information to achieve an excess return is limited from a legal point of view.

These main forms of efficiency are also valid for commodities.

2.3.1 Critics of the efficient-market hypothesis

As mentioned earlier, the EMH states that the market always is rational in various forms. This statement has taken a lot of critics lately because of the financial crisis. Experts are saying that the market can't be rational when we see such a huge and sharp fall in market prices over a short period of time.

Burton G. Malkiel is a well known professor who is especially known for his book "A random walk down wall street". Malkiel is a strong believer of the efficient market hypothesis and says that the sharp fall is just a combination of many small negative happenings. When the market becomes aware of the fact, this results in a sharp drop in prices. He does not discard behavioral theories and technicians but he states that if there is a possible effect that enables investors to make an additional earning above the market return, this is just a temporary advantage that disappears over time. (Malkiel, 2007)

2.3.2 Manipulated oil price

Due to the recent turbulence in the crude oil market, some have argued that the oil price has been manipulated by large market participants.

When oil prices reached an all time high last summer to \$147 a barrel, the biggest corporate casualty was oil pipeline giant Semgroup Holdings, a \$14 billion (sales) private company in Tulsa, Oklahoma, USA. They held short positions in crude oil equal to 20 percent of the

nation's crude oil reserves. People that now work to clean up the financial mess, state that there is evidence of a manipulation of the oil price. The oil price has been manipulated by traders to create a short squeeze to push up the price of West Texas Intermediate crude to the point that it would generate fatal losses in Semgroup's accounts. Some of the biggest investment banks like Citibank, Merrill Lynch and especially Goldman Sachs had knowledge about Semgroup's trading positions from their vetting of an ill-fated \$1.5 billion private placement deal in spring 2008. When the oil peaked in 2008 Semgroup could no longer stand the pressure and went bankrupt. Investment banks that were short in Semgroup earned a huge profit from this.

(Forbes, April 13th, 2009)

2.4 Futures

Forward and futures contracts are traded in the market with the purpose of obtaining a fixed price for a quantum of a specific asset in a given time ahead. In aim to reduce risk, as well as speculate in and even arbitrage, forward and futures contracts are being used.

The approach with forward and futures contracts could be looked upon as an alternative to storage of crude oil as described above for hedging risk.

The difference between a forward and a futures contract is the conditions of contract terms. Futures contracts are standardized and are exchange traded. Forward contracts are individual OTC, over-the-counter, contracts between two parties, and less standardized than the futures contracts. The futures contracts are settled daily and normally closed out prior to maturity.

2.4.1 Futures prices

The price of a future contract must be lower than today's price plus interest rate and cost of carry, or else it will be cheaper to hedge by storing the oil:

$$F_{t,t+1} < S_t(1 + r_t) + CoC_t \quad (2.5)$$

The convenience yield, which always is positive, must be taken into account and subtracted which makes the equilibrium price of futures contracts.

$$F_{t,t+1} = S_t(1 + r_t) + CoC_t - \Psi \tag{2.6}$$

A large convenience yield, Ψ , will make the today's futures price higher than the spot price, $F_{t,t+1} > S_t$, and the market is contango. Normally the convenience is small so the market has backwardation. Today we experience a contango market, which is illustrated in figure 2.4.

The futures price may differ from an investor's expectation of spot price in the future, $F_{t,t+1} \neq E_t(S_{t+1})$, and Hamilton (2008) adjusts this by adding $H^{\#}_t$:

$$F_{t,t+1} = E_t(S_{t+1}) + H^{\#}_t, \tag{2.7}$$

where $H^{\#}_t$ is a risk premium.

2.4.2 Where to buy futures

On the futures exchange you may trade in both futures and futures options. The two largest stock exchanges are New York Mercantile Exchange (NYMEX) and ICE Futures in London. A standard contract here is based on the buy of 1000 barrels with delivery on a future date. Currently (March 2010), one can buy oil for delivery up to and including 2018. Options can be written in many ways. A common example is that an oil consumer pays a premium for the right to buy oil at a fixed price at a future date. The option will only be exercised if the future option price exceeds the pre-agreed price.

Light Sweet Crude Oil Futures	
Product Symbol	CL
Barrels Volume	159 liters
Minimum Fluctuation	\$0.01 per barrel
Settlement Type	Physical
Contract Unit	1,000 barrels
Price Quotation	U.S. Dollars

Table 2.1: Crude oil futures contracts specifications at NYMEX.

The NYMEX and ICE exchanges are competitors, but each of them dominates trade within a certain type of oil. The most traded contract on the NYMEX for delivery of light, sweet North American crude oil is West Texas Intermediate (WTI). Benchmark contract

by ICE is a different light, sweet crude oil, namely Brent.

There are other exchanges that offer trading in oil-related contracts, mainly Tokyo Commodity Exchange (TOCOM). In June 2007, the Dubai Mercantile Exchange opened, and benchmark contract that is offered here is sour crude oil produced in the Middle East.

The futures trading on NYMEX is done through a Central Counterparty (CCP). The Central Counterparty matches the buyers and sellers and make sure that all parts get their payments. This implies that the traders don't expose any credit risk for each other. Traders are therefore protected by the CCP if the other part goes bankrupt. To offer this service, the CCP charges margin payments, a percentage of the total transaction, in order to carry the credit risk.

From figure 2.4 we see the prices of newly traded future contracts with maturity until December 2018. We observe that the future contract for delivery in November 2010 is traded for \$84. The following years is characterized by an increasing oil price. This implies that the market expect a higher oil price in a longer time perspective or requires a very high risk premium, $H^{\#}_t$.

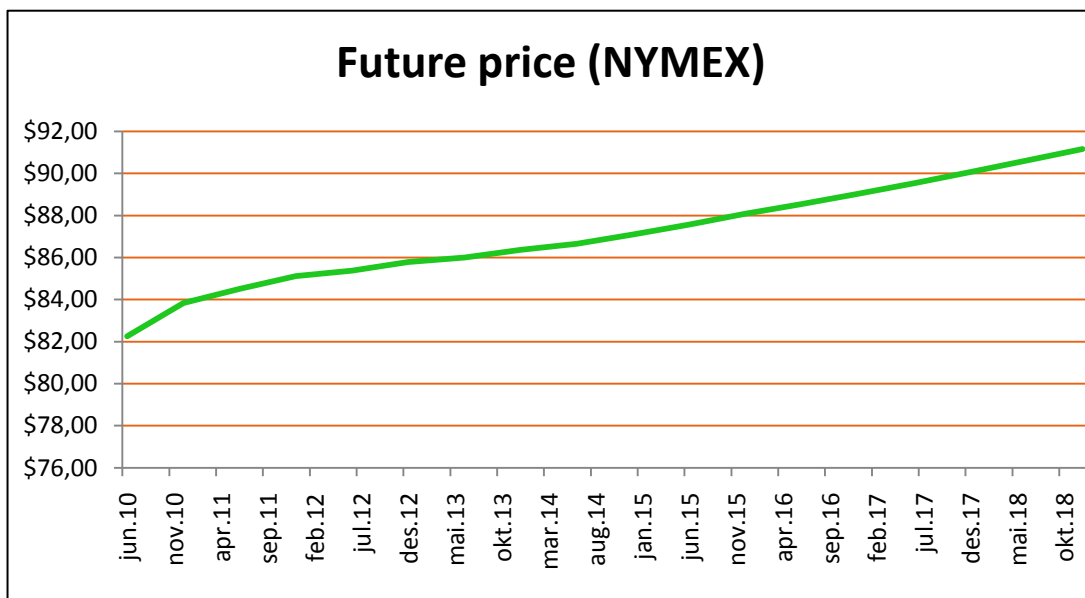


Figure 2.4: Illustrates the future price for WTI until december 2018.

2.4.3 Market participants

There are a multitude of players in the oil market, each with different objectives and investment horizons. Larger commercial oil companies are involved in higher or lower degree, where the most active companies are involved on both the buyer and seller side. Oil companies have expert knowledge of producing and manufacturing various oil products, which could be said to give them an information advantage in many trades. Sometimes the oil companies act in hedging contracts around their delivery dates. In next two sections we will look into oil companies' use of oil price hedging contracts.

National oil companies in both the Middle East and Latin America are participating in the OTC market, but only to a limited extent, suggesting that they seldom hedge future oil production. Investment banks are intermediaries, and also take their own risks, such as when they incur risk from a seller of oil, without having to immediately find a new buyer who is willing to take the risk.

Hedge funds have increasingly been active in the oil market in recent years. Several sources have alleged that the hedge funds' speculation in oil derivatives has contributed to the high oil prices we have seen in lately, as discussed in section 2.3.5. Hedge funds usually take positions in the most liquid segments of the oil markets, so that positions quickly can be terminated if it would be necessary. In general, hedge funds contribute to an increase in arbitrage-related activities. For example, a hedge fund could speculate that a previously observed price ratio between two assets will be re-established. The oil market gives hedge funds and other traders many opportunities to speculate on price differences between different petroleum products or types of crude oil. Some of the major global consumers of oil such as airlines and other transport are also trading in the future market for oil. A recently released report states that most airlines will hedge at least part of its needs for fuel (Morell and Swan, 2006).

2.4.4 Why use hedging contracts

In a general perspective a company is risk neutral and the owners are risk averse. This will in other words say that the company is only interesting in maximizing profit and will not seek to

hedge production in order to reduce risk. There are however exceptions in the real world. A typical example is when a principal agent problem occurs. The essence of the agency problem is the separation of management and of ownership and control (Schleifer and Vishny, 1997). The owners want return on the capital they invest and they need to ensure that the company does not waste their investments. This can be a problem if there are not specified contracts between the two parts. Managers need to be given the right incentives for choosing the risk management policy preferred by owners of the company (Chang, 1997). If there is a strong ownership structure in the company, this can give reduced power to the management in solely focusing on maximizing the return. A manager that is afraid of losing his job and reputation will act thereafter. If the shareholders are risk averse they can demand that the management focuses stronger on hedging to eliminate unsystematic risk that the company is exposed to.

It is important to stress that an oil company can only hedge away the unsystematic risk. Systematic risk such as government policy, wars, collapse of a financial system etc. cannot be eliminated by any hedging strategy.

If Miller and Modigliani's perfect financial markets hold, hedging will not be useful. In imperfect markets there is however a possibility that hedging may contribute to a company's value by influencing investments decisions, expected costs of financial distress or expected taxes. (Haushalter, 2000) We see that several oil companies use hedging consequently in their risk management strategy. This tells us that there must be some advantages with implementing such strategies. Below we have listed some of the reasons why companies use hedging contracts.

Robustness

Hedging will give a company an advantage compared to its competitors if the oil price should drop. The robustness they today achieve by being completely financed by equity could also be realized by locking in their revenues in the futures market. A drastic drop in the oil price could then give the hedging company a golden opportunity to act countercyclical in acquisitions. It is a big advantage with equity instead of debt when the company faces a downturn in the market they operate in.

Stability

A company that plays an active role in the future market will experience lower grade of uncertainty. This will in our point of view result in a gain in operational stability. The reduction of risk will give the company more opportunities when markets are in a downturn and they do not have to make drastic changes in the economic structure of the business. An “optimal” solution for this problem could be to hedge the price for as long as the oil field is active. This will, however, be problematic since there must be someone on the other side of the contract who is willing to take the risk of paying a locked-in-price for a long time horizon. Marginal oil fields are very sensitive to volatility in prices. With the use of hedging contracts the company can ensure the stability to make these projects remain profitable. A risk neutral company may in this situation have incentives to hedge the price. This is because it will reduce its bankruptcy costs and thereby increase the value of the company.

2.4.5 Oil companies use of hedging contracts

Oil companies that invest in increased production capacity risk that oil prices later will fall to a level that makes investment unprofitable. This risk may limit the oil companies urge to invest in increased production capacity. Similar problems apply to all business investments, but the problem is even bigger for oil companies. This is due to the long period from the investment is decided for the first oil barrels produced, 10 years are not uncommon. In addition, a relatively large share of production costs that are investment-related, production capacity that is invested has little or no alternative forms of use, and the price of oil itself has historically high volatility.

With high price risk, the forward market for crude oil seems to be a good solution for oil companies seeking to reduce their risk. An oil company will in theory be able to sell a futures contract and in this way "lock" the price it will receive for its future production.

Trough findings and a personal interview with a big oil company in Norway, we found that many of them consequent use short term contracts in their hedging strategy. This is because it is more risky to lock in the price for a longer period. The short term contracts (1-3 months) are also easier to deal with since they are more liquid and traded in a bigger volume.

2.4.6 Downside with hedging

Lack of buyers

Even if an oil company wants to hedge a larger proportion of its future production by selling futures contracts for oil, it is far from certain that there are buyers of such contracts or vice-versa. We observe today that the majority of contracts apply to the supply of oil within a year. This may mean that investors do not want to commit to hedge the oil price for a longer time horizon

Shareholders want exposure in oil prices

We believe shareholders in oil companies want exposure to the oil price, and it is therefore an important reason for management to choose not to enter into long-term price agreements on oil. It is difficult for an individual investor to get direct exposure to the oil price through positions in the futures market. The future market is primarily aimed at professional investors. On NYMEX the minimum contract is 1,000 barrels of oil, which means that at the current oil price around \$75 you need to take a position of approximately NOK 500 000. Thus, the indirect exposure to oil prices by holding shares in an oil company is therefore the best option for private investors.

Tax Authorities

Even if an oil company would attempt to "secure" investments by entering into long-term hedging contracts, a number of other risk factors affect to determine whether the investment turns out to be profitable. One of these risk factors is government policy regarding the international oil companies, including the taxes companies must deal with. There is no doubt that the government's tax policy will be increasingly important for oil companies to deal with.

International companies, including Statoil, have in recent years been forced to give up control of their fields, while the tax and royalties rates have gone up. The point is that fiscal authorities changing the tax regime represents a very significant risk that an oil company cannot hedge against. In addition, many international companies that extract oil as partners with national oil companies are already subject to contracts that are comparable with the hedging contracts. It is not unusual that companies have contracts that regulate the maximum price they receive per barrel of oil. The government receives the excess revenues if

oil prices would go above this level. In return the company receives such tax cuts if the oil price were to go under a prior agreement to the floor.

Focus on the upside rather than downside

A seller of oil that hedge the price at a favorable time, will be better off if the price drops. But the oil company may risk losing profit as a result of increasing oil prices. Management might be more concerned with the fear of bad timing, rather than the benefits of a good agreement. For the national oil companies, this risk aversion is particularly strong. No CEO wants to be remembered as the one who sold the national wealth for cheap money.

There are plenty of examples of oil companies that have signed hedging agreements that in a retrospect proved to be very unfavorable for them, but favorable for the counterparty. Saga Petroleum ASA, which in 1999 was acquired by Hydro, is an example of this. The company found itself in a financial squeeze in 1998 in a market where the oil price had reached a new bottom level. They chose to hedge the price in fear that the oil price should fall further and thereby bring them even closer to bankruptcy. Not long after they had entered into long-term hedging contracts, the market turned. While other oil companies experienced the "joy ride", Saga had committed them to sell oil at very low prices. (Andrén and Jankensgård, 2008)

2.5 Futures hedging strategies

The basic idea with hedging is to reduce risk, and a perfect hedge is one where risk has been totally eliminated. A perfect hedge is though never achievable. Strategies with futures hedging are constructed to perform close to a perfect hedge. (Hull, 2009)

A business or investor who seek to hedge, are generally doing it in the purpose of not being exposed to the price variations in the market. A hedge can counteract an unpleasant surprise of, for example a shock in commodity price of a necessary part of the final product to a company. With hedging, a producer using a commodity in the production can rather focus on

making the product than worry about the spot price. However, hedging may lead to big losses of income. (Hull, 2009)

An investor may either buy or sell a future contract. A position where a futures contract is sold in purposes of hedging risk is called a short hedge, while on the other hand a long hedge is when the hedger buys futures contracts. A company or investor who already own an asset and plans to sell the asset sometime in the future, may use a short hedge to reduce risk. The short hedge can be used by a risk averse management to hedge future income. A short position in the futures market is used for the short hedge. The long hedge is used by participants in the market who are using a commodity and plans to buy it in the future. Long hedge consist of going long in futures contracts. The main argument by hedging the price with a long futures contract is to lock in the price. This moves away the uncertainty for the buyer of the commodity. A long hedge may also be used if an investor already has a short position in the market. (Hull, 2009)

2.5.1 Naïve hedging strategy

A naïve hedging strategy is when the hedger takes one unit of a spot position and an opposite position of one unit in the futures market. This is a one-to-one strategy and will always have a hedge ratio equal to one. If spot and futures prices move equally, i.e. in the same directions and the same amounts, the hedge is perfect because the total value of the portfolio remains the same. However, changes in spot and futures prices are rarely equal. Lien et al (2008) did an empirical research in Chinese metal market that concluded that the naïve strategy has the worst performance.

2.5.2 Minimum variance hedge ratio

The hedge ratio is the amount of futures contract the hedger buys compare to its existing portfolio. The optimal hedge ratio is when the variance of the portfolio to the hedger is minimized.

To prove the formula for the hedge ratio, we will look at an example with a company who will sell N_S units of spot contracts at time t . To simplify, we will consider the futures contract as a forward contract. We therefore assume constant interest rate and no daily settlement of contracts.

The company will hedge the price, and since they are selling the asset, they will use a short hedge. They will therefore short futures contracts with N_F units of a similar asset at time t . The hedge ratio, h , is then:

$$h = N_F/N_S \quad (2.8)$$

The company will at time $t+1$ realize a profit or loss denoted as π_{t+1} , where S_t is spot price and F_t is futures price at time t :

$$\pi_{t+1} = S_{t+1}N_S - (F_{t+1} - F_t)N_F - C = S_tN_S + (S_{t+1} - S_t)N_S - (F_{t+1} - F_t)N_F - C \quad (2.9)$$

where C is the costs obtaining this portfolio.

We insert (2.8) into equation (2.9) and get:

$$\pi_{t+1} = S_tN_S + N_S(\Delta S - h\Delta F) - C, \quad (2.10)$$

where $\Delta S = S_{t+1} - S_t$ and $\Delta F = F_{t+1} - F_t$.

At time t , variables S_t and N_S are known. $\Delta S - h\Delta F$ is the unknown part of π , which the variance must be minimized to minimize the variance of π .

The variance of $\Delta S - h\Delta F$ is:

$$\text{Var}(\Delta S - h\Delta F) = \sigma_{\Delta S}^2 + h^2\sigma_{\Delta F}^2 - 2h\rho\sigma_{\Delta S}\sigma_{\Delta F} \quad (2.11)$$

The first order condition with regard to the hedge ratio is then:

$$d\text{Var}/dh = 2h\sigma_{\Delta F}^2 - 2\rho\sigma_{\Delta S}\sigma_{\Delta F} = 0 \quad (2.12)$$

which gives us the optimal hedge ratio:

$$h^* = \rho \frac{\sigma_{\Delta S}}{\sigma_{\Delta F}} \quad (2.13)$$

By estimating the standard deviation and the correlation for differentiated spot and futures prices, we can find the optimal hedge ratio. (Hull, 2009)

Instead of using differentiated prices, it is also possible to use the return. In this case we seek to minimize the variance of the return of the portfolio:

$$Var(r_p) = Var(r_S) + h^2 Var(r_F) - 2hCov(r_S, r_F) \quad (2.14)$$

This gives us the hedge ratio:

$$h^* = \frac{Cov(r_S, r_F)}{Var(r_F)} = \rho_{SF} \frac{\sigma_S}{\sigma_F} \quad (2.15)$$

where $r_i, i=P, S, F$, is the return of respectively portfolio, spot and futures and $\sigma_i, i=S, F$, is the standard deviation of the return. (Chet et al, 2003)

2.5.3 Optimum mean-variance hedge ratio

A concern with the minimum variance hedge ratio is that it does not focus directly on the return, but at the volatility of the portfolio. The optimum mean-variance hedge ratio maximizes the utility function with respect to amount of futures contracts:

$$\max_{N_F} U = E(r_p) - 0,5A\sigma_p^2 \quad (2.16)$$

where $E(r_p)$ is the expected return of the portfolio, σ_p^2 is the variance of the portfolio and A is a risk aversion parameter. This gives us the hedge ratio:

$$h = \rho_{SF} \frac{\sigma_S}{\sigma_F} - \frac{E(r_F)}{A\sigma_F^2} \quad (2.17)$$

If the return of the futures contract is zero or the risk aversion parameter goes to infinity, we see that the hedge ratio is equal to the minimum variance hedge ratio. (Chen et al, 2003)

2.5.4 Sharpe hedge ratio

Another hedging method we want to look into is the Sharpe ratio. The Sharpe ratio is a measure of the excess return (or risk premium) per unit of risk invested in an asset or a trading strategy. The Sharpe ratio is used to characterize how well the return of an asset compensates the investor for the risk taken. An investor will choose the combination that gives the highest value of the Sharpe ratio. The Sharpe ratio has as its principal advantage that it is directly computable from any observed series of returns without need for additional information surrounding the source of profitability. (Bodie et al, 2008)

The portfolio P, now consists of a risk free asset in addition to spot and futures contracts. The optimal hedge ratio is computed by maximizing the Sharpe ratio with respect to the amount of futures contracts:

$$\max_{N_F} S = \frac{E(r_P) - r_f}{\sigma_P} \quad (2.18)$$

Where r_p is the return of asset i, r_f is the risk free rate and σ_p is the standard deviation of the return to the risky asset. This gives us the following hedge ratio:

$$h = - \frac{\left(\frac{\sigma_S}{\sigma_F}\right) \left[\left(\frac{\sigma_S}{\sigma_F}\right) \left(\frac{E(r_F)}{E(r_S) - r_f} \right) - \rho_{SF} \right]}{\left[1 - \left(\frac{\sigma_S}{\sigma_F}\right) \left(\frac{E(r_F)\rho}{E(r_S) - r_f} \right) \right]} \quad (2.19)$$

As with mean-variance, the hedge ratio equals the minimum variance hedge ratio if the return of futures contracts is zero. (Chen et al, 2003) A problem with this approach is that the first order condition can minimize instead of maximize the Sharpe ratio. This will occur if the Sharpe ratio is continuously increasing with the hedging ratio. The second order condition is then not satisfied. (Chen et al. 2001)

2.5.5 Minimum variance strategy with two risk factors

A crude oil trader may face both the risk from price changes in the crude oil price and the risk of changes in the exchange rates.

We will consider two models (Yun and Kim, 2010), the first where the hedging ratios of crude oil futures and exchange rates are estimated separately and second, a more advanced one, where both risk are included in the model. Hereafter we will call the first model “separate” and the second “complex”. The models are based on the minimum variance approach.

The separate model will deal with hedge ratios separately, in the same approach as above with minimum variance. The difference is that we now transform the prices to local currency, NOK. The first hedge ratio, to hedge price changes, is based on the profit or loss, π_t , of buying futures contracts:

$$\pi_t = (S_t e_t - S_{t-1} e_{t-1}) N_S - (F_t e_t - F_{t-1} e_{t-1}) N_F - C \quad (2.20)$$

where N_S and N_F are the amount of spot and futures contracts, S_t are spot prices in USD, e_t is the spot exchange rate and C is costs. π_t has the variance:

$$VAR(\pi_t) = N_S^2 \sigma_{\Delta S e}^2 + N_F^2 \sigma_{\Delta F e}^2 - 2 N_S N_F \sigma_{\Delta S e, \Delta F e} \quad (2.21)$$

where $\sigma_{S e}$ and $\sigma_{F e}$ are the standard deviation of spot and futures price in local currency and $\sigma_{S e, F e}$ is the covariance between spot and futures prices in local currency. We get same hedge ratio as in 2.5.2, just adjusted for local currency:

$$h_j^* = \rho_{\Delta S e, \Delta F e} \frac{\sigma_{\Delta S e}}{\sigma_{\Delta F e}} \quad (2.22)$$

When only hedging the exchange rate risk, the profit is given by:

$$\pi_t = (S_t e_t - S_{t-1} e_{t-1}) N_S - (x_t - x_{t-1}) F_{t-1} N_X - C \quad (2.23)$$

where N_X is the amount of exchange futures contracts and x_t is the exchange futures. The following variance is:

$$VAR(\pi_t) = N_S^2 \sigma_{\Delta S e}^2 + N_X^2 \sigma_{\Delta x}^2 F_{t-1}^2 - 2 N_S N_X F_{t-1} \sigma_{\Delta S e, \Delta x} \quad (2.24)$$

This gives us the following hedge ratio:

$$h_{II}^* = \rho_{\Delta Se, \Delta x} \frac{\sigma_{\Delta Se}}{\sigma_{\Delta x} F_{t-1}} \quad (2.25)$$

h_I^* and h_{II}^* is the hedging ratios for the separate model.

In complex model, the trader wants to hedge both price risk and exchange rate risk. The trader will have following profits from his investments:

$$\ddot{\pi}_t = (S_t e_t - S_{t-1} e_{t-1}) N_S - (F_t e_t - F_{t-1} e_{t-1}) N_F - (x_t - x_{t-1}) F_{t-1} N_X - C \quad (2.26)$$

which gives us the variance:

$$\begin{aligned} VAR(\ddot{\pi}_t) = & N_S^2 \sigma_{\Delta Se}^2 + N_F^2 \sigma_{\Delta Fe}^2 + N_X^2 \sigma_{\Delta x}^2 F_{t-1}^2 - 2N_S N_F \sigma_{\Delta Se, \Delta Fe} - 2N_S N_X F_{t-1} \sigma_{\Delta Se, \Delta x} + \\ & 2N_F N_X F_{t-1} \sigma_{\Delta Fe, \Delta x} \end{aligned} \quad (2.27)$$

We set $H_{jk} = \frac{\sigma_{jk}}{\sigma_k^2}$, $j=1,2,3$, $k=1,2$, where 1 represent crude oil futures, 2 represent currency futures and 3 is crude oil spot. When minimizing the variance, we get following hedging ratios:

$$h_{III}^* = \frac{N_F^*}{N_S^*} = \frac{\begin{vmatrix} H_{31} & F_{t-1} H_{21} \\ H_{32} & F_{t-1} H_{22} \end{vmatrix}}{\begin{vmatrix} H_{11} & F_{t-1} H_{21} \\ H_{12} & F_{t-1} H_{22} \end{vmatrix}} = \frac{(H_{31} H_{22} - H_{21} H_{32})}{(H_{11} H_{22} - H_{21} H_{12})} \quad (2.28)$$

$$h_{IV}^* = \frac{N_X^*}{N_S^*} = \frac{\begin{vmatrix} H_{11} & H_{31} \\ H_{12} & H_{32} \end{vmatrix}}{\begin{vmatrix} H_{11} & F_{t-1} H_{21} \\ H_{12} & F_{t-1} H_{22} \end{vmatrix}} = \frac{1}{F_{t-1}} \frac{(H_{11} H_{32} - H_{31} H_{12})}{(H_{11} H_{22} - H_{21} H_{12})} \quad (2.29)$$

where h_{III}^* is the hedge ratio for crude oil futures and h_{IV}^* is hedge ratio for exchange futures in the complex model. (Yun and Kim, 2010)

3 Methodology

3.1.1 Random walk

A random walk implies that the correlation between the price change at time t and time $t+1$ is zero. Investors estimate the value of an asset on the basis of their expectations about the future, and these expectations are assumed to be unbiased and rational, given information investors have at this time. Under these assumptions the price changes will only be a result of new information. Information is by definition random, thus it is equally likely that there are good or bad news, i.e., the price goes up or down. A random walk process is a process of change in the value of any time interval which is independent from any changes that has occurred in the preceding time intervals, and the size and direction of future changes in the value are independent of the past. A market where successive price changes are independent is by definition a "random walk" market. In other words: the "random walk" hypothesis states that stock price changes have no memory and therefore historical prices can't be used to predict future price changes.

We let y_t be an economic variable that we observe over time. The variable is random since it cannot be predicted with certainty. The economic model which generates the time variable y_t is called a stochastic, or a random, process. A stochastic process is stationary if its mean and variance are constant over time, and the covariance between two values from the series depend only on the length of time separating the two values, and not on the actual times at which the variables are observed.

AR(1) process
$$y_t = \alpha + \rho y_{t-1} + v_t \quad (3.1)$$

The autoregressive process with one time lag, AR(1), is stationary if $|\rho| < 1$. If $\rho = 1$. The AR(1) process reduce to a nonstationary random walk series in which the value of y_t this period is equal to the value y_{t-1} from the previous period plus a disturbance v_t .

Random walk $y_t = y_{t-1} + v_t$ (3.2)

A random walk series shows no definite trend, and “slowly” turns one way or the other. If $\alpha \neq 0$ and $\rho = 1$ the series produced is also nonstationary and is called a random walk with drift.

Random walk with drift $y_t = \alpha + y_{t-1} + v_t$ (3.3)

Such series do show a trend and many macroeconomic and financial time series are nonstationary. (Hill, 2008)

3.1.2 Unit root test for stationarity

It is important to know whether our time series is stationary or nonstationary before we start doing regression analysis. This is because there is a danger of obtaining apparently significant regression results from unrelated data when nonstationary series are used in regression analysis. These regressions are said to be spurious. A spurious regression may indicate significant relationship even when there is none, and the results are nonsense. To solve this problem we can use models to test whether the series are stationary or nonstationary.

The stationarity of a time series can be tested directly by doing a unit root test. The AR(1) model for the time series variable y_t is,

$$y_t = \rho y_{t-1} + v_t \quad (3.4)$$

The AR(1) process shows that each realization of the random variable y_t contains a proportion ρ of last period’s value y_{t-1} plus an error v_t . We assume that the errors, v_t is a random disturbance with zero mean and constant variance, σ_v^2 . The errors are sometimes known as “shocks” or “innovations”. If $\rho = 1$ then y_t is the nonstationary random walk, $y_t = y_{t-1} + v_t$, and is said to have a unit root, because the coefficient ρ is equal to one.

To test for nonstationarity we can simply test for the null hypothesis that $\rho = 1$ against the alternative that $\rho < 1$. To run the test we need to subtract y_{t-1} from both sides of (1.4).

$$\begin{aligned} y_t - y_{t-1} &= \rho y_{t-1} - y_{t-1} + v_t \\ \Delta y_t &= (\rho - 1)y_{t-1} + v_t \\ &= \gamma y_{t-1} + v_t \end{aligned} \tag{3.5}$$

where $\Delta y_t = y_t - y_{t-1}$ and $\gamma = \rho - 1$. Then we can test the following hypothesis:

$$\begin{aligned} H_0: \rho = 1 &\leftrightarrow H_0: \gamma = 0 \\ H_A: \rho < 1 &\leftrightarrow H_A: \gamma < 0 \end{aligned}$$

The variable $\Delta y_t = y_t - y_{t-1}$ is called the first difference of the series y_t . If y_t follows a random walk, then $\gamma = 0$ and $\Delta y_t = y_t - y_{t-1} = v_t$. (Hill, 2008)

3.1.3 Dickey-Fuller

In addition to testing if a series follows a random walk, Dickey-Fuller also developed critical values for the presence of a unit root in the presence of drift (3.3). Such series display a definite trend.

It is also possible to allow a non-stochastic trend. The model is then further modified with including a time trend, or time t .

$$\Delta y_t = \alpha_0 + \alpha_1 t + \gamma y_{t-1} + v_t \tag{3.6}$$

The t-statistic must take larger values than usual in order for the null hypothesis $H_0: \gamma = 0$, a unit root nonstationary process, to be rejected in favor of the alternative hypothesis $H_A: \gamma < 0$. To control for the possibility that the error in term one of the equations is autocorrelated, additional terms are included:

$$\Delta y_t = \alpha_0 + \gamma y_{t-1} + \sum_{i=1}^m a_i \Delta y_{t-i} + v_t \tag{3.7}$$

where, $\Delta y_{t-1} = (y_{t-1} - y_{t-2})$, and $\Delta y_{t-2} = (y_{t-2} - y_{t-3})$,

Testing the null hypothesis that $\gamma = 0$ in the context of this model is called the Augmented Dickey-Fuller test (ADF). (Hill, 2008)

3.1.4 Cointegration

As a general rule nonstationary time series variables should not be used in regression model, in order to avoid the problem of spurious regression. There is however an exception to this rule. If y_t and x_t are nonstationary with one unit root variables, $I(1)$, then we would expect that their differences, or any linear combination of them, such as $e_t = y_t - \beta_1 - \beta_2 x_t$, to be $I(1)$ as well. There are however important cases when $e_t = y_t - \beta_1 - \beta_2 x_t$ is a stationary $I(0)$ process, without unit roots. In this case y_t and x_t are said to be cointegrated. Cointegration implies that y_t and x_t share similar stochastic trends since the error term e_t is stationary, they never diverge too far from each other. The cointegrated variables y_t and x_t exhibit a long-term equilibrium relationship defined by $y_t = \beta_1 + \beta_2 x_t$, and e_t is the equilibrium error, which represents short-term deviation from the long-term relationship.

We can test whether y_t and x_t are co-integrated by testing whether the errors $e_t = y_t - \beta_1 - \beta_2 x_t$ are stationary. We cannot observe e_t , so we therefore test the stationarity of the least squares residuals, $\hat{e}_t = y_t - b_1 - b_2 x_t$, using a Dickey-Fuller test. We estimate the regression:

$$\Delta \hat{e}_t = \alpha_0 + \gamma \hat{e}_{t-1} + v_t \quad (3.8)$$

where $\Delta \hat{e}_t = \hat{e}_t - \hat{e}_{t-1}$, and examine the t statistics for the estimated slope. (Hill, 2008)

3.1.5 Error correction model

As emphasized above, cointegration can be related to the idea of x and y trending together or bearing a long term equilibrium relationship to each other. A second important task is to estimate the long run multiplier or the long run influence of x on y. In some cases you may be interested in understanding short-run behavior in a manner that is not possible using only the regression of x and y. In these cases we can estimate an error correction model.

A theorem known as *Granger representation theorem*, says that, if x and y are cointegrated, then the relationship between them can be expressed as an ECM.

The error correction model we will use is:

$$\Delta y_t = \varphi + \theta \varepsilon_{t-1} + \omega \Delta x_t + \epsilon_t \quad (3.9)$$

where ε_{t-1} is the residuals obtained for the regression with the cointegrating variables y and x (i.e. $\varepsilon_{t-1} = y_{t-1} + \alpha + \beta x_{t-1}$). ε can be seen as equilibrium error, and if $\theta \neq 0$ the model is out of equilibrium. If $\theta < 0$ the error will be “corrected” in next period, and if $\theta > 0$ the error will be magnified in the model. We would expect the $\theta < 0$ and the value of θ tells us how fast the model is moving towards its equilibrium error. (Koop, 2007)

4 Data and descriptive statistics

In this thesis we look at weak-form efficiency in the markets and into different hedging strategies in the crude oil market, and try to analyze the use of futures contracts regarding the optimal hedge ratio and hedging effectiveness. We use figures for both futures and spot in the crude oil market and in the exchange rate market. Western Texas Intermediate (WTI) is traded in US dollars and we therefore use the exchange rate between US dollars and Norwegian Kroner since we focus on a Norwegian oil producer. The time horizon we look at is from 1987 until 2010. Our study will focus on weekly data for two reasons. Firstly the data is more stable than daily data. Secondly, studies suggest that weekly hedges are more efficient than daily hedges. (Laws and Thompson, 2005) For the calculations of WTI we use weekly numbers, but we use monthly numbers in chapter 5.3 of both WTI and the exchange rates USD/NOK. This is because we could not find the future contract figures for the exchange rates on a weekly basis. However, we will test daily, weekly and monthly data for efficiency in chapter 5.1. The dataset for WTI is found at EIA, U.S. Energy Information Administration. The exchange rates were found at Norges Bank, Norway's central bank, and interest rate is found at Bloomberg. The weekly prices for WTI are collected on Fridays or the closest trading day. For monthly crude oil prices, the prices are collected the 15th every month or the closest trading day. The exchange rates are average monthly figures.

Descriptive statistics

	<i>WTI Spot</i>	<i>WTI Futures</i>	<i>Returns WTI Spot</i>	<i>Returns WTI Futures</i>
Mean	33.803	33.795	0.0012	0.0012
Standard Error	0.687	0.698	0.0013	0.0010
Standard Deviation	23.719	24.113	0.0437	0.0356
Kurtosis	3.382	3.059	3.0501	2.5817
Skewness	1.864	1.815	-0.2161	-0.4999
Minimum	11	11.64	-0.1923	-0.1843
Maximum	142.52	143.39	0.2512	0.1518
Count	1192	1192	1191	1191

Table 4.1: Shows the descriptive statistics for the data set from 1987 to 2010 (weekly figures). The returns are calculated as logarithmic differences. WTI Futures are 3 month contract.

From table 4.1 we can see that both spot and futures have an average return of 0,12%. We also noticed that the standard deviation is higher for the futures contracts if we look at relative prices, but is higher for the spot when we calculate the returns in a logarithmic scale. Further we notice that the figures are not completely normally distributed. A simple way to test this is

to see if the skewness and excess kurtosis are zero, as is the case with a normal distribution. The skewness and excess kurtosis for the 24 year weekly log spot returns are -0.2161 and 3,05 respectively. This tells us that the left tail is the longest, it has higher peak at the mean and fatter tails. The same conclusion applies for the futures contracts.

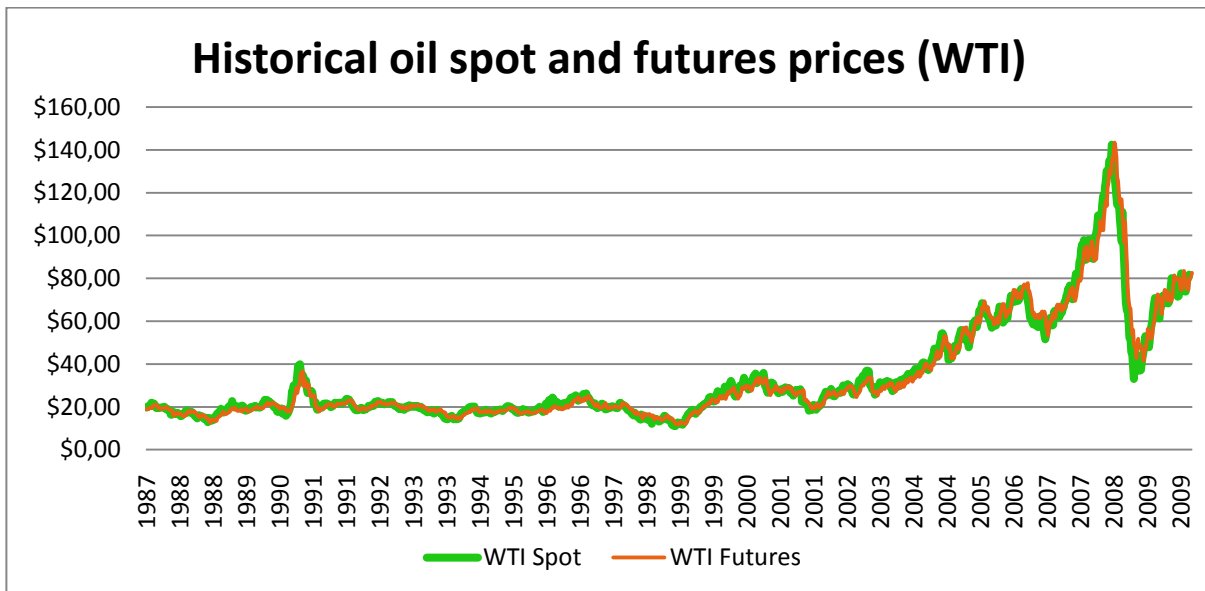


Figure 4.1: Historical oil spot and futures prices (WTI). Illustrates the development of the WTI spot price and WTI futures price from 1987 to 2010 (Weekly figures).

We observe from figure 4.1 that the spot price and future price follow almost the same path. This indicates that the future price seems to be an unbiased estimator of the spot price.

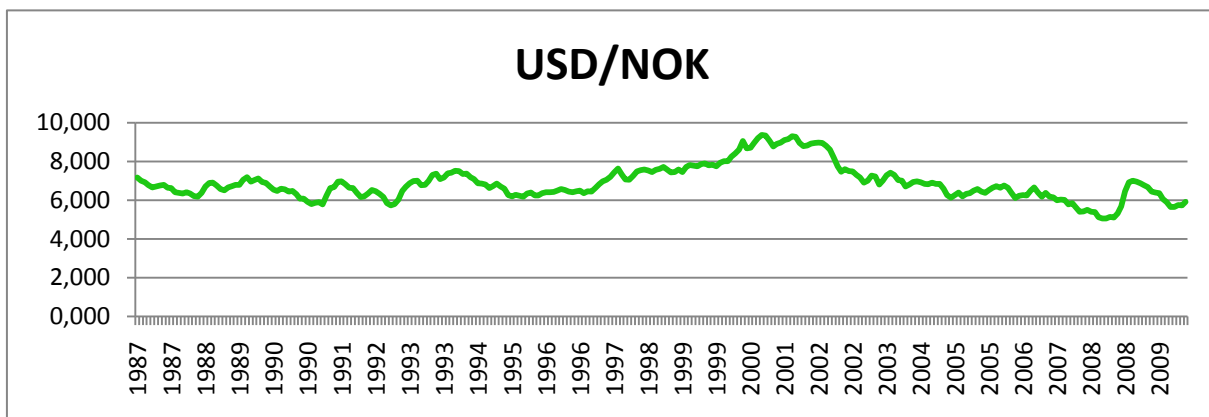


Figure 4.2: Illustrates the development of the exchange rate between Norwegian Kroner (NOK) and the US Dollar (USD).

The data we use for the exchange rates is based on monthly figures and the future contracts for USD/NOK are 3 month contracts. In figure 4.2 we can see the development of the exchange rate between the USD and NOK. As we can see, this graph seems to contain less sharp price movements than in the oil price. There are however some interesting periods where we see major movements in the exchange rates.

5 Empirical Analyses

In our empirical analysis we use the data described in chapter 4. First we will look into the efficiency of the crude oil prices and then move on to look at hedging in the crude oil market. We have pointed out that OPEC work as a cartel and therefore have significant market power. We base our analysis on that both the spot and future market for oil is a perfect competition market, where demand and supply is decided by the all the market participants. For the spot market this is a vague argument since OPEC set the production level on a regular basis. For the future market, which is a financial market, the argument would be stronger.

5.1 Efficiency market hypothesis

There are several studies that look at efficiency in the crude oil market. Green and Mork (1991) examine the efficiency and integration between the spot and future market. They found that the market for crude oil has, at times, produced large and persistent differences between the official contract prices and the spot prices. Such differences are not evidence per se of an inefficient market, as they may reflect risk or monopoly premia or the institutional fact that the contract prices are adjusted only at discrete and infrequent intervals. However, testable implications of the efficient-market hypothesis within this setting can be derived. In particular, information available at the time the official price was set should not be helpful in predicting contract-spot differentials.

In this section we will analyze both the spot market and future market for WTI oil. We will look at the whole period and also divide the data into sub periods to test our findings.

5.1.1 Results of unit-root testing

In order to test our hypothesis we need to establish whether the market we analyze is efficient or not. We will test if the oil price follows a random walk process. There are several different oil markets on a global basis, but we choose to analyze the West Texas Intermediate (WTI) market. Since this paper only focuses on the WTI market, we assume that other oil markets

have the same behavioral pattern as WTI. This indicates that you cannot take advantage of mispricing in one oil market and use it to make arbitrage profit in another oil market.

To test for weak-form efficiency we check the WTI prices for unit-roots. As we can see from table 5.1 we keep the null hypothesis for all prices which implicates that the prices follow a random walk process. We include results with a constant and also with a constant and a trend. The null hypothesis is kept on a significant level of one percent for every oil type except for the WTI Spot monthly. When we include a trend we reject the null hypothesis on a 5 percent significant level. This signalizes that there might be a pattern in prices since they are stationary. This is an interesting finding, but the trend is however not significantly different from zero. We therefore overall fail to reject that the series are stationary and keep the null hypothesis that the WTI spot and futures prices are non-stationary and follow a random walk process. We therefore say that there exists a weak-form efficiency in the markets.

Test for stationarity

Oil type	Level		First differences	
	Constant	Constant & trend	Constant	Constant & trend
WTI Spot daily	-1.026	-2.580	-29.27**	-29.29**
WTI Spot weekly	-1.016	-2.394	-10.86**	-10.88**
WTI Spot monthly	-2.038	-3.687*	-9.006**	-8.991**
Futures WTI daily	-0.767	1.645	-11.46**	-11.46**
Futures WTI weekly	-0.772	-2.173	-10.7**	-10.73**
Futures WTI monthly	-1.810	-3.163	-7.371**	-7.502**

Table 5.1: Contains the critical values for the Augmented Dickey-Fuller test. Test period is 1987-2010.

*significant at 5% level, **significant at 1% level.

The lags of the dependent variable used to obtain white-noise residuals are determined using Akaike Information Criterion (AIC). It is important to try to find it optimal number of lags of the explained variable which are to be included in the regression. If we include too few lags the auto correlation will not be eliminated and if we include too many lags we will observe increased standard deviation in the coefficients. This latter effect occurs because multiple parameters in the regression are consuming the degrees of freedom. Given everything else, the absolute value of test statistics will decrease, resulting in that the null hypothesis for a unit root will be rejected too seldom (Brooks 2005). In other words, we will conclude non-stationarity in cases when the time series actually are stationary.

5.1.2 Sub periods

We have seen that the spot and futures markets seem to be weak-form efficient for the whole period and follow a random walk process. This however does not imply that the markets will be efficient in all years or periods. To investigate this we choose three sub periods to analyze. The first sub period is from 1990 to 2000 and is a period where the oil price was quite stable compared to recent years. The two other sub periods are much more volatile and is characterized by a sharp upturns and sharp drops. By doing the same test as before (ADF) we want to test whether these sub periods give the same result as for the whole period.

Test for stationarity

Constant	WTI Spot	WTI Futures
1990 - 2000	-2.493	-2.405
2000 - 2007	-0.8965	-0.6647
2007 - 2010	-1.521	-1.577

Table 5.2: Shows the critical values from the unit root test for the 3 sub periods at weekly data. The results include only the constant. *significant at 5% level, **significant at 1% level.

Test for stationarity

Constant & Trend	WTI Spot	WTI Futures
1990 – 2000	-2.397	-2.332
2000 – 2007	-2.357	-2.082
2007 – 2010	-1.556	-1.600

Table 5.3: Shows the critical values from the unit root test for the 3 sub periods at weekly data. The results include a constant and a trend. *significant at 5% level, **significant at 1% level.

From table 5.2 and 5.3 we observe that we get the same results as for the entire period: We cannot reject the null hypothesis that the time series is stationary and we conclude that the spot and future market also follows a random walk process in all the sub periods. It is worth noticing that the critical value from period 1990 – 2000 is closer to rejection. This may indicate that the prices have become more efficient recent years. It is necessary to stress that we reject the hypothesis with a 5 percent probability. There is a possibility for type I and type II errors in our analysis. A type I error occurs when one rejects the null hypothesis when it is

true and a type II error occurs when one fails to reject the null hypothesis when the alternative hypothesis is true. There is a possibility that our results are a type II error.

As mentioned earlier it is important to accommodate for OPEC's strong market position. OPEC has significant market power and may therefore be able to affect the oil price, to their advantage. In a market situation with a price leader and a competitive fringe, we will not expect the market to be efficient though. If the cartel has the possibility to influence the price setting, the prices will not be a result of Adam Smith's invisible hand, and truly are the markets not efficient. However, the price changes due to changes in production volume of OPEC will though not be absorbed in our models of testing for efficiency. We find in our analysis that the prices follow a random walk process, thus are weak form efficient. OPEC's changes in production quotas will in our model just be shifts in the price pattern as other news, such as wars, disasters etc. that have influence on the oil price.

We will state that participant outside OPEC does not have the possibilities to predict the future crude oil prices. On the other hand, we don't know opportunities OPEC members have to do so. This is contrary to the efficiency concept and we are aware of that this is an important factor even if our data set does not capture OPEC's position.

5.1.3 Cointegration

Since spot and futures prices have unit roots we would expect that the residuals also have a non-stationary behavior. Though, are the residuals stationary, then the spot and futures prices are cointegrated. While spot and futures prices might significantly diverge over the life of the futures contract, futures prices have to converge to spot prices once the contract expires. But, in the long-run, it can be argued that spot and futures prices are driven by the same fundamentals, such as interest rates, macroeconomic variables and oil reserves, because futures prices represent expectations of the future spot prices of the physical commodity. For this reason we should expect spot and futures prices for any commodity to be linked through a long-run equilibrium relationship. This relationship can be tested by examining whether spot and futures prices are cointegrated. Granger (1986) claims that if two pairs of prices are cointegrated, they cannot be jointly efficient.

Cointegration test

	Constant	Constant & trend
1987 – 2010	-6.284**	-6.332**
1990 – 2000	-4.866**	-4.971**
2000 – 2007	-4.674**	-4.699**
2007 – 2010	-3.052*	-3.159

Table 5.4: Residual's critical values from the cointegration test. *implies that the values are significant on a 5% level, ** implies that the values are significant on a 1% level.

From table 5.4 we see that we reject the null hypothesis at 5% significance level that the residuals follow a random walk process for all periods. We thereby conclude that the crude oil spot and futures prices are cointegrated. If we include a trend in the model, we see that we cannot conclude that there exists a cointegration relationship between the two prices from 2007-2010. This indicates that the prices will be jointly efficient in this period because they tend to not follow the same pattern. We must however take into consideration that this result is based on a limited number of observations. Previously in our analysis we found that the spot and future prices are following a random walk process and we conclude that the prices are efficient in a weak-form. We find with the cointegration test that the spot and futures prices are not jointly efficient. This means that there exist a prediction factor and this can isolated be viewed upon as a weakness to the price efficiency. However, Dwyers and Wallace (1992) find that there is no general equivalence between the existence of arbitrage opportunities and cointegration. We therefore mean that the results from cointegration test are not strong enough to reject the hypothesis that the prices are efficient. Both prices are individually weak-form efficient, but not jointly efficient because there exist a long term equilibrium.

5.1.4 Error correction model

We have now found that there is a long-term equilibrium between the markets and would continue to test how quickly deviations from this equilibrium are adjusted. We will therefore adopt a misalignment model in the form of ECM. The advantage of this model is that it contains both short-and long-term factors. In addition, the standard regression techniques are valid if cointegration exists, since all the processes in the model are stationary. If the two markets are cointegrated the trend effect for each market will cancel out. (Koop, 2007)

Error Correction Model

	ΔF_t	ε_{t-1}
Coefficients	1.076**	-0.092**

Table 5.5: Shows the results for the error correction model between WTI spot and WTI futures for the entire period. *significant at 5% level, **significant at 1% level.

The results from the error correction model are shown above in table 5.5. The coefficient on ε_{t-1} of -0.092 measures how much the spot price responds to equilibrium errors. The coefficient is negative and significantly different from zero. This implicates that model is out of its equilibrium error, but moves towards it. A positive error will cause a fall in the spot price. Assuming a equilibrium error of 1 dollar and everything else remain the same, tends the spot price to fall 9,2 cents the next period. This must be considered as a slow adjustment to equilibrium error. The coefficient on ΔF_t is estimated to be 1,076. Assuming everything remains the same but an increase in the futures price of 1 dollar, the ECM implies that the spot price would instantly increase by 1,076 dollars. As we expected, price changes in the futures market will respond quickly in the spot prices and vice versa. The result supports the weak-form efficiency hypothesis, since the price changes will be absorbed quickly in the markets and cannot be used as forecasting estimates.

5.1.5 Summary Efficiency market hypothesis

Through our efficiency analysis of the oil prices we concluded with weak form efficiency. The prices were efficient for the whole period (1987-2010) and also for the three sub periods we tested. Our analysis does not accommodate for a cartel operating in the market. We saw that there existed a cointegration relationship between the spot and the future price. This means that the two markets will tend to fluctuate towards a long-run equilibrium. The error correction model showed that the changes in the futures prices were quickly adjusted in the spot price and therefore supports the weak-form efficiency hypothesis.

The results from the different methods used in this section signalize that there are no arbitrage opportunities, and prices cannot be predicted unless you have inside information.

5.2 Hedging strategies

From the previous chapter we found that the crude oil price and future price seemed to be efficient. Based on these findings we want to carry on with testing different hedging strategies. We divide this chapter in two sections. The first section looks only towards the price risk. We include three different strategies: 1) Minimum variance hedging method 2) Naïve hedging method and 3) Sharpe hedging method. In section two we look at price and exchange rate risk hedging strategies. We here include 1) Naïve hedging method 2) Separate hedging method and 3) Complex hedging method. By analyzing the different strategies we want to investigate if some methods are more efficient in a risk management process. This is done by looking at the hedge ratio and comparing the hedge effectiveness in each strategy. We will also compare risk and returns to calculate which strategy that is most suitable for an oil company based on risk aversion in the management.

To simplify our analysis we need to make some assumptions. We do not include transaction costs, neither the include cost of carry. We also assume that the participants have access to the same information and that both long and short positions are permitted. These are relevant and may affect our results to some extent.

5.2.1 Minimum variance hedge ratio

We will estimate the minimum variance hedge ratios by OLS regressions. The following regression used to find the estimated hedge ratio is:

$$(S_t - S_{t-1}) = \alpha + h^*(F_t - F_{t-1}) + \varepsilon_t \quad (5.1)$$

S_t and F_t are spot and futures prices at time t . α is constant, h^* is the optimal hedge ratio and ε_t is the error term. We know the prices are non-stationary, but since the prices are differenced once, we avoid spurious regressions.

Minimum variance hedge ratios

Year	Hedge ratio, h^*	$HE=R^2$	$\sigma_{\Delta S}$	$\sigma_{\Delta F}$	F test
1987 - 2010	1,077**	0,899	1,846	1,625	1,291**
1987	0,978**	0,800	0,553	0,505	1,195
1988	0,969**	0,842	0,607	0,577	1,104
1989	1,150**	0,639	0,656	0,456	2,072**
1990	1,257**	0,902	2,072	1,566	1,752*
1991	0,919**	0,667	0,852	0,754	1,277
1992	1,131**	0,933	0,449	0,384	1,366
1993	1,100**	0,891	0,481	0,415	1,345
1994	1,252**	0,903	0,594	0,452	1,731*
1995	1,242**	0,730	0,441	0,298	2,185**
1996	1,395**	0,612	1,038	0,594	3,049**
1997	1,143**	0,927	0,639	0,554	1,330
1998	1,197**	0,813	0,794	0,599	1,757*
1999	1,191**	0,854	0,736	0,573	1,649*
2000	1,238**	0,828	1,600	1,189	1,810*
2001	1,078**	0,844	1,162	0,981	1,402
2002	1,084**	0,857	1,030	0,853	1,458
2003	1,118**	0,840	1,449	1,224	1,402
2004	1,017**	0,913	1,598	1,499	1,136
2005	1,074**	0,896	1,944	1,728	1,266
2006	1,018**	0,908	2,050	1,899	1,165
2007	1,083**	0,929	2,609	2,300	1,287
2008	1,075**	0,969	5,478	4,991	1,205
2009	1,024**	0,796	3,303	2,958	1,247
2010	1,074**	0,991	2,708	2,589	1,094

Table 5.6: Shows hedge ratios and R^2 derived from regression of weekly data crude oil. h^* is tested if it is significantly different from zero. The F-test tests whether the variances of changes in spot and futures prices are equal, or if variance changes in spot prices are larger. *significant at 5% level, **significant at 1% level.

The yearly results of hedge ratios with respect to minimum variance, give static hedge ratios that fluctuate from the lowest ratio in 1991 at 0,919 to the highest ratio in 1996 at 1,395 based on weekly data. For the whole period 1987 – 2010 the static hedge ratio is 1,077. The results are close to one, and it looks similar to the naïve hedge. However, when testing the whole sample with respect to hedge ratio equal the naïve hedge of one, the results of 1,077 is statistical significant different from 1,000 at 1% level.

The interpretation of α from regression is that α is the cost difference in spot and futures markets. α is not significantly different from zero in any of the regression and therefore not included in the table 5.6. There does not seem to be any cost differences in the two markets.

The R^2 from the regression is the portfolios hedging effectiveness, HE. The direct interpretation of the hedging effectiveness is how much of the change in spot prices can be

explained by the changes in the futures prices. Hull (2009) defines the hedging effectiveness as the proportion of the variance that is eliminated by hedging. A hedging effectiveness that is equal to one means that the portfolio value remains the same. If the portfolio value remains the same, we say that the hedge is perfect.

We observe from table 5.6 that the hedging effectiveness for the entire period is 0,899 which indicate that a hedge with 3 months futures contracts at hedge ratio 1,077 is close to a perfect hedge. A perfect hedge is obtained when the hedging effectiveness is equal one. The observed hedging effectiveness is roughly between 0,8 and 0,9 according to the regressions. The hedging effectiveness of 1996 stands out as the lowest. This year also have highest hedging ratio in the sample and we observe a significant difference in the variance of the prices changes. An explanation for this could be that Saudi Arabia in 1996 increased its production (Pirog, 2005). This could have influenced the spot price, but the market probably expected this just to be temporary and the changes in prices could therefore have been lower in the futures market.

The null hypothesis from the F-test in table 5.6 is that the standard deviations for spot and futures price changes are equal, with the alternative hypothesis that standard deviation for changes in spot prices are larger. For most individual years from year 2000, the standard deviations for changes in spot and futures prices are not significantly different. Although, do we look at the entire period, we find that the volatility of the changes in spot prices are higher in futures prices.

The reason why it is interesting to look at standard deviation of price changes is because it will tells us if the two prices changes with same direction and amount and thereby will be able to use a naïve hedge. We have interviewed an oil companies in Norway, and they are in general using the naïve hedge strategy in their trading. The naïve hedging strategy is very simple to follow and could be cost efficient in form of reduced analysis costs.

A weakness in our model of finding the minimum variance hedge ratio is that the model is static. The model weights all observations equally. A better approach would probably be to use a dynamic model. Kroner and Sultan (1993) use a bivariate GARCH error correction model to estimate the hedge ratio in a dynamic approach.

5.2.2 Sharpe hedge ratio

In contrast to the minimum variance hedging strategy, it is interesting to look at a method which focuses on maximizing the return per unit risk. This can be computed using the Sharpe ratio. By using this method we want to investigate whether the hedge ratio will be more effective than a method that focuses solely on the risk of the portfolio.

In our calculations we need an estimate of the risk free rate. Since our data are in US dollars we choose the risk free rate in the US (T-bill). Since the oil producing companies often choose to use short contracts in their strategy we choose the 3 month Treasury bill. We find the interest rate to be 0,15%. On a weekly basis this is 0,038%. Even if this holds up in our analysis some might argue that the risk free rate should include a rate over a longer time horizon. We are aware of the fact and realize that our results would be different if we would implement this in our model.

An investor should, in periods with negative Sharpe ratio, place his assets in a risk free position or in another market (stock market, bonds etc.). For an oil producing company this is however impossible since they always need to trade their oil in the market. An alternative is to store the oil until the market has recovered from a downturn. Statoil has now the opportunity to do this in a bigger scale because of expanded capacity at Mongstad. It is however expensive to rent storages for the oil and this is not an optimal solution in the long run.

When we calculated the hedge ratio using the Sharpe ratio, we discovered some disturbing results. In some years the Sharpe ratio was minimized instead of being maximized. These hedge ratios are useless since they do not satisfy the Sharpe model.

Hedging Effectiveness

Year	HE min var	HE Sharpe	HE naive
1987 - 2010	0.822 (1.08)	0.585 (1.71)	0.814 (1.00)

Table 5.7: Contains the hedging effectiveness for the three methods used. The hedging ratio is shown in the parentheses.

From table 5.7 we see that the hedging effectiveness also is lowest for the Sharpe method. Since the crude oil price is so volatile it is very difficult to choose a good active strategy over a longer time period. A company that bases its strategy on the Sharpe ratio would therefore

need to use a lot of resources trying to time the cycles in the crude oil market. The results from the Sharpe method might be a result of OPEC's production quotas. The Sharpe method is based on perfect markets and as mentioned earlier, OPEC can be a possible reason to market imperfections. Our analysis does not capture this, but it could be interesting to test for in further work.

We observe that the minimum variance method has the highest hedging effectiveness and is therefore the best alternative for a hedging strategy if the management focuses solely on risk. This strategy is, however, based on a changing hedge ratio from a year to year basis. We see that the naïve hedge (1:1) gives a hedging effectiveness close to the minimum variance method. This method would be easier to implement in a business strategy, since it does not require time and resources to find the optimal hedge ratio every year. This is also a result we see some of the big oil companies use in their strategy today.

5.2.3 Risk aversion

As we have stated earlier in this thesis, the company is risk neutral in a general perspective and the owners are risk averse. We also mentioned that the real world often differs from theory and therefore management might have incentives to hedge the production. In the highlight of this we want to illustrate the hedge ratio compared to the risk aversion in this chapter. The point of view here applies to a risk averse management/manager or a single investor that operates in the crude oil market.

From financial theory it is known that investors make their decisions based on their degree of risk aversion. It would be wrong to conclude that a strategy that yields higher return would be better even if the risk is higher. It is therefore important to interpret our results in the light of the risk aversion parameter A , as mentioned in section 2.5.3, equation (2.16). From figure 5.1, we can see how the hedge ratio varies with the different levels of A with the mean variance method.

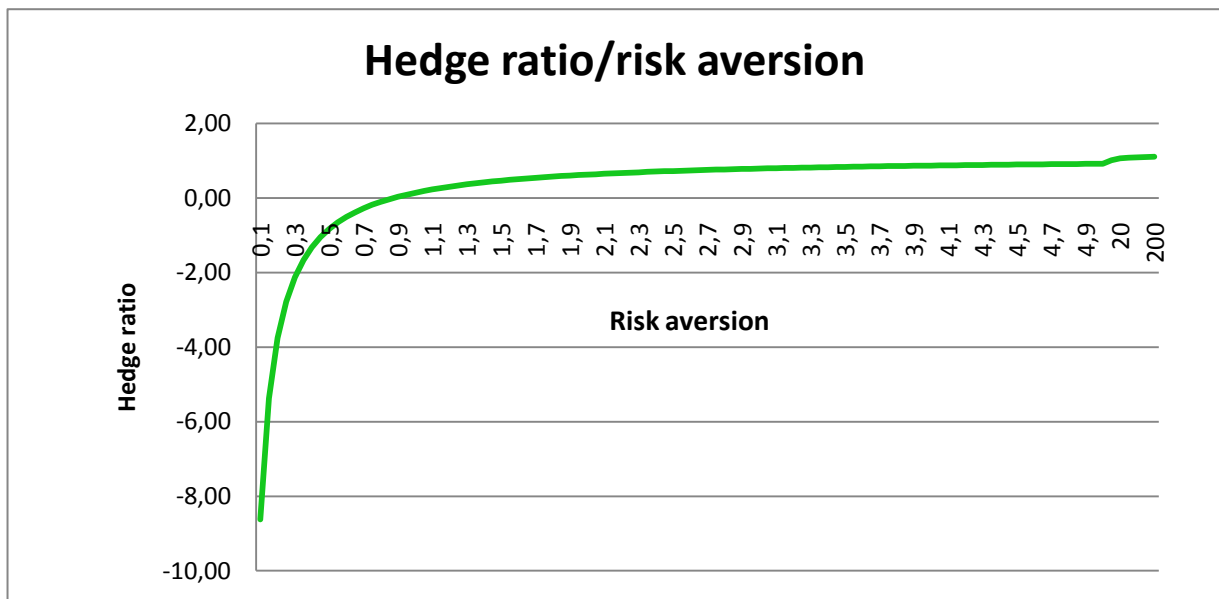


Figure 5.1: Illustrates the balance between risk aversion and optimal hedging ratio.

We observe that when an investor has a risk aversion parameter equal to 0.8, the hedge ratio will be 0 and indicate that he will only act in the spot market. We also register that when A becomes relatively high ($A > 20$) the hedge ratio will be equal to the hedge ratio we found by using the minimum variance method (1,077).

It is however difficult to find a correct value for A. If we were to calculate the A, we would have to collect the different values for A from all investors in the oil market. It is however common known that the average risk parameter have a value equal to 2. This would imply a hedge ratio of 0.63.

5.2.4 Multiple risk factors hedging strategy

“Fluctuating foreign exchange rates can have a significant impact on our operating results. Our revenues and cash flows are mainly denominated in, or driven by US dollars, while our operating expenses and income taxes payable largely accrue in NOK”.(Statoil, 2009)

At last we will look at a trading company who is in addition to the risk of prices in crude oil market, also is exposed to exchange rate risk. This is not relevant for an oil producing company if it has all its income and costs in one currency. It is however a more relevant issue

for a country or company that have a larger proportion of revenues or costs in a foreign currency.

In order to get an overview of the oil price and the exchange rate risk we graph the WTI spot price in USD and NOK indexed, where both starts at a value of 100. The result is shown in figure 5.2. We observe that the two lines follow each other closely most of the period. Overall it seems that PPP holds for crude oil in US dollars and NOK. However, we notice that the two lines differ from each other from 2000-2002 and again from 2007-2009. These periods can signalize that the PPP does not hold. This is an interesting finding and we therefore want to see if we can get a better hedging strategy by including the exchange rate risk in a more advanced model which takes the exchange rate risk into consideration.

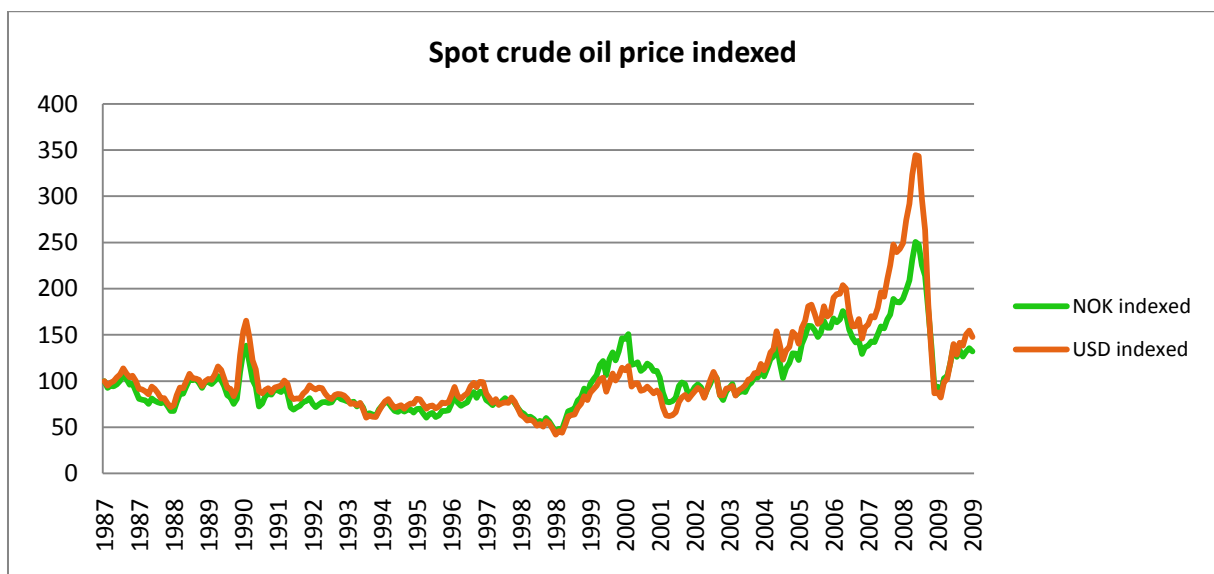


Figure 5.2: Shows indexed values of the WTI spot price in USD and NOK where both starts at 100 in 1987.

The first step is to calculate the optimal hedging ratio and hedging effectiveness by looking only at the exchange rate risk.

Exchange rate risk (USD/NOK)

In our process of estimating the optimal hedge ratio for the exchange rates we use the minimum variance ratio as before. We now change our input with numbers for the USD/NOK ratio. We use 3 month future contracts in our data set.

From figure 4.2 we have observed the historical exchange rates of USD/NOK. The average exchange rate is 6,9 USD/NOK with a standard deviation of 0,9 during the past 20 years. Meese and Rogoff (1983) found that no prediction models of exchange rates were able to beat a random walk model and this result has also been reinforced in later studies. This implies that the market follows a random walk process. If we believe that crude oil prices and exchange rates cannot be predicted, a risk strategy is essential for a risk averse management in order to deal in markets with high volatility.

Combined risk

In figure 5.2 we observe that the two lines follow each other closely in the beginning of the data set, but that there are some major differences and especially in the latest years during the financial crisis. This indicates that there is a certain risk factor that can be a potential problem if you are concerned about the exchange rates in the trading. In general we observe that the indexed USD crude oil price is higher than the indexed NOK crude oil price. Analyzing further, we observe that the standard deviation of the indexed USD crude oil price is 32,7, while for NOK it is only 22,1 for the whole period. These results may be a sign of an overall reduced risk for a Norwegian crude oil trader due to the negative correlation between USD/NOK and WTI crude oil price.

There has been done much research on the relationship between crude oil price and US dollars. Lizardo and Mollick (2010) find that an increase in real oil prices will lead to a significant depreciation of US dollars against currencies of oil exporting nations, such as Canada, Russia and Mexico, and that US dollar will lead relative to an appreciation to oil import currencies, such as Japan.

Analysis

Our analysis takes as a starting point the research of Yun and Kim (2010). Their study looks at Korean oil traders risk, where crude oil price and the exchange rates of Korean Won and U.S. dollars. In our study, we will take a Norwegian oil traders point of view, and look at the exchange rate risk of U.S. dollars (USD) and Norwegian Kroner (NOK).

For the separate model, we will estimate the hedge ratios with same approach as with minimum variance above, just with some modifications. For the crude oil futures we will transform the prices into NOK instead of USD. The data will also be on monthly basis. The regression of the separate crude oil futures hedge ratio, h_I^* , is as follow:

$$(S_t e_t - S_{t-1} e_{t-1}) = \hat{\alpha} + \widehat{h}_I^*(F_t e_t - F_{t-1} e_{t-1}) + \varepsilon_t \quad (5.2)$$

where e_t is the spot exchange rate. The exchange futures separate hedge ratio, h_{II}^* , is estimated by:

$$(e_t - e_{t-1}) = \hat{\alpha} + \widehat{h}_{II}^*(x_t - x_{t-1}) + \varepsilon_t \quad (5.3)$$

where e_t and x_t is spot and futures of exchange rate.

We must perform multiple regressions to derive the estimated hedge ratios for the complex model. H_{ij} is estimated by the regression:

$$D_j = \hat{\alpha} + \widehat{H}_{jk} D_k + \varepsilon_t, \quad (5.4)$$

where $j=1,2,3$; $k=1,2$, there $D_1 = (F_t e_t - F_{t-1} e_{t-1})$, $D_2 = (x_t - x_{t-1})$ and $D_3 = (S_t e_t - S_{t-1} e_{t-1})$

This gives us six regressions to carry out:

$$(F_t e_t - F_{t-1} e_{t-1}) = \hat{\alpha} + \widehat{H}_{11}(F_t e_t - F_{t-1} e_{t-1}) + \varepsilon_t \quad (5.5)$$

$$(F_t e_t - F_{t-1} e_{t-1}) = \hat{\alpha} + \widehat{H}_{12}(x_t - x_{t-1}) + \varepsilon_t \quad (5.6)$$

$$(x_t - x_{t-1}) = \hat{\alpha} + \widehat{H}_{21}(F_t e_t - F_{t-1} e_{t-1}) + \varepsilon_t \quad (5.7)$$

$$(x_t - x_{t-1}) = \hat{\alpha} + \widehat{H}_{22}(x_t - x_{t-1}) + \varepsilon_t \quad (5.8)$$

$$(S_t e_t - S_{t-1} e_{t-1}) = \hat{\alpha} + \widehat{H}_{31}(F_t e_t - F_{t-1} e_{t-1}) + \varepsilon_t \quad (5.9)$$

$$(S_t e_t - S_{t-1} e_{t-1}) = \hat{\alpha} + \widehat{H}_{32}(x_t - x_{t-1}) + \varepsilon_t \quad (5.10)$$

The estimated H_{ij} are used to obtain estimations of the hedge ratios h_{III}^* and h_{IV}^* in section 2.5.5.

To be able to compare the different hedging strategies, we will again use hedging effectiveness. We cannot now use the R-squared from regressions since we are dealing with portfolios. The hedging effectiveness of the portfolio is estimated by:

$$HE = 1 - \frac{VAR(r_H)}{VAR(r_U)} \quad (5.11)$$

where $VAR(r_H)$ is the variance of the return to the hedged portfolio, while $VAR(r_U)$ is the variance of the unhedged portfolio. (Ederington, 1979)

Hedge ratios including exchange rate risk

Year	Naive			Separate			Complex		
	h Oil	h USD/NOK	HE	\widehat{h}_I^*	\widehat{h}_{II}^*	HE	\widehat{h}_{III}^*	\widehat{h}_{IV}^*	HE
1987 - 2010	1,00	1,00	0,88	1,05	1,00	0,89	1,07	-0,06	0,95
1987	1,00	1,00	0,70	0,98	1,02	0,71	0,98	0,03	0,71
1988	1,00	1,00	0,75	1,01	0,98	0,75	1,00	-0,03	0,77
1989	1,00	1,00	0,70	1,23	1,04	0,65	1,23	-0,13	0,71
1990	1,00	1,00	0,77	1,23	1,00	0,79	1,20	-0,74	0,82
1991	1,00	1,00	0,76	1,20	1,00	0,61	1,06	-0,24	0,80
1992	1,00	1,00	0,62	1,12	0,98	0,52	1,09	-0,18	0,83
1993	1,00	1,00	0,80	1,07	1,03	0,78	1,07	-0,08	0,81
1994	1,00	1,00	0,75	1,33	1,00	0,77	1,36	-0,11	0,79
1995	1,00	1,00	0,86	1,16	0,98	0,79	1,16	-0,05	0,81
1996	1,00	1,00	0,68	1,40	0,98	0,64	1,41	-0,38	0,67
1997	1,00	1,00	0,75	1,14	1,01	0,73	1,12	-0,22	0,83
1998	1,00	1,00	0,71	1,05	0,99	0,72	1,16	0,39	0,71
1999	1,00	1,00	0,81	1,22	0,99	0,79	1,23	0,03	0,79
2000	1,00	1,00	0,77	1,21	1,00	0,70	1,33	-1,14	0,84
2001	1,00	1,00	0,57	0,97	0,99	0,58	0,93	-0,82	0,75
2002	1,00	1,00	0,80	0,97	0,99	0,81	0,98	0,14	0,79
2003	1,00	1,00	0,81	1,18	0,99	0,78	1,18	-0,04	0,79
2004	1,00	1,00	0,87	1,10	1,00	0,85	1,09	0,29	0,83
2005	1,00	1,00	0,79	1,01	1,00	0,79	1,00	-0,03	0,80
2006	1,00	1,00	0,67	1,02	1,00	0,67	0,95	-0,26	0,83
2007	1,00	1,00	0,68	1,02	0,99	0,70	0,93	-0,19	0,80
2008	1,00	1,00	0,80	1,02	1,01	0,81	1,07	0,05	0,81
2009	1,00	1,00	0,70	1,07	0,98	0,70	1,04	-0,38	0,77

Table 5.8: Summary of hedge ratios (h) for oil futures and exchange rates and the hedging effectiveness (HE) for naive hedging strategy and minimum variance hedging strategy for respectively separate and complex model.

From table 5.8, we see that the results from the separate crude oil futures hedge with monthly data are similar to the weekly data. The fact that the OLS is only based on 12 observations is though a weakness to our model, but all hedge ratios are statistical different from zero at a 1% significant level. Also monthly data of crude oil for the whole sample have a hedge ratio that is statistically significantly different from one at a 1% significance level. The yearly estimated hedge ratios are also close to the ones estimated with weekly data.

For USD/NOK exchange rates, the hedge rate for the whole sample is not statistical significant different from one at a 5% significance level, and equals the naïve hedge. This seems to be applicable for the estimated hedge ratios for all years.

Comparing the separate model strategy to the naïve hedging strategy, they both seem to be practically equal in the hedge ratios and hedging effectiveness. This means that it wasted use of resources to calculate a separate hedging model. We also observed that in about half of the estimated hedging effectiveness of the naïve hedging strategy is better than the separate model. These results contradict with the results of Lien et al. (2008).

For the complex model, we observe that hedge ratio for crude oil futures, \widehat{h}_{III}^* , are similar to the separate model. However, hedge ratio with concern to exchange futures, \widehat{h}_{IV}^* , are remarkably different. We observe that the overall hedge ratio for currency is negative. This means that the complex model suggests that the trading company should instead of sell exchange futures, buy exchange futures. Seen isolated, this will increase the trader's risk in the exchange rate market, but limit the risk of the portfolio. These results are similar to the findings of Yum and Kim (2010) which use Korean Won, KRW, instead of NOK.

The hedging effectiveness for the complex model is in general better than the two other strategies. 1999 and 2004 distinguish where the naïve strategy beats both of the two models in hedging effectiveness. Although the hedging effectiveness of the complex model seems to be best choice, it is not superior in all years. These results differs some from Yun and Kim (2010) who found the complex model to be superior in all periods.

Do we look at the hedging effectiveness in times of crisis, there does not seems to be any noteworthy differences in hedge ratios and hedging effectiveness compared to other years.

To get a broader perspective of the three hedging strategies, we will in table 5.10 look at the added returns and standard deviations compared to the unhedged portfolio.

Added returns and standard deviation for the different hedging strategies

Year	Only Spot (Unhedged)		Naïve		Separate		Complex	
	Return	St.dev	Return	St.dev	Return	St.dev	Return	St.dev
1987 - 2009	4,7 %	25,6 %	0,48 %	15,2 %	-2,24 %	15,7 %	0,52 %	12,0 %
1987	-28 %	22 %	5 %	13 %	-2 %	13 %	0 %	12 %
1988	-3 %	21 %	2 %	13 %	-2 %	13 %	0 %	10 %
1989	28 %	19 %	-5 %	12 %	-2 %	14 %	0 %	10 %
1990	12 %	52 %	17 %	26 %	-1 %	25 %	2 %	23 %
1991	-28 %	34 %	-12 %	22 %	-6 %	26 %	0 %	16 %
1992	8 %	14 %	-10 %	14 %	-4 %	15 %	0 %	6 %
1993	-19 %	19 %	-12 %	12 %	-2 %	12 %	0 %	8 %
1994	9 %	19 %	13 %	11 %	-2 %	11 %	0 %	9 %
1995	3 %	19 %	12 %	10 %	-2 %	12 %	0 %	8 %
1996	30 %	24 %	0 %	14 %	-1 %	15 %	1 %	14 %
1997	-21 %	19 %	-19 %	13 %	-3 %	13 %	1 %	8 %
1998	-43 %	20 %	-9 %	12 %	-1 %	12 %	0 %	11 %
1999	89 %	26 %	6 %	13 %	-2 %	14 %	0 %	12 %
2000	21 %	37 %	-14 %	20 %	-4 %	23 %	1 %	18 %
2001	-40 %	21 %	-7 %	15 %	-2 %	15 %	2 %	11 %
2002	20 %	27 %	28 %	14 %	-2 %	14 %	0 %	12 %
2003	2 %	31 %	6 %	18 %	-4 %	19 %	0 %	14 %
2004	21 %	30 %	6 %	13 %	-2 %	14 %	0 %	13 %
2005	41 %	22 %	-10 %	11 %	-2 %	11 %	0 %	9 %
2006	-4 %	18 %	7 %	15 %	-3 %	15 %	1 %	8 %
2007	28 %	18 %	15 %	13 %	-2 %	13 %	1 %	8 %
2008	-56 %	46 %	-39 %	27 %	-3 %	26 %	1 %	20 %
2009	40 %	31 %	30 %	19 %	-1 %	18 %	2 %	16 %

Table 5.9: Shows annual added returns and standard deviation for the different hedging strategies based on monthly data in NOK. 1987-2009 is an average of the data from all years.

As we expected, the total average standard deviation is reduced for all hedging strategies compared to the unhedged portfolio. The unhedged consists only of spot crude oil prices and spot exchange rates. We see that the added returns on the unhedged portfolio are greater than the hedged ones. The average annual added returns on the unhedged portfolio are 4,70%.

One of the most interesting finding in our research, is the hedging effectiveness in terms of return. As we can see from table 5.9, the added returns of the complex hedge for all years are close to zero. Using this model, the value of the portfolio remains the same, which implicates practically a perfect hedge.

Looking at the period of Financial crisis, we observe that the return of the unhedged portfolio is -56% in 2008. The naïve hedge takes away some of the volatility, and have some lower loss. However, the complex model actually gives profit in the same period.

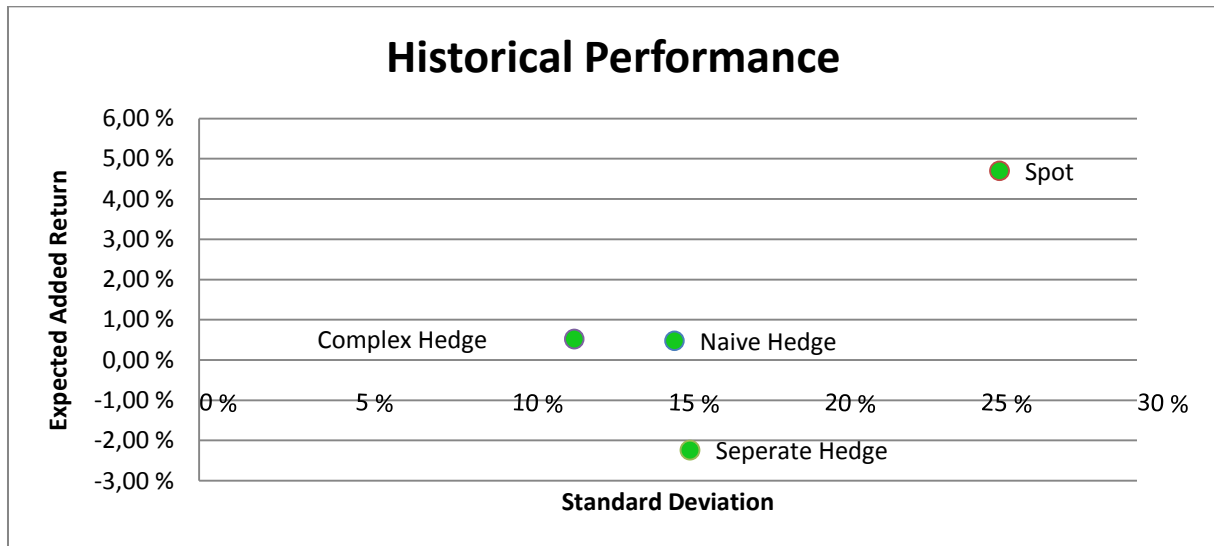


Figure 5.3: Illustrates the historical performance of each strategy from 1987 to 2010.

The choice of strategy is matter of the overall business situation. A company capable of taking risk will in the long run probably profit from not hedging, but risks big losses in some periods. If we assume that the prices follow a random walk, it is not possible to predict the future prices. For a company that requires a strong fixed control of income or costs, a hedging strategy should be appropriate. Figure 5.3 provides a graphical view of the strategies, and as we see the complex hedge is the best in concern of risk. On the other side, spot has a higher expected added return, but a higher risk.

5.2.5 Summery hedging strategies

We find a close relation between the naïve hedge and the minimum variance hedge ratio. It seems to be possible to remain a relatively high hedging effectiveness regardless of the volatility in the market. We find the Sharpe model to be inappropriate for hedging purposes. This may be a consequence of imperfect markets.

In the case of multiple risk factors hedging strategy, we find that it is actually possible to achieve a hedging effectiveness that is close to a perfect hedge. A company that finds it necessary to hedge price and exchange rate risks should use the complex model.

If a company chooses to hedge, it should either be risk averse or hedge in speculative purposes.

6 Discussion of assumptions, limitations and improvements

In this thesis we have looked at three month futures contracts as the only instrument to hedge the oil price. There are more alternatives than this. It is also possible to use forward contracts and options in the companies hedging strategies. There are also other futures contracts with different time horizon. On NYMEX you can trade future contracts with maturity from 1 month to long horizon contracts (3 to 6 years). This could have affected our results and maybe we could have discovered a better hedging strategy with a mix of different contracts and time horizons. This would however be much more time consuming and difficult to interpret.

As an alternative to use futures contracts, an oil company could invest in a commodity index to remove more of the unsystematic risk. We have not included such an index in our thesis, but it could have been interesting to compare the performance of this index with the hedging strategies we have used.

Our analysis does not correct for the tailing problem. This implies that the gains or losses from daily settlement in the futures market are not taken into consideration. This becomes a weakness in our thesis since our data do not capture this problem. (Hull, 2009)

When we carry out with different hedging strategies we do not consider the different types of oil companies. The so called big-oil companies are integrated which means that they operates both upstream and downstream. With the upstream we mean exploration and production, while downstream is what we characterize as refining and distribution. There are also differences between oil companies in financing and diversification. Big-oil companies have often very low share of debt compared to equity with some exceptions. Big-oil companies also operate in many countries worldwide and are therefore less vulnerable for political disturbance.

Based on the fact that oil companies are different it is a bit premature to conclude that one strategy should hold for all. A smaller company might not have the opportunity to run the risk of not hedging when the oil price is low. As mentioned earlier, this was the case with SAGA Petroleum.

In the calculations of the different hedging strategies we do not include the transaction cost of trading in the crude oil market. These costs might affect our results to some extent.

7 Conclusion

In this thesis we have analyzed price movements in the crude oil market in the period 1987 - 2010 and possible strategies for hedging. We have investigated whether the prices is weak-form efficient. The hedging strategies we use are naïve, minimum variance and Sharpe. Price and exchange rate risk has been considered.

Through our efficiency analysis of the crude oil prices, we concluded with weak form efficiency in both the spot and the futures market. The prices were efficient for the entire period and also for the three sub periods we tested. These results were based on an Augmented Dickey-Fuller test for unit roots where we failed to reject the null hypothesis that the prices were following a random walk process. We have discussed the impact of OPEC in the market, but our tests were not strong enough to capture this effect. We find that the physical spot market and the financial futures market are cointegrated. This means that they move towards a long term equilibrium price. By conducting an error correction model (ECM) we found that the WTI spot and future prices seem to adjust quickly to price changes, but moves slowly towards the equilibrium error in the short run, which strengthens the efficiency hypothesis.

We claim that it is not possible to predict the spot price, unless you have inside information. A risk averse management of a company should therefore consider implementing a hedging strategy.

This thesis has focused on naïve and minimum variance hedging strategies. We have also looked at the use of a Sharpe model for hedging purposes. The main outcome from our analysis, looking at the price risk, is that the minimum variance almost equals the naïve. The hedging effectiveness is not remarkable better with a minimum variance hedging strategy, and because a naïve hedging strategy is easier to implement, we suggest using the naïve. This is also a strategy supported by the oil company we interviewed. We find the Sharpe model not to be suitable for risk management in the crude oil market.

When we add the exchange rate risk in addition to the price risk, we observe similarity between the separate minimum variance and the naïve strategy. In relation to return and risk, the naïve is preferable. The complex model is however superior compared to the two other strategies. The complex model gives a hedging effectiveness close to a perfect hedge. The

complex model differs with the amount of exchange futures to hedge. The complex model suggests increasing the exchange rate risk in order to reduce the total risk of the portfolio.

To summarize the different hedging strategies, it all boils down to a matter of risk willingness. We have not discovered a unique and superior hedging strategy, but we have established that the management should not try to time the cycles to make an excess return. The management of an oil company should buy and sell in the spot market if they are risk neutral. If the management on the other hand is dependent of a certain share of revenues and therefore are risk averse, they should implement a hedging strategy based on a one to one hedge. This strategy is easy to implement and ensure a relatively low volatility in periods with high turbulence.

For future research we would find it interesting to look at price efficiency between every period OPEC sets its production quotas. We could then accommodate for the price leading function of OPEC. We would also suggest a development of a dynamic hedging model with multiple risk factors. A dynamic model focus stronger on newer observations compared to a static model which weight all data equally.

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