Section I

Hedging Of Crude Oil Price Risks With Application Of Derivative Instruments

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Post Graduate Diploma Thesis
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INTRODUCTION

When Lord Keynes travelled to Bretton Woods in 1944 in his briefcase were four files to be decided upon by distinguished world financial leaders as the basis for stable economic growth and recovery after the Second World War. Three of these files came to fruition in institutions which we know today as the World Bank, WTO and IMF.
The fourth file never saw the light of day – The World Commodity Fund (WTF) – this was considered too big a challenge for struggling post-war economies.
Since then, the best experts of governments and business have tried to solve the economic problems of commodity-dependent countries and businesses. They have experimented with buffer stock, price support mechanisms and other ideas, but most of these schemes have failed. Fortunately, today the modern financial services industry has developed risk management instruments such as derivatives to manage volatile commodity markets such as crude oil.
I chose the topic "Application of Derivative Instruments in Hedging of Crude Price Risks" for my postgraduate diploma thesis because crude oil is by far the most influential commodity in the world and it has recently affected many economies around the globe, not to mention India. Rapid rise in crude oil prices has brought up inflationary pressures and started to hamper economic growth not only in India but also, in many other countries. Furthermore, higher oil prices do not affect only countries but also individuals as crude oil prices have a direct impact on gasoline, gas and heating oil price levels and therefore also on
the budgets of households.

All life is the management of risk, not its elimination.
Walter Wriston
former Chairman of Citibank

In the context of high oil prices, economists and corporate leaders around the world have started to focus on the possibilities of protecting businesses from the dramatic fluctuations of oil prices. This has been the case particularly among airlines. Therefore, recently the hottest topic among energy end-users and oil companies has been price risk management and hedging. Again, this tendency can be detected among upcoming Indian companies.

Hedging is the process in which an organization with energy price risk will take a position in a derivative instrument that gives an equal and opposite financial exposure to the underlying physical position to protect against major adverse price changes. Hedging and the integration of derivative instruments such as forwards, futures, options and swaps with the cash markets are now an integral part of an oil company's or energy consumer's operations in the global oil markets.

Particularly in crude oil there is no such dimension as Indian, Chinese or French market. Crude oil and energy products trading in general is conducted on the global arena and this are also where the so-called rules of the game are set. It is much like the global inter-bank foreign exchange market in a sense that prices are universal and most of the participants besides a few are price-takers.

Crude oil forms the basis of global energy markets and is the most important trendsetter for energy products. The most common strategies used regarding crude oil hedging can also be applied to other energy products as the specifics of various derivative instruments are often similar or even identical. This is the reason why companies worldwide can apply the same strategies to the hedging of price risks of gasoline, diesel oil, heating oil, jet fuel etc.

The objective of writing the thesis is to study and analyse the various derivative instruments available on the global financial market and to present practical examples for hedging crude oil price risks in accordance with broad-based hedging strategies.

I try to accomplish the objective of the thesis by studying the current research available on crude oil hedging, by communicating with individuals involved with derivatives and oil market in trading commodity, foreign exchange and equity derivatives. Based on the objective, the thesis is structured into three parts. Section 1 provides an introduction to modern oil industry and explains the importance of crude oil on the global market. Specifics of hedging, basis risk and the structure of the oil market are also analysed.

Section 2 gives an in-depth theoretical explanation of derivative instruments and the strategies applied in energy hedging. It also specifies how the derivatives industry works and provides a description of the role of market participants.

Section 3 provides practical examples for hedging price risks and gives out general recommendations in regard to hedging with derivative instruments. The prices used in the examples reflect actual market prices.

I wish to thank the following persons for information and comments that helped to make the thesis more valuable:

REVIEW OF LITERATURE

I was able to find a fairly large literature on price risk management, energy products hedging and empirical research on the use of various hedging strategies. It must be noted, however, that it was quite difficult to obtain relevant literature from Indian oil companies' sources as the local target audience regarding oil industry materials is quite limited. This is the reason why majority of the literature used for writing this thesis was obtained using personal contacts and international libraries specializing on energy trading.

The key terms used in the thesis are price risks, hedging and derivative instruments. There are multiple definitions to these terms and, therefore, I have chosen the ones that explain the essence of these terms as clearly as possible.

According to James (2002) price risk is a risk resulting from the possibility that the value of a security or physical commodity may decline.

There are many definitions to hedging. Faruqee et al (1996) define hedging as a method of managing price risks that involves the buying and selling of financial assets whose values are linked to the underlying commodity markets. James (2003) defines hedging as the process in which an organization with energy price risk will take a position in a derivative instrument that gives an equal and opposite financial exposure to the underlying physical position to protect against major adverse price changes.

According to Kaminski (2004) hedging can be used by any market participants who intend to buy or sell a commodity sometime in the future, and who wish to know with greater certainty what price they will pay or receive. Hedging enables better financial management and planning, and allows buyers and sellers of commodities to protect themselves against the potentially catastrophic consequences of sudden and unforeseen changes in market conditions.

Hull (2003) defines derivative instrument as an instrument whose price depends on, or is derived from, the price of another asset. Hull's work on derivatives provided with in-depth information on derivatives and their application.

Same applies to the work of Culp (2002) and Cuthbertson and Nitzsche (2001).

Natenberg (1994) gives also detailed explanation of derivatives, particularly on options. Clubley (1998) gives the overview of the development of the oil industry and explains how the derivatives, in particular options and futures, industry conducts its business. Pegado (1989) provides detailed explanation on world energy products trading agreements and procedures, including contractual relationships regarding physical delivery. Long (2000), Kaminski (2004) and James (2003) classify derivatives and derivatives markets. Long (2000) also gives an overview of major crude oil products and regional markets. It should be emphasized that the energy industry considers Kaminski (2004) as one of the most complete publications on energy hedging (Stany Schrans, Fortis Bank Global Markets, personal communication, September 21, 2005).

Faruqee et al (1996), Pärn (2004) and Fusaro (1998) provide empirical research on the usage of derivative instruments in hedging price risks.

Wengler (2001) provides a detailed example of risk management policies and procedures (RMPP) document that a company could use when hedging price risks.

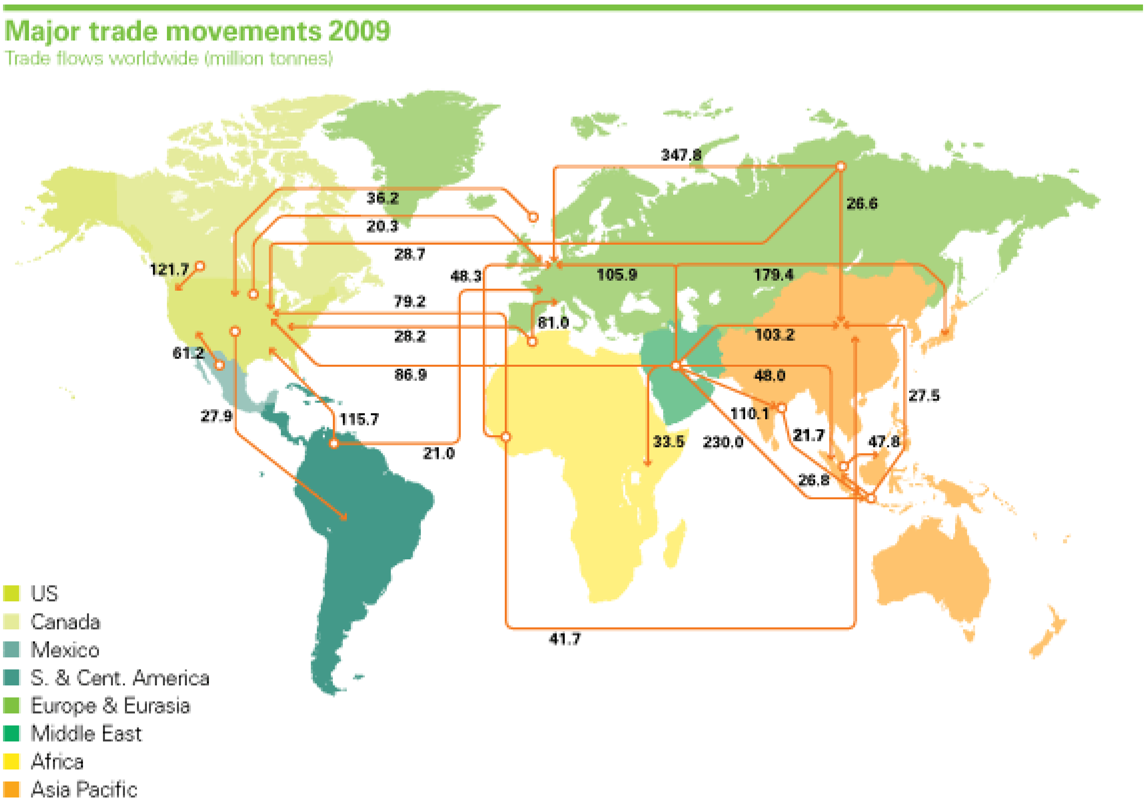
Additionally, in regard to energy products and risk management in general, there is much information provided by the NYMEX and IPE, International Swaps and Derivatives Association (ISDA) and major oil companies (such as Reliance Industries) and investment banks.

1. INTRODUCTION TO THE OIL MARKET

1.1. Why is Oil Traded

Over the last twenty years oil has become the biggest commodity market in the world. During this period, oil trading has evolved from a primarily physical activity into a sophisticated financial market. In the process it has attracted the interest of a wide range of participants who now include banks and fund managers as well as the traditional oil majors, independents and physical oil traders. To illustrate the high volume of oil trading Figure 1-1 shows major trade movements.

Figure 1-1: Major Crude Oil Trade Movements (million tonnes)



Source: BP (2009).

As well as being the largest commodity market in the world, oil is also the most complicated. The physical oil market trades many different types of crude oil and refined products, and the relative values of each grade are continually shifting in response to changes in supply and demand on both a global and a local scale (Pärn 2004). The industry has therefore developed a complex set of interlocking markets not only to establish prices across the entire spectrum of crude and product qualities, but also, to enable buyers and sellers to accommodate changes in relative prices wherever they might occur (Long 2000).

The driving force behind the rapid growth in oil trading is the huge variability in the price of oil. Daily price movements of $1/barrel are not uncommon and prices frequently change by up to 50 cents/barrel. Since there is no obvious upper or lower bound to oil prices, the value of a barrel of oil can double or halve within the space of a few months. As a result, everyone involved in the industry is exposed to the risk of very large changes in the value of any oil that they are producing, transporting, refining or purchasing, and a range of new markets have evolved in order to provide effective hedging instruments against the elaborate combination of absolute and relative price risks that characterize the oil business (Long 2000). This has not only generated a very large volume of activity, but also attracted liquidity from other financial and commodity markets.

1.1. Structure of the Oil Market

Successful markets need standardized trading instruments in order to generate liquidity and improve price transparency, and oil is no exception. But since oil is an inherently non-standard commodity, the industry has chosen a small number of "reference" or "marker" grades of crude oil and refined products to provide the physical basis for a much larger "paper" market which trades derivative instruments such as forward and futures contracts (Long 2000). Although the choice is often arbitrary and problems can arise due to unforeseen changes in the underlying physical market, the industry has invariably found ways of adapting the contracts since the rest of the market now depends on their continued existence.
The most important derivative trading instrument is the Multi Commodity Exchange of India (MCX) Light Sweet Crude contract (the specifications of the contracts are explained in paragraph 2.3.4). It is usually known as "WTI" since West Texas Intermediate crude still effectively underpins the market despite the introduction of alternative delivery grades in recent years. NYMEX WTI is the most actively traded oil market in the world and not only provides a key price marker for the industry as a whole, but also supports a wide range of other, more sophisticated, derivative instruments such as options and swaps.
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1.1.1. Spectrum of Instruments

The oil market now offers an almost bewildering array of paper trading instruments that can be used to reduce the price risks incurred by companies buying and selling physical oil. According to Hull (2003) these include futures and forward contracts, price swaps and options.
These derivative trading instruments have transformed the structure and operation of the oil market over the past decades, giving companies much more control over prices and bringing new participants into the market, such as banks and financial trading houses, who are prepared to take on some of the risks created by oil price volatility. Oil market now involves many non-traditional participants.

1.1.2. Trading Horizons

Most important change to the oil market has been the
gradual extension of trading horizons further and further into the future. Before the introduction of forward and futures contracts, oil companies had no effective means setting prices for future delivery. As a result, the spot market was forced to bear the brunt of trading decisions that might relate to time periods ranging anywhere from a day to a year ahead, which could only have added to price volatility (Long 2000). Over the past few years, however, the time horizon of the oil market has been extended much further forward as can be seen from Figure 1-2. The most active futures contracts, such as NYMEX WTI, now trade for delivery up to seven years ahead and the industry has acquired a new set of trading instruments that enable participants to establish prices even further into the future (NYMEX 2002). Instead of being limited to a time horizon of only a few months, prices can now be reliably obtained for periods from one to ten years ahead (Long 2000). This has been made possible by the introduction of financial instruments such as price swaps and OTC options, which have created a liquid market that enables companies to trade the price of oil over a time frame that is appropriate for producers investing in new oil fields or for consumers building new power stations.
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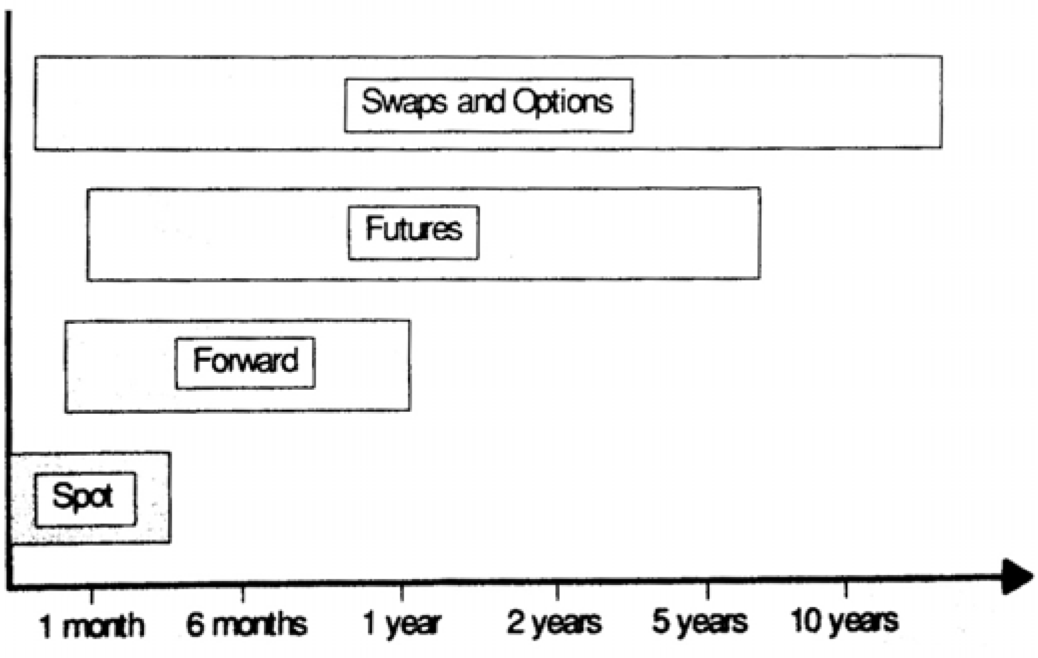
Figure 1-2: Oil Market Trading Horizons



1.2. Market Perspectives

The trading environment of the oil market is inherently unstable and large price fluctuations are common as can be seen from Figure 1-3. Geology, geopolitics, economics, law, taxation, finance, technology and environmental concerns are liable at any time to make a formidable

impact on the evolution of the market structure. The fundamental factors that generate risk in the oil industry, such as geological risk, may be reduced by the use of modern techniques and technology, but they cannot truly be managed.
India faces a large supply deficit, as domestic oil production is unlikely to keep pace with demand. India's rough production was only 0.8 million barrels per day. The oil reserves of the country (about 5.4 billion barrels) are located primarily in Mumbai High, Upper Assam, Cambay, Krishna-Godavari and Cauvery basins.
Balance recoverable reserve was about 733 million tons (in 2003) of which offshore was 394 million tones and on shore was 339 million tons. India had a total of 2.1 million barrels per day in refining capacity. Government has permitted foreign participation in oil exploration, an activity restricted earlier to state owned entities.

Instead, the management of risk in the oil industry has tended to focus on managing the relationship between time and price. According to Pegado (1989) to produce crude from and oil field requires several years and huge investment; to bring oil from the well to the customer requires at least a few weeks and sound logistics (pipelines, cargos, storage facilities, refineries, distribution networks). These logistical facts form the backdrop to the growth in risk management in the oil industry.
The physical oil market now plays a major role in creating the supply and demand equilibrium in local markets, and in global arbitrage. Oil companies and oil importing countries often consider the oil markets as a kind of dynamic counterweight to the dominance of producing countries or, more precisely, of OPEC.

1.3. Marketing Strategies in General

The oil derivative markets have developed around two complementary axes: hedging the oil price exposure of large companies, and the financing operations of the oil industry. Both of these have generated rapid growth for the OTC and exchange-traded energy derivatives industry. For the last ten years, the OTC market has fuelled much of the growth in liquidity in the exchanges, especially for backmonth trading.

1.3.1. Crude Oil

The physical crude market is the foundation of the oil market (James 2003). Prices of crude are generally quoted free on board (FOB) at their loading port. Most physical crude oil is priced as a differential to an actively traded futures or forward market. Instead of buyer and seller agreeing an absolute price for the cargo of crude oil, they agree a floating price, which is generally an average of several days around the bill of lading date (when the ship loads the oil). Most oil traded in Europe and many West African crudes, for example, are priced against Brent while almost all crude exported to the US, or traded within it, is priced against NYMEX futures. The short-term, the crude oil market is the trendsetter for the other energy markets; it is highly sensitive to OPEC rhetoric, to the general economic environment and to political events or uncertainties. It is the composition and structure of the underlying physical Brent market that account for much of its importance. There is always a large amount of oil available to the market, thus guaranteeing the market’s liquidity. Since the blend can be traded to within a few days of physical delivery, the Brent market fills on essential gap in the term structure of the world oil market by providing a price reference over a period of one to two months ahead. Finally, because North Sea crudes are
generally light and sweet, they are attractive to any refiner if the price is right.
The importance of the physical oil market in North Sea has encouraged the development of active and liquid paper markets. NYMEX WTI, on the other hand, is the leading benchmark

for the US domestic crude market and the physical underlying of the deepest commodity futures market in the world. Unlike the North Sea, virtually every barrel of US domestic crude, with the exception of Alaskan North Slope (ANS), is traded, priced and transported by pipeline rather than on waterborne tankers and barges. It should be remembered that the main instruments of the crude oil market are futures, forwards or swaps based on WTI and Brent indices. Cargoes of Brent blend crude oil are traded on an active forward market, so that one cargo may change hands many times before it is finally collected from Sullom Voe, its loading terminal. A forward contract requires the seller to give the buyer 15 days' notice of physical lifting dates. Once cargo has been nominated, it is known as a "dated cargo", and specific loading dates are attached to it (Pegado 1989). Many types of physical crude oil are priced against dated Brent. According to Kaminski (2004) flat price risks are hedged using International Petroleum Exchange or in short IPE Brent (please see paragraph 2.3.4 for details) contracts and the differentials between dated Brent and the first future contract are traded through "contracts for difference" (CFDs).

International oil price variation

Particulars	**Frequency of % variation**			
	0 to 3.1%	3.2 to 6.2%	6.3 to 9.3%	More than 9.3%
Refiner acquisition cost for Crude oil (composite) - Average monthly price from Apr 01 to Mar 04	8	16	4	>8

Maximum price variation

Period considered (Based on data from Apr 94 to Mar 04	**Percentage**
Monthly	**23.25**
Yearly	**28.73**

1.4. Risks and Hedging

Hedging is the process in which an organization with energy price risk will take a position in a derivative instrument that gives an equal and opposite financial exposure to the underlying physical position to protect against major adverse price changes. The way the definition is that the volumetric price exposure to the derivatives hedging instrument should be equal and

opposite to the price exposure of the physical energy commodity that the organization wishes to reduce its price risk exposure in.
In most financial markets there are small number of fundamental price drivers which can be easily translated into pricing and risk management models. In currency markets, for example, the commodity that has to be delivered in cash, a piece of paper which is easily stored, transferred and not sensitive to weather conditions.
But energy markets are concerned with bulky, dangerous commodities that have to be transported over vast distances trough some of the most politically unstable regions of the world. This means that there are many factors that can affect energy prices. A fairly short list might include: the weather, the balance of supply and demand, political tensions, comments from country leaders, decisions taken by OPEC, analysts' reports, shipping problems, and changes to tax and legal systems. All these contribute to the high levels of volatility in energy markets which often experience sudden price movements from one day to the next, or even one minute to the next. Fluctuating foreign currency cash flow represents an additional source of uncertainty for many companies.
When designing an energy price risk management or trading program, it is essential to be aware of all the risks that are involved in the energy market and the ways in which they interrelate. But it is important to remember that any hedging strategy which focuses narrowly on any one of the possible risks and ignores the others may be worse than having no hedging strategy at all.

1.4.1. Basis Risk

The term "basis risk" is generally used to describe the risk that the value of the commodity being hedged may not change in tandem with the value of the derivative contract used to hedge the price risk. Basis risk is the risk of loss due to an adverse move or the breakdown of expected differentials between two prices (usually different products). In the context of price risk management, basis risk describes the risk that the value of a hedge (using derivative contract or structure) may not move up or down in sync with the value of the price exposure that is being managed (Hull 2003).
When conducting price risk management, the ideal derivatives contract is one that has zero risk or the lowest basis risk with the energy price that protection is needed from. The larger the basis risk, the less useful the derivative is for risk management purposes (Hull 2003). The attraction of OTC swaps and options is that basis risk can at times be zero, as OTC contracts can often price against the same price reference as the physical oil. However, futures contracts traded on exchanges like IPE, NYMEX or Tokyo Commodity Exchange all have their pricing references and terms fixed in the exchange's regulations. This means that if their pricing reference does not match the underlying physical exposure, the basis risk must either be accepted or an OTC alternative need to be sought.

1.4.2. Trading and Risk Management Within an Oil Company

Oil price risk has traditionally been at the heart of the oil business, and most oil companies have now adapted their vertical structure to the new challenges created by oil price risk trading and management. Trading in oil companies can be divided into the three main areas of business outlined below:

♦ **System trading.** This is aimed mainly at optimizing the supply, import and export requirements of the oil group. It involves the systematic researching of the most profitable markets for the crudes produced by the group. The transfer of risks from the production sector of the company to the trading sector requires that the latter should be able to handle logistics and security matters, to offer contractual and financial guarantees, and to provide adequate hedging programs against large price fluctuations. The supply trading entity will also arrange physical supplies at competitive prices for the oil group’s refining, distribution and chemical divisions, if any.

♦ **Third party trading.** This business sector handles trading crudes and products with large oil companies and traders. Such transactions are usually independent of direct supply concerns, but form part of global arbitrage strategies. They may also be associated with pre-financing and barter operations.

♦ **Risk management.** Risk management consists of monitoring and managing price volatility, maturity and basis risks. Third party trading clearly requires risk management, and more so if it is done through an independent entity which supplies and trades with other companies of the group under pre-agreed pricing formulas, because the number of risks accumulated can become substantial. The risk management team acts principally for the group itself, mainly for production, transportation, refining, distribution, chemicals and international trading. An oil company’s hedging program should be designed to ensure the company’s financial stability (repayment of liabilities);
minimum profitability (distribution to shareholders), and the successful development of new projects (putting existing reserves on stream or discovering new reserves). The time duration and the payout structure would depend on the exact needs of the company:

♦ profitability over one or more accounting year(s);
♦ duration of liabilities if debtors require guarantee of repayments.
♦ return on investment for long-term projects.

Short-term hedging is usually made on a cargo-by-cargo basis and must be designed to take account of tax factors because there is usually an asymmetry between taxation on oil revenues and taxation on hedging (financial) revenues or losses. The structure of market oil prices can move violently between backwardation and contangoand these different structural contexts strongly influence the hedging strategies available to oil companies.

2. DERIVATIVE INSTRUMENTS

2.1. General Principles and Market Structure

The standard definition of a derivative transaction is a bilateral contract whose value is derived from the value of some underlying assets, reference rate or index (Culp 2002). Culp (2002) also defines a derivatives contract as a zero net supply, bilateral contract that derives most of its value from some underlying asset, reference rate, or index: This definition contains three distinct characteristics: zero net supply, based on some “underlying”, and bilateral. “zero net supply” means that for every “purchaser” of a derivatives contract, there is a “seller.” If we view a purchaser of an asset as having a long position in the asset and a seller as having a short position, we can restate the zero net supply criterion as follows: For every long, there is a corresponding short.

An asset that exists in zero net supply is essentially created by the agreement of parties to establish corresponding long and short positions in the market. Prior to the agreement of buyer and seller to exchange the asset in the future, the contract defining the terms of future exchange for that asset did not exist. Derivatives, moreover, are not the only type of zero net supply asset. A more familiar example is a bank loan, which

is literally created by agreement of a lender to transfer a cash balance temporarily to a borrower.
Derivatives contracts also must be based on at least one “underlying.” An underlying is the asset price, reference rate, or index level from which a derivatives transaction inherits its principal source of value (Hull 2003). In practice,
derivatives cover a diverse spectrum of underlying, including physical assets, exchange rates, interest rates, commodity prices, equity prices, and indexes. Practically nothing limits the assets, reference rates, or indexes that can serve as the underlying for a derivatives contract. Some derivatives, moreover, can cover more than one underlying.
Finally, derivatives are bilateral contracts. They represent an obligation by one party to the other party in the contract, and vice versa. The value of a bilateral contract thus depends not only on the value of its underlying but also on the performance of the two parties to the contract. The value of a contract in which one party sells a shoe to another party, for example, depends not just on the value of the shoe but also on the ability and intention of the seller actually to deliver the shoe to the buyer.

2.1.1. Participants in Derivatives Activity

The broadest way to categorize derivatives activity is to distinguish between those transactions privately negotiated in an opaque, off-exchange environment (in other words OTC) and those conducted on organized financial exchanges. Figure 2-1 shows the explosive growth in derivatives activity over the last decade. At year-end 2004, for example, notional principal value outstanding of OTC derivatives was $248 trillion. Despite experiencing slower growth over the last decade, exchange-traded derivatives are also hugely popular.

Figure 2-1: Global Derivatives Market*****

$ trillions, end of year
Exchange-traded OTC
* Notional principal value outstanding. Data after 1998 not strictly comparable to prior years.
Source: Bank for International Settlements
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2.2. Forwards

Forward contracts have played an important role in the development of the oil market. Forward paper markets such as 15-day Brent made a significant contribution to the rapid growth in trading activity during 1980s and the consequent improvements in liquidity and price transparency. Without the flexibility offered by informal forward paper contracts, the speed of development of the oil market might have been much slower since new futures contracts take time to develop and have not always been successful. But forward markets also have their limitations since they
ultimately involve physical delivery – which can make it difficult or costly to close out positions – and the industry now prefers to use swaps wherever possible.
To begin with, forward and futures contracts were seen as competing instruments and

many expected that futures markets would eventually replace the forward paper markets, as often happened in other commodity markets. However, experience has shown that forward paper contracts can still play a key role in the oil market, often in parallel with successful futures contracts such as Brent and NYMEX WTI. In the case of oil, forward markets appear to play a complementary role to the futures markets since they provide some benefits that are not available from futures contracts.

Firstly, they can be traded around the clock and therefore provide a trading instrument that can be used outside normal futures exchange hours – this proved invaluable at the start of the Gulf War, for example. Secondly, they enable companies to trade much larger quantities of oil in a single transaction. Thirdly, they enable participants to choose their trading partners. And, fourthly, they involve physical delivery which some companies prefer either for practical or fiscal reasons.

Although forward paper markets fulfil many of the same functions as futures markets they differ in terms of their method of operation, structure and organization. Forward paper contracts are not traded on a formal futures exchange (which is subject to external regulation) but are traded informally between principals who must regulate themselves.

In addition, there is no clearing house to manage and guarantee the matching and delivery contracts so the participants must also do this for themselves. Nor is there any obligation to publish the details of any deal that is done so there is less price transparency than on a futures market. As a result, forward paper markets tend to attract a narrower set of participants than futures markets since using them involves risks and requires dedicated manpower to maintain contact with the market. These are the larger oil companies and traders who are active in the physical oil market and the Wall Street investment banks who also play the role of market maker.

Compared with the markets for new trading instruments such as swaps and OTC options which are growing rapidly, forward paper markets have reached a more mature phase of development. Nevertheless, they remain an important and potentially innovative sector of the oil market capable of generating new contracts if required, especially if swaps are subjected to a more restrictive regulatory regime than applies at present. Although the turnover of the forward paper markets is now much smaller than that of the futures markets, forward paper contracts still play a key role in areas where they retain a comparative advantage.

There are still more forward paper contracts in active use around the world than futures contracts – although forward trading volumes are now much lower and time horizons are much nearer than they used to be. In practice, the strongest competition has come not from the futures market, but from swaps which are able to mimic many of the essential characteristics of a forward paper contract without posing the problems sometimes associated with physical delivery. As a result, most of the recent innovations such as Brent “contracts for differences” (CFDs) and the so called “Paper” Tapis market have been based on swaps rather than conventional forward paper contract. Also, several previously active forward paper markets, such as Russian gasoil, Littlebrook fuel oil, and European open spec naphtha has now been replaced by swaps. However, forward paper trading remains an important part of the oil market in the North Sea, the United States and the Far East and still plays a significant role in establishing prices for forward delivery.

2.2.1. Operation of Forward Deals

Business on the forward paper markets is usually conducted over the telephone. Participants either trade directly between each other or through specialist brokers (like Goldman Sachs) who provide a useful service by quoting bid-ask levels for forward contracts and enabling participants to test the market without revealing their identity. However, forward deals cannot be concluded anonymously (as they can on the futures market) since the identity of the counterpart will affect the terms of the deal if credit or delivery risks arise. In such cases, credit guarantees such as letter of credit will be usually required. Once the terms of the deal have been agreed between the counterparts, confirmation will be sent by telex or fax.

Forward contracts are based on physical delivery of the underlying commodity during an agreed time period in the future, either a full calendar month or a specified part of it. Although they specify standard quantities and qualities, and are subject to a mutually agreed set of terms and conditions in order to provide a flexible trading instrument, they can only be discharged by nominating a suitable physical cargo against the paper contract.

Nominations are usually at the seller's discretion[1], subject to a minimum notice period, and the buyer therefore has no control over the precise date on which the contract will be liquidated. As a result, forward paper positions remain open until the seller nominates a particular cargo of physical oil to meet his contractual obligations. At this point the buyer must either decide to accept physical delivery, or pass on the nomination to a third party against another forward sale, thus closing out his position. This rather haphazard process creates what is known as a "daisy chain" of paper contracts that link the original supplier of the physical cargo to the ultimate purchaser. In active forward markets daisy chains can include hundreds of links, many of which involve the same companies.

In order to reduce the complexity and uncertainty of the market clearing process, participants can agree in advance to identify and "book out" circles of contracts that start and end with the same party. In this case the parties involved agree to pay each other the difference between the purchase and sale price, thus reducing the cash flow associated with the transactions. However, booking out does not remove the obligation to make physical nominations and the process only works as long as no one defaults on the agreement when contracts are actually discharged.

2.2.2. Market organization

Since forward markets are organized by the participants and not by an exchange or clearinghouse, forward contracts involve a number of delivery risks for the parties concerned that do not arise in the case of futures contracts.

Firstly, it is not always possible to close out a position even if a company has both bought and sold a paper contract. If, for example, the notice period for nominations has expired the buyer cannot pass on his cargo to another company which leaves him with not only an unwanted physical cargo, but also the obligation to supply another physical cargo with suitable delivery dates.

In the 15-day Brent market, for example, sellers are obliged to give 15 working days notice of the first day of the loading date range for the physical cargo and the working day is deemed to end at 17:00 London time (Long 2000). Nominations received just before or at 17:00 on the 16th day before loading cannot therefore be passed on and unscrupulous traders have been known to disconnect telephones and telex machines to avoid being "five o'clock".

Secondly, forward contracts typically involve a loading tolerance of plus or minus 5 or 10 per cent that can be exercised at the seller's discretion (Long 2000). Although this is meant to provide for operational flexibility, it is often used by paper sellers to maximize their profits or minimize their losses. Companies can therefore never be certain of the exact size of their positions since the seller may nominate minimum or maximum volumes against the paper contract.
Thirdly, in forward markets which trade cargoes for CIF[2] delivery, it is possible to pass nominations from one delivery month to the next thus delaying the discharge of vessels and incurring demurrage charges that get passed down the chain of paper contracts (Long 2000). As a result, buyers can find that they are facing hidden costs and may need to resort to legal action to recover them from the companies that are responsible.

2.3. Futures

The introduction of financial futures – futures on currencies and interest rates – during the 1970s transformed the futures markets, which had been trading agricultural commodities for more than 100 years. Financial futures brought new participants and new strategies to the futures markets, and many more types of risks could now be hedged.
The commodity concept has broadened to include energy, beginning with heating oil futures in 1978, for many of the strategies that were devised for financial futures have been adapted and applied to the energy markets. Energy futures contracts are used by producers, refiners, and consumers to hedge against price fluctuations in these volatile markets. Another function of energy futures contracts has been to protect the inventory value of crude oil, refined products, and natural gas (James 2003).
The oil futures market developed to allow oil traders to offset some of their risk by taking a position on the futures market opposite their physical position. A producer, who has the physical commodity to sell, hedges by selling futures. The producer's positions are then long cash and short futures. A consumer, who needs to buy the commodity, hedges by buying futures. The consumer's position is then short cash and long futures.
A futures contract is an agreement between two parties, a buyer and seller, for delivery of a particular quality and quantity of a commodity at a specified time, place

[2] Cost, insurance and freight - a trade term requiring the seller to arrange for the carriage of goods by sea to a port of destination, and provide the buyer with the documents necessary to obtain the goods from the carrier.

and price (Fusaro 1998). Futures can be used as a proxy for a transaction in the physical cash market before the actual transaction takes place.
The commodity exchanges set margin requirements for hedgers and speculators. The buyer or seller of a futures contract is required to deposit with the clearinghouse a percentage of the value of the contract as a guarantee of contract fulfilments. The margin deposit made when the position is established is called "original margin." Hedge margins generally are lower than speculative margins. At the end of each trading day, each position is *marked to market* – the margin requirement for each account is adjusted based on the day's price changes. If the value of the position has decreased, the holder of the contract will have to make an additional deposit, called "Variation margin." This fulfilment of margin requirements daily means

that the extent of default in the futures market is limited to one day's price change (Hull 2003).

Futures have become firmly established over the past decade and their trading volume has grown steadily over the years as can be seen from Figure 2-2. The first viable petroleum futures contract launched was for #2 heating oil on the NYMEX in November 1978. Trade interest in the futures market was slow to develop, but the contract had the elements necessary for success. Heating oil was actively traded on the physical market, the futures contract had an adequate delivery mechanism, and there was good local, trade, and speculative interest (Culp 2002).

Most futures contracts do not go to physical delivery. Therefore, futures are generally used as a price risk management tool, not as a source of physical supply. This basic concept is still a stumbling block to futures trading, as many potential futures players think that physical delivery is a key component of futures trading (Culp 2002). In fact, the IPE Brent crude oil is based on cash settlement rather than physical delivery.

The three major energy futures exchanges are the NYMEX, IPE, and SIMEX (Singapore International Monetary Exchange). For electricity and natural gas, only NYMEX and IPE are significant. Contracts listed on the NYMEX include WTI crude oil, soar crude oil, New York Harbor unleaded gasoline, Gulf Coast unleaded gasoline, #2 heating oil, propane, and three natural gas contracts (Fusaro 1998). The sour crude and Gulf Coast gasoline contracts are not actively traded. The IPE trades Brent crude oil, gasoil, and unleaded gasoline futures contracts.

The SIMEX trades residual fuel oil (relaunched in April 1997)
and has an inactive gasoil futures contract which may be relaunched in the future. In 1995, the SIMEX listed the IPE's Brent crude oil futures contract as a mutual offset contract for the Far East, where it trades much smaller volumes compared to London based Brent trading (Long 2000).

All three established energy futures exchanges have indicated they will continue to launch futures contracts that conceptually hedge the entire barrel of crude oil as it makes its way from the ground to the consumer, as well as natural gas, electricity, and coal contracts. However, most refiners and end-users are more comfortable using other OTC financial instruments to hedge fewer liquid products such as residual fuel oil, jet fuel, naphtha and diesel fuel.

In 1990, the NYMEX initiated long-dated options for the WTI crude oil contract. These options trade 12 months out. Long-dated options were a direct response to the growth of OTC markets. They allow users to lock in a fixed price or price range and are useful for refiners and end-users entering long-term supply contracts where crude oil prices are likely to be variable. Since that time, NYMEX has extended the WTI contract out 7 years (Long 2000). The IPE has been particularly successful with its Brent crude oil options and also has a gasoil options contract.

In the oil futures market, the quotes are usually for a period of about six months and the buyer of the future needs to take a position for a particular quantity to be physically delivered at a particular point of time. The advantage for the buyer would be that if prices moved up by the time that the physical delivery of the product takes place, the buyer is compensated with an adjustment and a settlement with the difference being paid back. The buyer thus is able to hedge against an increase in the prices of crude and petroleum products. In the case wherein there is a fall in the prices of crude and petroleum products then the seller's interest is protected as the delivery is made on the agreed price by the buyer.

2.3.1. Specifications of a Futures Contract

A futures contract is a standardized agreement between two parties that commits one party to sell and the other party to buy stipulated quantity and grade of oil, gas power, coal, or other specified item at a set price on or before a given date in the future (Dominguez et al. 1989). All futures contract
require the daily settlement of all gains and losses as long as the contract remains open. For futures contracts remaining open until trading terminates, the expiry of the contract provides either for delivery of the underlying physical energy product or a final cash payment (cash settlement).

Futures contracts have several key features. For example, the buyer of a futures contract, the "long", agrees to receive delivery while the seller, the "short", agrees to make delivery (Hull 2003). The contracts are traded on regulated exchanges either by open outcry in specified trading areas (called pits or rings) or electronically via a computerized network.

The contracts are marked to market each day at their end of-
day settlement prices, and their resulting daily gains and losses are passed through to the gaining or losing futures accounts held by brokers for their customers. The contracts can be terminated by an offsetting transaction (i.e., an equal and opposite transaction to the one that opened the position) executed at any time prior to the contract's expiration (Culp 2002). The vast majority of futures contracts are terminated by offset or a final cash payment rather than by delivery. For example, on the IPE and NYMEX less than 2% of the open interest (total contracts open) in them energy futures contracts go to physical delivery each month (James 2003).

A standardized energy futures contract always has the following specific items (Cuthbertson and Nitzsche 2001):

♦ **underlying instrument -** the energy commodity or price index upon which the contract is based;

♦ **size** - the amount of the underlying item covered by each contract;

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♦ **delivery cycle** – the specified months for which contracts can be traded.

♦ **expiration date** – the date on which a particular futures trading month will cease to exist and therefore all obligations under it will terminate.

♦ **grade or quality specification and delivery location** – a detailed description of the energy commodity, or other item that is being traded and, as permitted by the contract, a specification of items of higher or lower quality or of alternate delivery locations available at a premium or discount (e.g., NYMEX WTI crude futures contract allows traders to deliver alternative crudes and they have a table of premium and discounts that are fixed for those alternative crude oils);

♦ **settlement mechanism** – the terms of the physical delivery of the underlying item or of a terminal cash payment. In fact, the only non-standard item of a futures contract is the price of an underlying unit, which is determined in the trading arena.

The trading process of futures can be seen from Figure 2-3. The mechanics of futures trading is straightforward: as already mentioned both buyers and seller's deposit funds called initial margin (a sort of good faith deposit) with a brokerage firm who would be a clearing member of the exchange the futures contract is on. This initial margin amount is typically a small percentage – around 10% of the total notional contract value (Long 2000).

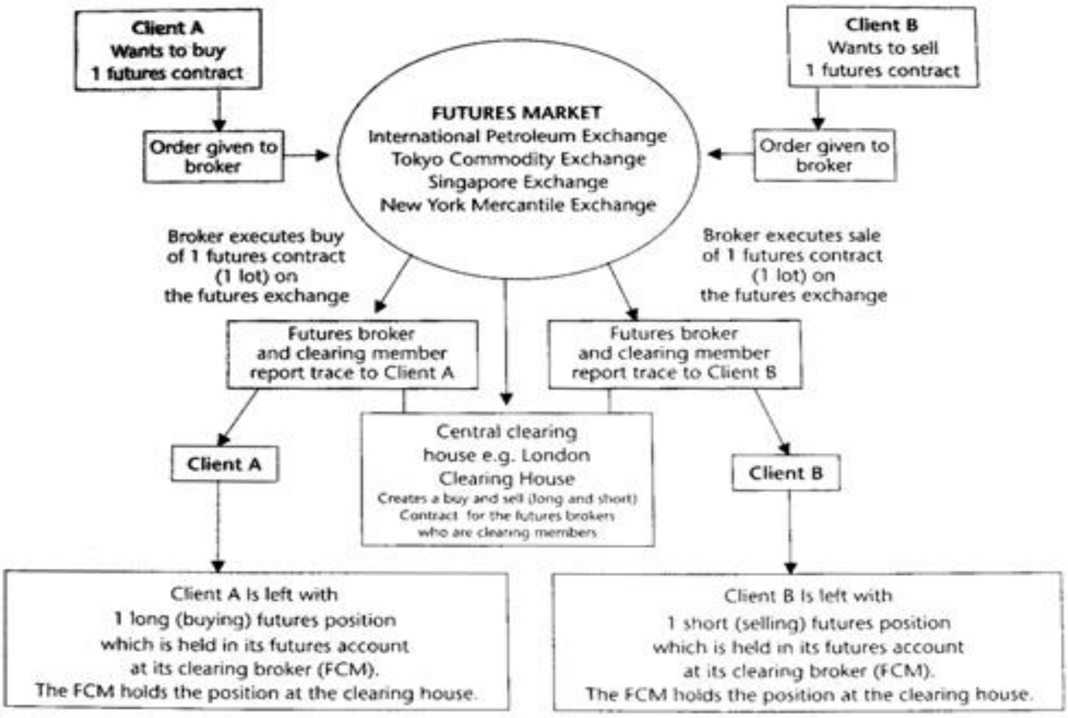

Figure 2-3: The Trading Process of Futures

If you buy (go long) a futures contract and the price goes up, you profit by the amount of the price increase multiplied by the contract size. On the other hand, if you buy and the price goes down, you lose an amount equal to the price decrease multiplied by the contract size. If you sell a futures contract (go short) and the price goes down, you profit by the amount of the price decrease multiplied by the contract size. If you sell and the price goes up, you lose an amount equal to the price increase multiplied by the contract size.

Some futures exchanges have position limits dependent on whether you are a speculator, trader or hedger (Long 2000). Sometimes daily maximum price movements are also enforced. These usually only apply to USA-based exchanges contracts. For example, price limit and positions limits do not apply to IPE oil futures contracts. During the Gulf War some participants found that NYMEX was forced to suspend trading, while the IPE carried on trading (Long 2000). These are points to consider when choosing futures contracts.

For the Indian market the relevance of the permission by the government allowing oil companies to hedge against price risks in the crude and petroleum products markets lies in the facts that

• Large crude buyers such as the Indian Oil Corporation, Reliance Petroleum and MRPL will be able to improve profitability.

• The impact of the volatile international oil prices can be tamed by being able to hedge against price hikes using oil futures.

Lastly this will enable the Indian oil companies to gear up to competition from global oil players such as Morgan Stanley and Citibank who are poised the enter the Indian markets.

2.3.2. Cash vs. Futures Price Relationships

Cash prices are the prices for which the commodity is sold at the various market locations (Wengler 2001). The futures price represents the current market opinion of what the commodity will be worth at some time in the future. Under normal circumstances of adequate supply, the price of the physical commodity for future delivery will be approximately equal to the present cash price, plus the amount it costs to carry or store the commodity from the present to the month of delivery. These costs, known as carrying charges, determine the normal premium of futures over cash .

As a result, one would ordinarily expect to see an upward trend to the prices of distant contract months. Such a market condition is known as contango and is typical of many futures markets. In most physical markets, the crucial determinant of the price differential between two contract months is the cost of storing the commodity over that length of time. As a result, markets which compensate an individual fully for carry charges – interest rates, insurance, and storage – are known as full contango markets, or full carrying charge markets.

Under normal market conditions, when supplies are adequate, the price of a commodity for future delivery should be equal to the present spot price plus carrying charges. The contango structure of the futures market is kept intact by the ability of dealers and financial institutions to bring carrying charges back into line through arbitrage.

Futures markets are typically contango markets, although seasonal factors in energy markets play an important role in market relationships. For example, during the summer, heating oil futures are often in contango as the industry begins to build inventory for the approaching cold weather. On any given day, prices in the forward contract months are progressively higher through the fall, reflecting the costs of storage, interest rates, and the assumption of increased demand.

The opposite of contango is backwardation, a market condition where the nearby month trades at a higher price relative to the outer months. Such a price relationship usually indicates a tightness of supply; a market can also be in backwardation when seasonal factors predominate.

As a futures contract approaches its last day of trading, there is little difference between it and the cash price. The futures and cash prices will get closer and closer, a process known as convergence, as any premium the futures have had disappears over time. A futures contract nearing expiration becomes, in effect, a spot contract (Culp 2002).

2.3.3. Short and Long Hedges

One of the most common commercial applications of futures is the short hedge, or seller's hedge, which is used for the protection of inventory value. Once title to a shipment of a commodity is taken anywhere along the supply chain, from wellhead, barge, or refinery to consumer, its value is subject to price risk until it is sold or used (NYMEX 2002). Because the value of a commodity in storage or transit is known, a short hedge can be used to essentially lock in the inventory value. A general decline in prices generates profits in the futures market, which are offset by a decline in the value of the physical inventory. The opposite applies when prices rise.

A long hedge is the purchase of a futures contract by someone who has a commitment to buy (is short) in the cash market (NYMEX 2002). It is used to protect against price increases in the future. An end-user with a fixed budget, such as a manufacturing

company that uses natural gas, can use a long hedge to establish a fixed cost. Sometimes the risk of an adverse change in the difference between cash and futures prices, also known as basis risk, can be an important consideration for hedgers of refined petroleum products.
A fuel marketer may offer customers fixed-price contracts for a number of reasons: to avoid the loss of market share to other marketers or alternative fuels, to expand market share; or to bid on municipal contracts requiring a fixed price. However, by offering to sell at a fixed price over a period of time, the marketer is exposed to the risk that wholesale costs will increase, perhaps to the point of unprofitability (NYMEX 2002).

2.3.4. Most Influential Futures Contracts of Crude Oil

Most of global crude oil trading in regard to futures contracts is made using NYMEX and IPE relevant contracts. These contracts have the highest trading volume and the importance as references for pricing other derivatives such as options and swaps.

NYMEX Light Sweet Crude Oil (WTI)

As previously mentioned, NYMEX's light sweet crude oil futures contract is normally called WTI after the West Texas Intermediate crude delivered as standard against it (WTI is a gasoline rich crude oil). This traded an average daily volume of 389,679 contracts during 2004, an increase of more than 10 per cent over the previous year. The contract requires delivery to be made by pipeline, FOB or free on board at seller's facility Cushing, Oklahoma, with special rules for small (5,000 barrels or less) deliveries. The delivery system matches the normal physical delivery for NYMEX WTI very closely: all deliveries are rateable over the course of the month and must be initiated on or after the first calendar day and completed by the last calendar day of the delivery month (Long 2000). The futures contract ceases trading, or expires, three business days before the 25th calendar day of the month before delivery. (This is to allow for pipeline scheduling.) There is provision for other crude oils to be delivered, at seller's option, with certain differentials agreed by the exchange. At present, the list
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of alternative grades is confined to three North Sea crudes (Brent Blend, Oseberg and Forties), two Nigerian crudes (Bonny Light and Qua Iboe) and a Colombian crude, Cusiana (Long 2000).
NYMEX WTI trades further forward than any of the other current futures contracts. There are 30 consecutive months traded at any time, plus a further five long dated contracts extending up to seven years ahead for the 36th, 48th, 60th, 72nd and 84th months. The exchange has also introduced "strip" trading, which allows market users to trade an equal number of crude oil futures contracts for any number of consecutive months from two to 30 months in a single transaction. Prices are fixed at a differential to the previous night's settlement. As with all commodities futures, the activity is concentrated in the nearby months.
Dominguez et al (1989) provide strong support for the proposition that the introduction of the NYMEX WTI crude oil futures market has increased the efficiency of the operation of the oil market. Their tests show that long-term futures contract prices are neither biased nor excessively volatile, while shorter-term contract and spot prices show some tendency to overreact to new information. On days with or without substantial oil market news, long-term futures contract prices move less than shorter-term contract prices, which in turn move less than do spot prices. From this it can conclude that the market does distinguish between short-term and long-term supply and demand conditions.
The NYMEX WTI contract has become, to a large extent, the industry's world-wide standard price. This is, on the face of it, a little surprising as NYMEX WTI is a low

volume US domestic crude and cannot be exported. It is not, therefore, a truly international crude oil. But the US is the largest importer of crude oil in the world and as such its traders, who use WTI as standard, have a very large influence on international prices.

IPE Brent Crude Oil

The only exchange to trade nothing but energy contracts is the IPE which introduced its first contract in gasoil in 1981. The IPE's Brent contract, which now trades for up to 36 months ahead, has also become very successful as NYMEX WTI, though in this case at the third attempt. Brent's cumbersome physical delivery procedures are

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unsuitable for a futures contract and the IPE finally settled on a cash settlement contract instead of the more common physical delivery, although there is also provision for physical delivery of whole cargoes using the EFP mechanism (Long 2000).

Cash settlement simply means that contracts left open at expiry are settled by cash transfer instead of the physical transfer of crude oil. Anyone with an open hedge position should therefore be in a position to buy or sell physical Brent at the cash settlement price, which is derived from physical transaction during the day, so the hedge provides as good a protection against adverse price movement as a physical delivery contract. Traders with full-cargo sized positions can use the EFP mechanism to effect physical delivery.

According to Brent traded an average of 106,076 contracts per day during 2004, an increase of 6 per cent over the previous year. Like NYMEX WTI, the contract is for 1,000 barrels.

2.3.5. Comparison of Forwards and Futures

Forward and futures contracts have different strengths and weaknesses when used for either hedging or speculation. These are summarized in Table 2.2.

The choice of futures or forwards and of which particular contract will depend on the circumstances. The most important consideration is that of a basis risk: how closely does the product or crude to be hedged match the hedging instrument. The better the match, the better will be the hedge.

2.4. Options

Options allow the user to create positions that reflects virtually any market view or risk profile. They are more flexible than forwards or futures, which can only be used to take a long or short position. Combining options with other instruments allows participant to structure risk management and trading strategies that can match or control their exposure.

Options have existed for many years, often embedded in normal commercial contracts, but they were rarely regarded as an asset and – as a result – were largely undervalued. However, now that mathematical models provide an accepted method for valuing assets, a standardized methodology is widely used for calculating option values and risk.

Energy options are currently traded both on the regulated futures exchanges and on the unregulated OTC market. The OTC market offers more flexibility and frequently provides the innovative pressure required to develop new contracts. Exchange trading of options formally began in 1973 when the Chicago Board of Trade (CBOT) created the Chicago Board Options Exchange (CBOE) to offer options on individual company stocks and many other exchanges have followed suit. The first exchange traded options in oil were traded on the IPE in 1983 on an informal basis, and by the end of 1986 there was enough interest from the industry for NYMEX to launch and options contract based on WTI crude. Since then, several more exchange-traded options contracts have been created by the NYMEX and the IPE including New York Harbor heating oil and gasoline, the NYMEX 3:2:1 "crack spread", US natural gas, Brent crude oil and north-west Europe gasoil. The OTC market has also expanded greatly. Over the past ten years, the use of options in the energy industry has increased rapidly, largely because of their success as an effective risk management and trading tool. Further growth in the options market will come from a wider acceptance by those sectors of the economy that recognize the need to protect the value of their assets from the volatility of the market.

2.4.1. Specifications of Option Contracts

Hull (2003) defines option as the right to buy or sell an asset. Options work like insurance. According to they provide the buyer (or option holder) with protection against the adverse effects of unpredictable future price movements in exchange for a fixed payment (or premium) that is paid in advance to the seller (or option writer). The option holder's risk is limited to the premium – which is retained by the option writer whatever happens to prices – while the options writer's risk is unlimited, because the option holder must be compensated for any adverse price movements. Options are different from other trading instruments because they give the option holder **the right, but not the obligation**, to buy (or sell) an underlying asset at a specified price during an agreed period of time. As a result, an options contract will only be exercised if the market moves in favour of the holder.

There are two basic types of option contract (Hull 2003):

- **call options**, which give the holder the right to buy; and
- **put options**, which give the holder the right to sell.

The buyer of a call option pays a premium to the seller and, in return, has the right (but not the obligation) to buy a specific amount and type of oil at a fixed price, before or at a given date. The buyer of a put option pays a premium to the seller and, in return, has the right (but not the obligation) to sell a specific amount and type of oil at a fixed price, before or at a given date. It is important to remember, that the option seller is obliged under the contract to buy or sell should the buyer exercise its right. In return for assuming this obligation, the option seller receives the option premium – a non-refundable payment – from the option buyer. Option premiums are typically paid-up front (usually within two business days following the date of transaction) unless the option contract is traded on an exchange, in which case the margin rules operated by the exchange will apply. The fixed price is usually known as the strike or exercise price. The date agreed in the contracts is usually known as the expiration date, exercise date or the maturity of the option. If the market price of the underlying asset changes so that it becomes profitable for the buyer to exercise the option, it is described as in the money and acquires an intrinsic value as a result. Options that remain unprofitable are described as being out of the money. If the market price is the same as the exercise price, the option is described as at the money. A call option has an intrinsic value when the strike price is below the market price. For example, if the strike price is $15/barrel and the market price is $17/barrel, the intrinsic value of the call option is $2/barrel.

A put option has an intrinsic value when the strike price is above the market price. For example, if the strike price is $19/barrel and the market price is $17/barrel, the intrinsic value of the put option is $2/barrel.

An option may be out of the money and still have a premium value. This is because of the option's time value or extrinsic value. As long as an option has time left to expiry, there is a probability that it might and up in the money before expiry, in which case it would acquire an intrinsic value.

For example, if a call option has 30 days left to expiration, the strike price is $18/barrel and the market price is $17/barrel, the option premium could be $0.21/barrel even though it has no intrinsic value at present.

2.4.2. Types of Option

Options can be based on and therefore exercised into a wide variety of trading instruments. They can also be traded either on a futures exchange or as private transactions on the OTC market. Exchange traded energy options are based on futures contracts and are standardized contracts. The settlement terms are fixed, the expiry dates are fixed, and only a limited range of strike prices are quoted at any point in time. As a result, the premium is the only negotiable component. OTC options are more flexible as they can be tailored to meet any set of specifications required. Everything in the contract is negotiable: the quantity, type, delivery or settlement procedure of the underlying asset, the expiry date, and the strike price for the contract. Like futures contracts, exchange-traded options are guaranteed by the clearing organization that underwrites the exchange. OTC options are guaranteed by the counterparties in the contract and are subject to the normal contractual performance risks associated with trading directly with companies. OTC contracts are usually based on ISDA (International Swaps and Derivatives Association) contract or sometimes on a company's own contract – although this is now being discouraged for the sake of standardization.

2.4.3. Exercising Options

There are two basic methods of exercising options (Hull 2003):

- **American options**, which can be exercised at any time up to the expiry date;
- **European options**, which can only be exercised on the expiry date.

Exchange traded options are all American, while OTC options can be of either type. Some option writers prefer to sell European options as this allows them to plan them exposure more accurately. Options are usually exercised when the buyer notifies the option writer of their intention to do so. In the case of an exchange traded energy option the notification is sent to the clearing organization via a clearing member of the exchange, the option is then converted into an appropriate futures position on the following business day. In the case of an OTC option the buyer typically notifies the option writer by telephone (followed up with the telex or fax confirmation) and the underlying asset is delivered as specified in the contract. In both cases, options are usually automatically exercised on the last day of trading if they are deemed to be in the money.

Another important method of settling or exercising options that is regularly used in the OTC market is the Asian or average settlement price option. Asian or average price options are typically settled in cash. The settlement is calculated using the average of the price settlements of an index over the life of a contract. Asian options are typically used to match the pricing methods used in the physical markets. Sellers of options sometimes prefer these to American or European types as exposure to volatile market movements may be reduced due to the averaging of prices.

2.4.4. Option Trading Positions

There are four basic option trading positions, each of which has its own characteristic profile of risk and reward (Hull 2003):

- buy a call, i.e., purchase an option to buy the underlying commodity or asset.
- buy a put, i.e., purchase an option to sell the underlying commodity or asset.
- sell a call, i.e., write a contract that gives the purchaser the option to buy the underlying commodity or asset.
- sell a put, i.e., write a contract that gives the purchaser the option to sell the underlying commodity or asset.

In forward and futures markets, both buyer and seller have the same symmetric price risks. In the case of the buyer, any potential profit from a rise in prices is mirrored by the potential loss from a decline in prices. And the exact opposite applies to the seller. As a result, there are only two basic types of forward or futures trading position, long and short. In the options market, however, the buyer and seller have very different exposure to price risk. The option holder's profit is unlimited, while the loss is limited to the premium paid. And the option writer's profit is limited to the premium received, while the loss is unlimited.

2.4.5. Options Pricing

In their 1973 paper, "The Pricing of Options and Corporate Liabilities", Fischer Black and Myron Scholes published an option valuation formula that today is known as the Black-Scholes model. It has become the standard method of pricing options. Black and Scholes developed their pricing model using the assumptions that asset prices adjust to prevent arbitrage, that stock prices change continuously, and that securities follow log normal distribution. From the original Black-Scholes formula, scholars and industry practitioners have developed a number of options pricing models suited for the different needs of the financial commodity industry. One pricing model, which is a simplified approach but analogous to Black-Scholes, is expressed as follows:

$$C = [FN(d_1) - XN(d_2) \times D$$

where F = the forward or futures price
X = the exercise price
D = the discount factor
$N(.)$ = the area under the normal curve

$$d_1 = \frac{In(F/X) + 1/2\sigma^2 t}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{t}$$

As we can see, this simplified options pricing model still maintains the main assumption, which originated in the Black-Scholes pricing model. The latter is widely used in the energy options futures market and in most exchange-traded options. This is the reason to choose exactly this model for the thesis.

There are five key factors that affect the price of an option based on the underlying commodity, such as oil, that pays no dividend:

- the current price of the underlying commodity.
- the strike price of the option.
- the time remaining to expiry.
- the future price volatility of the underlying commodity; and
- the current (risk free) interest rate for borrowing money.

In financial terms, the price of an option is simply the present value of the future income stream that can be expected from holding the option contract. Although the actual value of any future income stream from the option will not be known for certain until it expires, the market takes a view based on the expected price volatility of the underlying commodity and this can be deduced from the option premium by comparing it with the strike price and the current price of the underlying commodity.

σ = volatility of the underlying's price

T = delivery date of the asset

t = time until option expiration

The value of any option premium can therefore be split into two parts, the current (or intrinsic) value of the contract and the future (or time) value of the contracts:

OPTION PREMIUM = INTRINSIC VALUE + TIME VALUE

The intrinsic value of an option contract is easily determined since it depends on whether or not the contract is in the money.

INTRINSIC VALUE OF CALL = UNDERLYING VALUE – STRIKE PRICE
INTRINSIC VALUE OF PUT = STRIKE PRICE – UNDERLYING VALUE
TIME VALUE = OPTION PREMIUM – INTRINSIC VALUE

There is an important relationship called put/call parity which means that a put and a call have equal (theoretical) value when they are both struck at the forward price.

Volatility

The volatility is the most important factor in option pricing. It measures the likely magnitude of price changes over a given period and is expressed as a percentage of the underlying market price. Volatility is calculated as the annualized standard deviation of the distribution of percentage changes in daily prices, which is assumed to be a normal distribution. This allows option users to assign known confidence limits to the future trading range of the market. For example, a market volatility of 20 per cent means there is a 68 per cent chance that the price of oil will lie within a range of ± 20 per cent around the current price level a year from now. The greater the market volatility, the greater the range that prices are likely to trade in. The time value of an option increases with the volatility of the market. If volatility is expected to be low, the future trading range will be narrower and the present value of the potential income stream from holding an option will be smaller since there is a lower probability of a large change in prices before expiry. However, if volatility is expected to be high, the future trading range will be wider and the present value of the potential income stream from holding an option will be larger since there is a higher probability of a large change in prices before expiry.

There are two types of price volatility used in pricing options (Hull 2003):

- ♦ historical volatility; and
- ♦ implied volatility.

Historical volatility – as its name suggests – is the range that prices have traded in over a given period in the past. Implied volatility is the range that prices are expected to trade over a given period in the future (Hull 2003). Implied values are calculated by inputting option premiums into an option pricing model. When assessing the appropriate volatility to use when calculating option premiums, it is important to look at both. Historical volatility allows us to see how prices have behaved under known market conditions. From this, we may be able to build a confidence level to help us in assessing the predictability of current situations. Implied volatility allows us to see the market's view of what the expected trading range of prices will be over a given period. Implied rates are continually changing to reflect the market's view. Implied volatility is a powerful tool for analysing price risk. It allows us to assess the impact that prices will have on our assets with a given probability.

2.4.6. Trading Strategies

Caps

Caps, which are simply "strips", or consecutive series, of call options with the same strike price, are some of the commonest option-based instruments in energy price risk management.

To understand how they are applied, imagine that a major European oil refiner has decided to protect itself against price rises in crude oil over the next financial year. The company arranges to buy a cap with a strike price of US$20 per barrel, a maturity of 12 months, and monthly settlement; the volume hedged is 200,000 barrels per month, and the premium charged is 60 US cents a barrel at the end of each month, the average price over the month (representing the cost of physical supply) is compared with the strike price of $20.00 per barrel. If the average price rises above $20.00 per barrel ($24.00 for example), the seller of the cap pays the refiner ($4.00 multiplied 200,000 times = $800,000). The cap thus assures the refiner of a supply of 200,000 barrels, at a maximum price of $20.60 per barrel, for a year.

Floors and Collars

A floor, composed of a strip of put options, is simply a cap in reverse. By selling a floor, consumer fixes the minimum price that it will pay for energy, and thus gives up any chance of profiting from a fall in prices below a certain level. But the sum raised from the sale may be used to subside the price the consumer pays for energy or for risk management. For example, imagine that the management of the refinery decide they cannot afford to pay the full price of the cap (the $0.60 per barrel premium). They therefore agree to purchase a $20.00 cap and finance it through the sale of a $17.50 floor. This provides them with a "collar" at zero cost. If the price of the crude rises above $20, to $24.00 for example, the refinery exercises its cap at $20.00 and receives $4.00 per barrel from the collar provider. If the price of crude falls below $17.50, to $15.00 for example, the collar provider exercises its floor at $17.50 and the refinery pays out $2.50 per barrel. If the crude price stays between $17.50 and $20.00, the refinery obtains its supplies at the market price. At first sight, using zero-cost collar may appear to be the safest course of action for the refinery: it involves no upfront cost and offers no speculative return. However, if oil prices fall considerably, the refinery may end up paying much more for its feedstock than its competitors – who may lower their prices aggressively as a result. The zero-cost collar is thus really a "zero upfront cost" collar – true price insurance can be secured only by purchasing a cap.

Volatility Strategies

A trader who wants to take advantage of the underlying volatility of the market increasing or decreasing can use the following option strategies:

- **Straddles**. Sell call (cap) and sell put (floor) at the same strike price in the same market.
- **Strangles**. These are essentially the same as straddles except that a trader will use out of the money options. They also use different strike prices. A trader who thinks that volume is going down would normally short (sell) these options, while if he thinks that volume is going up, the trader will go long (buy) them.

2.5. Swaps

The development of the swaps derivatives markets in the oil industry has been fraught with many difficult events. Metallgesellschaft foundered, TXU slipped away in the night, Enron exploded, and Williams divested. Although the market stalled dramatically in the 2002-3 period, these issues have not prevented the rise and rise of the swap contract as an effective management tool for the energy industry. Swaps are a relatively new form of OTC derivative trading instrument that has proved to be ideally suited to the complexities of the oil market. They were first introduced into financial markets in the early 1980s where they were used to hedge interest rate risks. But it was soon realized that the same instrument could be used to transfer price risks for any asset, and swaps spread rapidly to the commodity markets, including oil. With them came new players such as the banks, who were seeking opportunities to diversify their investment activities and to apply their recently acquired financial engineering skills. The attraction of swaps is three-fold. First, they are purely financial transactions and can therefore be traded without incurring the quality risks and other delivery problems normally associated with physical oil contracts. Secondly, they offer the prospect of the "perfect hedge" since they can be tailored exactly to meet the requirements of each participant. And, thirdly, and most importantly, they can be traded far into the future since they are not constrained by the more limited time-horizons of existing futures or forward markets. Therefore, that swaps provide a uniquely flexible means of filling the gaps in the oil market left by other trading instruments. As a result, the oil swaps business has grown rapidly over the past few years.

Swaps are now firmly established as an integral part of the oil market. Short-term swaps have evolved from being largely private transactions between companies to become more standardized and transparent form of trading instrument that is widely used as a substitute for forward paper contracts, many of which have now been replaced by swaps. Negotiating long-term swaps is still more time consuming than using other oil trading instruments, which can sometimes provide the same degree of risk protection at a lower cost. Companies are also exposed to credit risks that can be difficult to control. But, despite these problems, swaps have made an important contribution to the oil market and are here to stay.

2.5.1. Specifications of Swaps

A swap is a purely financial transaction that is designed to transfer price risk. It is a private agreement between two parties to exchange cash at pre-arranged dates in the future according to an agreed price formula. It guarantees the swap user (who is risk averse) a fixed price for a specified asset over an agreed time period in the future and assigns any profit (or loss) that might arise as a result of subsequent price changes to the swap provider (who is a risk taker). A swap can be applied to any asset for which a mutually acceptable pricing mechanism can be established and, since it does not involve delivery, leaves the swap user free to make separate arrangements for the physical disposal of the asset.

In some ways swaps are very similar to futures contracts. Both involve an agreement to buy or sell a specified quantity and quality of oil (or any other commodity) at a particular location and date in the future at a fixed price agreed at the time the contract is negotiated. And both can be used to hedge price risks created as a result of positions held in the physical oil market, or to speculate over the future course of prices. But, although the objectives may be similar, the operation of the two types of contracts is very different and has led to an entirely different market structure and regulatory environment for swaps. The basic or "plain vanilla" energy swap differs little from swaps on other derivative markets and is really a very simple financial instrument. However, several interrelated factors have combined to cause an increase in the diversity of the instruments used in the oil swap market. In particular, a more liquid and competitive market for swaps has attracted oil industry participants that are very aware of the specific price risks that they face and who are demanding more customized structures. Therefore, after briefly describing the basic building blocks, this paragraph will outline the most important tailored instruments; the practical application of these structures is demonstrated in paragraph 3.3.

"Plain Vanilla" Swap

A simple oil swap is an agreement whereby a floating price is exchanged for a fixed price over a specified period. It is an off-balance-sheet financial arrangement that involves no transfer of physical oil: both parties settle their contractual obligations by means of a transfer of cash. The agreement defines the volume, duration, fixed price and floating price. Differences are settled in cash for specific periods usually monthly, but sometimes quarterly, six-monthly or annually. Swaps are also known as "contracts for differences" and as "fixed-for-floating" contracts – terms that summarize the essence of these financial arrangements. Producers sell swaps to lock in their sales price. The producer and its market counterpart agree a fixed price, for example, $18 per barrel, for an agreed oil specification index, and a floating price, almost always a reference price derived from Platt's or Argus (oil reporting services who publish daily prices for a range of commodities) or one of the futures markets. For the period agreed, the producer receives from the intermediary the difference between fixed and floating price if the latter is lower. If the floating price is higher, the difference is paid by the producer to the intermediary. The consumer of energy uses a swap in order to stabilize the buying price.

For example, an airline buying jet fuel (jet) would contract to buy a jet swap with a fixed price element of $140 per tonne. If the floating average was $150 per tonne, then the airline would receive a monthly settlement of $10 per tonne multiplied by the volume hedged. If the floating price averaged $135 per tonne, then the airline would pay out $5 per tonne.

Differential Swap

Whereas a standard swap is based on the differential between fixed and floating prices, a differential swap is based on the difference between a fixed differential for two products, and the actual or floating differential over time. Some examples of energy products that might attract differential swaps include jet versus gasoil, physical (Platt's) gasoil versus futures, 3.5% fuel versus 1% and Brent versus NYMEX WTI but the possibilities are limited only by the number of indices that exist. Differential swaps are typically used by refiners to hedge changing margins of refined products. Refiners usually receive the fixed-price side of the swap, ensuring a known, forward relationship for the price of their various products. If they sell the differential and the differential swap narrows (the margin has fallen for the covered period), then the refiner receives the difference between the contractually fixed differential and the floating differential; if it expands, the refiner pays out. Differential swaps may also be used by companies as a way of managing the basis risk assumed during their normal hedging activity. For example, an airline that prefers to hedge its jet exposure with gasoil swaps, because of the perceived value of these deals, may enter into a jet-gasoil differential swap to hedge this potential basis risk.

Margin or Crack Spread

Refiners who prefer to fix a known refining margin can construct elaborate forward (physical) and futures (exchange) deals for their products. However, such constructions can be costly and rarely provide complete cover. Alternatively, they can enter into a refining margin swap, whereby the product output of the refinery and the crude (or feedstock) input are simultaneously hedged, i.e., the products are sold, and the crude is bought for forward periods. The deal is usually expressed as US$x per barrel margin. At settlement, the refiner either pays or receives the difference between the margins; the calculation is based on the price settlements in the spot markets and those locked in. In this way, the probability of a refinery can be guaranteed for a few years forward. This kind of hedging is often integrated into development projects and upgrading schemes when the financiers are keen to ensure the viability of the project and seek to underwrite a minimum revenue stream.

2.5.2 Pricing Swaps

Arbitrage relationships between the swap and forward of futures markets create the basic framework for determining the price of a swap. In addition, there are other, less tangible, components to the swap price that are determined partly by the market and partly by the nature of the parties involved.

Generally speaking, the price of a swap depends on three main factors:

- the cost of hedging the swap position.
- the credit rating of the swap user; and
- the margin required by the swap provider.

However, by far the most important of these is the cost of hedging the position created by the swap agreement. This, in turn, depends partly on the term structure of the forward or futures

market being used to hedge the price risk, partly on the different payment structures, and partly on the basis risk associated with the hedging instrument. Although other factors, such as the credit rating of the swap user and the margin
required by the swap provider do play a role, their significance has diminished as the market becomes more liquid and the level of competition between the swaps providers has intensified.

2.5.2. Term Structure of Prices

The most important factor determining the price of a swap is the term structure of futures prices in the market that is being used by the swap providers to hedge their exposure in the swaps market. The basic difference between swaps and futures is that a swap agreement offers a single fixed price for an entire period while the portfolio of futures contracts offers a sequence of different prices for each delivery month. Although it is theoretically possible for all the futures prices to be the same, it is more likely that the futures prices will be on a rising (in contango) or falling (in backwardation) trend as described in paragraph 2.3.2. The relative value of the swap agreement compared with the futures portfolio therefore depends on the slope of futures prices and whether the swap user is hedging a long or short position on the physical market. In the case of an oil producer, who has a long position in the physical market and wants to hedge his selling price, the floating price is likely to be above the fixed price during the early part of the contract period when the market is in backwardation as the term structure of futures prices is downward sloping. The swap user would therefore expect to make cash payments to the swap provider which he would otherwise be able to earn interest on.

Swaps are therefore potentially more costly for producers when the market is in backwardation as they entail an initial net cash outflow. According to the literature the reverse is true if the market is in contango, since the term structure of futures prices is upward sloping, and it is the swap provider who suffers the initial cash outflow.

2.6. Hedgers, Speculators and Arbitrageurs

Derivatives have a very wide range of applications in business as well as in finance. There are three main participants in the derivatives market: hedgers, speculators and arbitrageurs (Hull 2003). The same individuals and organizations may play different roles in different market circumstances. There are also large numbers of individuals and organizations supporting the market in various ways.

2.6.1. Hedgers

Corporations, investing institutions, banks and governments all use derivative products to hedge or reduce their exposures to market variables such as interest rates, share values, bond prices, currency exchange rates and commodity prices such as oil. The classic example is the farmer who sells futures contracts to lock into a price for delivering a crop on a future date. The buyer might be a food-processing company which wishes to fix a price for taking delivery of the crop in the future, or a speculator. Another typical case is that of a company due to receive a payment in a foreign currency on a future date. It enters into a forward transaction with a bank agreeing to sell the foreign currency and receive a predetermined quantity of domestic currency. Or it buys an option which gives it the right but not the obligation to sell the foreign currency at a set exchange rate (Hull 2003).

2.6.2. Speculators

Derivatives are very well suited to speculating on the prices of commodities and financial assets and on key market variables such as interest rates, stock market indices, currency exchange rates and commodities. Generally speaking, it is much less expensive to create a speculative position using derivatives than by actually trading the underlying commodity or asset. As a result, the potential returns are that much greater. A classic application is the trader who believes that increasing demand or reduced production is likely to boost the market price of a commodity. As it would be too expensive to buy and store the physical commodity, the trader buys an exchange traded futures contract, agreeing to take delivery on a future date at a fixed price. If the commodity price increases, the value of the contract will also rise and can then be sold back into the market at a profit.

2.6.3. Arbitrageurs

An arbitrage is a deal that produces risk-free profits by exploiting a mispricing in the market. A simple example occurs when a trader can purchase an asset cheaply in one location and simultaneously arrange to sell it in another at a higher price. Such opportunities are unlikely to persist for very long, since arbitrageurs would rush in to buy the asset in the 'cheap' location, thus closing the pricing gap. In the derivatives business arbitrage opportunities typically arise because a product can be assembled in different ways out of different building blocks (Hull 2003). If it is possible to sell a product for more than it costs to buy the constituent parts, then a risk-free profit can be generated. In practice the presence of transaction costs often means that only the larger market players can benefit from such opportunities.

3. HEDGING IN PRACTICE

All companies that are dependent on commodities are affected by the price changes in the commodities.

3.1. Hedging with Forwards and Futures

As previously mentioned, forwards are quite similar to futures though there are a few differences. Due to their similarity the thesis presents practical hedging recommendations only for futures. Companies involved in the physical oil market can protect themselves against adverse price movements by taking an opposite position on the futures or forward market to that held on the physical market. In this way any loss in the physical market should be offset by a corresponding gain on the futures or forward market. A hedge will rarely, if ever, be perfect, but if chosen correctly will provide some insurance. Hedging can be used for various purposes. It can, for example, protect a buyer of oil against a fall in price while oil is in transit. An oil trader who has bought a cargo of physical oil would sell an equivalent volume of oil futures or forward contracts. This is known as a short hedge because the trader takes a short futures position. As soon as the physical cargo is sold, the hedge is lifted, i.e., the futures contracts are bought back. Effective hedging depends on the assumption that prices in the physical and forward
or futures markets move together. Ideally the differential between the two, the basis, would remain constant but in practice this rarely happens either because the product or crude being hedged is not identical in every respect to the futures or forward contract being used, or because the degree of backwardation or contango in the forward or futures market changes.

3.1.1. HEDGING SCENARIOS

SHORT HEDGE

On April 26, 2011, an oil company buys a 500,000-barrel cargo of WTI at Haldia port at spot price FOB for $54.33/barrel. The current futures price is $54.20/barrel. It decides to sell futures as a hedge. A few days later, on May 2, it sells the physical cargo for $49.50/barrel and buys back its futures contracts, which are
now trading at $50.94/barrel.

Table 3.1: Short Hedge

Days	Physical Market($/bl)	Futures Market($/bl)
Day1	Cargo bought at 54.33	Future sold at 54.20
Day7	Cargo sold at 49.50	Future bought at 50.92

Net Loss(cargo)=$4.83 Net Profit(futures)=$3.28
In this case the hedger has taken a smaller profit on the futures than he has made loss on the physical market. This results from a change in the basis, which is the differential between the futures market and the product being traded.
However, the total loss would have been substantially larger without the hedge.

3.1.2. LONG HEDGE SCENARIO

In the same way, a company which is short of oil in the physical market will use a long hedge, i.e., will buy futures, to protect itself against a rise in price. ONGC might agree on May 3, 2011, to sell WTI to a customer at a fixed price (equal to the current price $49.60/barrel) for some months ahead, say June 30. In order to protect itself against a rise in price it will buy futures on May 3 for $51.23/barrel. When the company buys the WTI at Cushing, Oklahoma at spot price FOB on June 30 to fulfil the order, the hedge will be lifted.

Table 3.2: Long Hedge

Months	**Physical Market($/bl)**	**Futures Market($/bl)**
Month 1	Oil sold at 49.60	Future bought at 51.23
Month 2	Oil bought at 56.63	Future sold at 56.65

Net Loss(oil)=$7.03 Net Profit(futures)=$5.42
In this case the futures profit did not quite match the loss on the physical market – again, it was due to a change in the basis.

3.1.3. SCENARIO: SPECULATING ON A PRICE RISE

Speculation is the opposite of hedging. Speculators take a position on the market purely in order to make a profit. Futures and forwards are ideally suited to this activity as there are none of the operational problems which can arise if speculation is carried out with physical cargoes of oil. Usually, speculators are regarded as undesirable by some in the market, but they are a necessary part of any futures market as they take on the risk which hedgers are trying to lay off. Many speculators, particularly the local floor traders, hold onto their positions for a very short time and are in and out of the market several times each day, increasing liquidity and making it easier for hedgers to trade when they want to. Even oil companies can sometimes become speculators when the chance of a reasonable profit arises.
Let's presume that on August 26, 2010, a bad weather condition at an offshore oil platform of the speculating oil company interrupts production in the Paradip port.
As a result, prices are expected to rise, and the oil company buys futures in the hope of making a profit. Several days later, on August 30, the weather condition improves and production is restored so the oil company closes out his position before prices can fall back again. Since there is no physical transaction involved the two trades must be classed as purely speculative.
Table 3.3: Speculative Trade

Days	**Physical Market($/bl)**	**Futures Market($/bl)**
Day 1	No transaction	Future bought at 66.13
Day 2	No transaction	Future sold at 68.81

Net Profit(futures)=$3.68

3.1.4. GENERAL RECOMMENDATIONS

Basis risk is an essential consideration in any hedging program. The basis is the difference in price between the product or crude to be hedged and the hedging instrument being used. The closer the relationship between the two the more effective the hedging will be. As there are very few futures contracts traded almost everyone using them is exposed to some basis risk. Before starting any hedging program, it is necessary to establish the historical basis relationship by comparing prices over as long a period as possible. In many cases, there is a clearly defined seasonal change in the relationship and provided this is taken into account hedging can be effective. Or the relationship can be affected by other factors some of which may be foreseeable. But there will be some products and crudes for which no satisfactory relationship can be identified. In these cases, it would be worth looking at other futures and forward contracts to see if a more effective instrument can be found. In many cases, however, a satisfactory basis can be established, and this should be considered each time a hedging decision is made. In a major price move, basis relationships can become insignificant since any protection is better than none.
But in a quieter market change in the basis can outweigh any benefits to be obtained from hedging.

3.2. HEDGING WITH OPTIONS

Options can be used to achieve a great variety of possible outcomes depending on the exposure and risk preferences of the user. Given the inherent flexibility of the four basic options positions, even simple trading strategies can be used to produce tailor-made risk management and trading profiles, often at a very low cost. This section describes two common option trading strategies that are widely used in the oil industry.

3.2.1. OPTION HEDGING SCENARIO: PRODUCER HEDGE

An oil producer or distributor would like to hedge the value of its production. On January 19, 2010, the current price of WTI crude oil is $47.55/barrel. The producer expects prices to fluctuate in the range of $50 to $45/barrel during the one-month period of the hedge (from January19 – February 18), but is concerned about the risk of prices falling below $45/barrel.

If the producer is also prepared to accept a maximum price of $50/barrel for its production, a combination of put and call options can be used to hedge at no cost.

Buy a $45/barrel put option	-$0.25/barrel
Sell an $50/barrel call option	+$0.25/barrel

Net cost of transaction: $0.00/barrel
The result of this strategy is to limit the downside and upside price risks to a range between $45/barrel and $50/barrel.
If prices fall below $45/barrel, the $45 put option will be exercised giving the producer the right to sell its output at $45/barrel, however low prices go.
If prices rise above $50/barrel, the $50 call option will be exercised and the producer will be obliged to sell crude at $50/barrel, however high prices go. If prices are between $45/barrel and $50/barrel, neither option will be exercised and the producer sells its crude at the prevailing market price. This is exactly what happened in the period of January 19 – February 18, 2010, as WTI prices stayed between $45/barrel and $50/barrel.
This strategy is known as zero cost collar. The strike price of the option can be set at any level, but the put and call options must be equally far out of the money if the cost of the put and call premium is to be the same.

3.2.2. OPTION HEDGING SCENARIO: CONSUMER HEDGE

A crude oil consumer has based its crude oil purchasing plan on a maximum price of $62/barrel for August 2010 with the latest purchase date of August 15. On July 20, 2010 the current price for WTI crude oil is $56.72/barrel. The purchasing department have decided not to lock in a price at the current market level because they feel that prices may fall further to around $50/barrel. To protect themselves against a price, move above $62/barrel, the purchasing department could buy August $62 call options at a cost of $0.20/barrel.
Buy a $62/barrel call option: -$0.20/barrel
Net cost of transaction: -$0.20/barrel
The result of this strategy is to limit the upside price risk so that the maximum price paid by the company for crude oil would be $62/barrel.
If prices remain below $62/barrel, the $62 call option will not be exercised and the purchasing department can meet its plan target with direct purchases on the spot market.
If prices rise above $62/barrel, the $62 call option will be exercised and the company can obtain its supplies from the option writer at $62/barrel, however spot market prices go.
On August 15 the purchasing department decides to buy the necessary amount of WTI crude oil. The current price for WTI is 66.27/barrel which means that the $62 call option is exercised and the company obtains its supplies from the option writer at $62/barrel instead of buying the crude from open market at $66.27/barrel.

3.2.3. GENERAL RECOMMENDATIONS

Combinations of various options can become quite complex. The hedging transaction so that the company can measure, monitor and anticipate the extent of its exposure on the trade (and explain the transaction to its Board, if necessary). Also, there should be a clear hedging policy. For example, “trading around the hedge” (i.e., taking profits and modifying hedge positions) can be a good tactic so long as the amount of trading is not excessive, and it fits the policies and strategies agreed by the company’s senior management.

3.3. HEDGING WITH SWAPS

A typical swap contract involves two linked transactions. First, there is an agreement for the swap provider to buy (or sell) a particular quantity of the underlying asset from the swap user at a fixed price over a specified future time period. And, secondly, there is an agreement for the swap user to sell (or buy) back the quantity of the same asset over the same period from the swap provider at a floating price, which can be determined by any mutually acceptable set of rules. The two notional transactions are necessary to eliminate any requirement to deliver the asset. But as the same parties are involved on both sides of the two transactions, the contracts are actually settled by paying the difference between the fixed price and the floating price to whichever party gained overall.
For example, an oil producer who is concerned about the risk of lower oil prices over the next six months could use a price swap to fix the price of all or part of his output for that period. Like hedging with a futures contract, this involves two parallel sets of transactions, one paper and one physical, in which the profits (or losses) from the paper transactions are used to offset any losses (or gains) on the physical transaction. In this case the paper transaction is the swap agreement, which specifies that the producer will:
a) sell a certain number of barrels of his particular grade of crude oil each month to the swap provider at an agreed fixed price; and
b) buy back the same quantity and quality of oil at the same time at a market related price determined according to an agreed formula.

If the formula price exceeds the fixed price, the producer pays the difference to the swaps provider, while, if the formula price is less than the fixed price, the swaps provider pays the difference to the producer. Any profits (or losses) which the swap user makes on the swap contract are then used to offset any losses (or gains) that arise because of changes in the market price when the producer actually sells his oil on the physical oil market. In this way the producer ends up with the equivalent of a fixed price for his oil over the entire period.

3.3.1. SWAP HEDGING SCENARIOS: PRODUCER AND SUPPLIER HEDGE

A WTI crude oil producer wants to take advantage of high oil prices during the fourth quarter of 2004 to lock in a good price for part of his next year's production in case prices collapse. He decides on October 26, 2004, that prices have peaked and agrees a price swap to sell 1,000 b/d (average barrels daily) at the current swap market price of $56/barrel for the first 3 quarters of 2005.

The structure of the swap deal is as follows:

a) The producer agrees to sell 1,000 b/d of WTI crude oil to the swap dealer at a fixed price of $56/barrel throughout first 3 quarters of 2005.

b) The producer agrees to buy back the same quantity from the swap dealer at a floating price based on the quarterly average spot price FOB of WTI crude oil.

c) Payments are to be made quarterly within five business days of the end of the quarter based on the difference between the agreed fixed price of $56/barrel and the value of the price index. If the index price is higher than the fixed price, the producer pays the swap dealer. If the index price is lower than the fixed price the swap dealer pays the producer. In the first 3 quarters of 2005, the producer sells his actual output in the physical market at market prices, which combined with the net value of the payments from the swap deal, provides him with the fixed price guaranteed by the swap deal.

The net payments to (+) or by (-) the producer in the swap deal are as follows (actual prices):

Table 3.4: Payments of the Swap Deal

Period	WTI Price	Fixed Price	Price Diff.	Quantity(bl)	Payment ($)
2005 Q1	50.03	56	+5.97	91000	543270
2005 Q2	54.44	56	+1.56	91000	141960
2005 Q3	63.99	56	-7.99	91000	-727090
2005 Q1-Q3	56.15	56	-0.15	273000	-40950

And the receipts from the sale of WTI in the physical oil markets are:

Table 3.5: Receipts from the Sale of Physical Oil

Period	WTI Price	Quantity(bl)	Receipt ($)
2005 Q1	50.03	91000	4552730
2005 Q2	54.44	91000	4954000
2005 Q3	63.99	91000	5823090
2005 Q1-Q3	56.15	273000	15328950

The combined proceeds from the swap deal and the physical sales are therefore:

Table 3.6: Combined Proceeds

Period	Sale Proceeds ($)	Swap Proceeds ($)	Total Proceeds ($)	Quantity(bl)	Price achieved ($)
2005 Q1	4552730	543270	+5096	91000	56
2005 Q2	4954000	141960	+5096	91000	56
2005 Q3	5823090	-727090	+5096	91000	56

2005 Q1-Q3	15328950	-40950	+15288000	273000	56

Thus, the producer achieved the target price of $56/barrel for his output in the first 3 quarters of 2005, compared with an annual average price of $56.15/barrel, which he would have received if he had not entered into the swap. In this case the swap price turned out to be lower than the actual market price. But prices could have fallen sharply as well. Either way, the producer can be sure of receiving an average price of $56/barrel for his crude – whatever happens to market prices in the first 3 quarters of 2005.

3.3.2. General Recommendations

The most common swap agreement presented in this paragraph and various swap agreements described in the theoretical part of this thesis (see paragraph 2.5) allow
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companies to manage their exposure to energy price risk with considerable flexibility. It should be remembered that (according to Fusaro 1998):

- ♦ producers and processors can offer fixed-price products to their consumers.
- ♦ refiners can lock their refining margins.
- ♦ banks can offer more attractive financing when price exposure is controlled.
- ♦ exposure to one oil product can be switched to another: for example, an airline fixing futures prices in gasoil can eliminate the inherent basis risk by using a jet-gasoil differential swap.
- ♦ competitive advantage can be secured by locking into high/low prices; and
- ♦ certain limitations of the exchanges (notably liquidity, duration, the need for margin adjustments and the limited range of product specifications) can be overcome with swaps.

Despite these points, few companies hedge all their price exposure, particularly in the longer term. Instead, the convention among end-users is to hedge the current financial/budget year plus one, while the percentage of this exposure that companies seek to cover is still somewhere between 40% and 60%.

One reason why companies hedge only a fraction of their exposure is that they do not want to risk forgoing gains if the market moves favourably. Companies may also be concerned that they will be left at a relative price disadvantage compared with them competitors. However, it would still appear that most companies are under-utilizing the risk-management potential of energy swaps.

One of the main limiting factors worldwide and even in India is a lack of knowledge about derivatives. Another problem is that, in the past, the energy swaps market has been inefficient about competition and liquidity.

Again, there is gradual improvement on these counts particularly for longer-term products.

4. CONCLUSIONS RESULTING FROM THE HEDGING SCENARIOS

Successful hedging of crude oil can be achieved with forwards, futures, options and swaps. The derivatives covered by the thesis all have their advantages and disadvantages when compared to each other. Forwards unfortunately almost always involve physical delivery, yet there are more forward contracts available for hedging than there are futures. Futures on crude oil (especially WTI and Brent-based) are subject to deep liquidity but the existence of basis risk undermines their success. Buyer of options does not obtain any liability with the transaction but this freedom has a cost that is usually higher when compared to other instruments. Swaps are an easy way to fix prices with the exchange of cash flows, yet the hedger must have a reliable credit rating and a margin has to be set up. Exchange-traded derivatives are effective instruments for hedging that requires fast execution and deep liquidity. OTC markets, on the other hand, are useful and necessary for those hedgers who aim for customized and specialized instruments such as the swap companies utilize both exchange traded and OTC derivatives in their hedging operations.

The practical examples represented in the current chapter point out the following:

- hedging stabilizes the fluctuations of company's cash flows.
- hedging decreases company's price risk exposure when being involved with physical products.
- hedging secures competitive advantage by locking into high/low prices.
- hedging enables producers and resellers to offer fixed-price products to them customers.
- hedging provides effective financial management of the company and enables the management to focus on other factors of the business.

Basis risk is an essential consideration in any hedging program. The basis is the difference in price between the product or crude to be hedged and the hedging instrument being used.

Combinations of various derivatives can become quite complex. There should be a clear understanding of the hedging transaction so that the company can measure, monitor and anticipate the extent of its exposure on the trade.

To conclude, when designing an energy price risk management or trading program, it is essential to be aware of all the risks that are involved in the energy market and the ways in which they interrelate. But it is important to remember that any hedging strategy which focuses narrowly on any one of the possible risks and ignores the others may be worse than having no hedging strategy at all.

5. CONCLUSIONS

Over the last twenty years oil has become the biggest commodity market in the world. During this period, oil trading has evolved from a primarily physical activity into a sophisticated financial market. In the process it has attracted the interest of a wide range of participants who now include banks and fund managers as well as the traditional oil majors, independents and physical oil traders. The oil market now offers an almost bewildering array of trading instruments that can be used to reduce the price risks incurred by companies buying and selling physical
oil. These instruments include forwards, futures, options and swaps. The instruments can be traded through organized financial exchanges or on the over-the-counter (OTC) markets.

Futures contracts enable companies to buy and sell oil of an agreed standardized quality, quantity and delivery terms for future delivery within the institutional framework of a futures exchange. Forward contracts enable companies to buy and sell oil privately between themselves for future delivery outside the institutional framework of a futures exchange. Price swaps enable companies to exchange price risk without involving the physical delivery of any oil. Like forward contracts, swaps are agreed directly between two parties and are not guaranteed or otherwise organized within any institutional framework. Options enable companies to lock in a maximum or minimum price for the purchase or sale of oil at a future date in exchange for a fixed non-refundable “insurance” premium.

These derivative trading instruments have
transformed the structure and operation of the oil market over the past decades, giving companies much more control over prices and bringing new participants into the market, such as banks and financial trading houses, who are prepared to take on some of the risks created by oil price volatility.

The price risk management tools such as derivative instruments
are used to manage price volatility in order to protect company revenues and profits. In the simplest terms, this is accomplished by hedging – establishing a “paper” position opposite to the physical position of the commodity buyer or seller.

The hedger uses derivatives to protect a physical position or other financial exposure in the market from adverse price moves which would reduce the value of the position. A seller of the commodity seeks protection against downside price moves, a buyer seeks protection against upside price moves. Hedging protects profit margins and reduces risk. The hedge position is established to buffer against day-to-day market fluctuations in accordance with strategic company objectives.

Companies should ensure that any derivatives activity remains within the parameters agreed by the Board and the risk management committee or risk manager. When designing an energy price risk management or trading program, it is essential to be aware of all the risks that are involved in the energy market and the ways in which they interrelate. But it is important to remember that any hedging strategy which focuses narrowly on any one of the possible risks and ignores the others may be worse than having no hedging strategy at all.

There are three main participants in the derivatives market: hedgers, speculators and arbitrageurs. Many corporations, investing institutions, banks and governments can be seen as hedgers as they all use derivative products to hedge or reduce their exposures to market variables such as interest rates, share values, bond prices, currency exchange rates and commodity prices such as oil. Speculators are aware of the fact, that derivatives are very well suited to speculating on the prices of commodities and financial assets and on key market variables such as interest rates, stock market indices, currency exchange rates and commodities. It is much less expensive to create a speculative position using derivatives than by trading the underlying commodity or asset. Arbitrageurs have also their share in the market place. An arbitrage is a deal that produces risk-free profits by exploiting a mispricing in the market. A simple example occurs when a trader can purchase an asset cheaply in one location and simultaneously arrange to sell it in another at a higher price.

The objective of this thesis was to study and analyses the various derivative instruments available on the global financial market and to present practical examples for hedging crude oil price risks in accordance with broad-based hedging strategies.

The thesis introduces modern oil industry and explains the importance of crude oil on the global market. The importance of basis risk and hedging in general was explained.

An in-depth theoretical explanation of derivative instruments and the strategies applied in energy hedging was given. The value of the thesis comes from practical examples for hedging price risks and from general recommendations regarding hedging with derivative instruments.

The objective of the thesis was successfully achieved. To conclude, it must be said, that crude oil forms the basis of global energy markets and is the most important trendsetter for energy products. It is important to clarify, though, that the most common strategies used regarding crude oil hedging can also be applied to other energy products as the specifics of various derivative instruments are often similar or even identical. This is the reason why companies worldwide and in India can and are applying the same strategies to the hedging of price risks of gasoline, diesel oil, heating oil, jet fuel etc.

BIBLIOGRAPHY

[1] BIS. 2005. BIS 75th Annual Report. Bank for International Settlements.
[2] BP. 2005. Statistical Review of World Energy. British Petroleum.
[3] Carter, D., Rogers, D., Simkins, B. 2001. Fuel Hedging in the Airline Industry: The Case of Southwest Airlines. *Working Paper Series*. Oklahoma State University.
[4] Clubley, S. 1998. *Trading in Oil Futures and Options*. Cambridge: Woodhead Publishing Ltd. pp. 9-31.
[5] Culp, C.L. 2002. *The Art of Risk Management*. New York: John Wiley & Sons, Inc. pp. 263-294.
[6] Cuthbertson, K., Nitzsche, D. 2001. *Financial Engineering: Derivatives and Risk Management*. Chichester: John Wiley & Sons, Inc. pp. 25-236
[7] Dominguez, K.M., Strong, J.S., Weiner, R.J. 1989. Oil and Money: Coping with Price Risk Trough Financial Markets. *Harvard International Energy Studies*. Energy and Environmental Policy Center. Harvard University.
[8] Faruqee, R., Coleman, J.R. 1996. Managing Price Risk in the Pakistan Wheat Market. *World Bank Discussion Paper nr 334*. Washington: World Bank.
[9] Fusaro, P.C. 1998. *Energy Risk Management: Hedging Strategies and Instruments for the International Energy Markets*. 1st ed. New York: McGraw-Hill. pp. 9-37
[10] Haglund, F., Wramsby, G. 2005. The Volatility Race in Commodities. Master Thesis. Jönköping University.
[11] Howe, J.T., Chowdhry, B. 1999. Corporate Risk Management for Multinational Corporations: Financial and Operational Hedging Policies. *European Finance Review*, 2: pp. 229–246.
[12] Hull, J.C. 2003. *Options, Futures, and Other Derivatives*. 5th ed. New Jersey: Pearson Education, Inc.
[13] James, T. 2003. *Energy Price Risk*. New York: Palgrave Macmillan. pp. 176-205.
[14] Kaminski, V. 2004. *Managing Energy Price Risk: The New Challenges and Solutions*, 3rd ed. London: Risk Books. pp. 3-45.
[15] Long, D. 2000. *Oil Trading Manual*. Cambridge: Woodhead Publishing Ltd. Supplement 3.
[16] Natenberg, S. 1994. *Option Volatility & Pricing: Advanced Trading Strategies and Techniques*. Chicago: Probus Publishing Company. pp. 257-330.
[17] NYMEX. 2002. A Guide to Energy Hedging. New York: New York Mercantile Exchange, Inc. pp. 10-21.
[18] Pegado, A. 1989. *World Crude Oil Trading Agreements & Procedures*. Barrows Company. pp. 32-87.
[19] PWC. 2005. Energy Commodity, Trading and Risk Management. PricewaterhouseCoopers LLP.
[20] Pärn, P. 2004. Kütusefirma riskid kaubatarnetel: nelja tuletisinstrumendi võrdlus hinnariskide katmisel firma OT näitel. Magistritöö. Majandusarvestuse ja rahanduse õppetool, Estonian Business School.

[21] Wengler, J. 2001. *Managing Energy Risk: a Nontechnical Guide to Markets and Trading*. Tulsa, Oklahoma: PennWell Publishing Company. pp. 47-89.

APPENDICES

Appendix 1: Market Sectors

Major oil companies

Most major oil companies maintain specific derivatives trading or risk-management teams. In addition to dealing in forward, futures and options, these teams also use swaps to manage some physical exposure, more commonly to hedge particular deals with their own clients and, increasingly, to trade for profit. The culture of each organisation has an enormous amount of influence upon their participation in the derivatives markets. On one-off bases, derivatives are also used in project finance, structured finance and tax-related strategies.

Airlines

The jet fuel sector is the most mature and developed oil product sector. Airlines were the first serious users of commodity swaps, largely because jet accounts for up to 20% of airline operating costs and is the cost that is most exposed to short- and medium-term price fluctuation. They have also been among the first to explore exotic options that add flexibility and generate savings but concede some risk control to their swap/option issuers. The recent war crises have reinforced the need to manage this risk, as during these periods, jet prices rose even further than the 80-100% price rise in crude oil. Most major airlines now manage their jet exposure to some extent. Tight competition in the US airline sector has discouraged airlines from adopting new exposure-management practices until recently. This is now beginning to change. The most significant evolution in recent years has been the rapid disintegration of balance sheets across the industry. With the notable exception of the discount airlines, most of the US and many European airlines have been unable to hedge more than 11 months forward due to concerns about default. There are many airlines forced to use their "house" backs for access to energy derivatives. Market bid-offers have widened.

Shipping companies

The variable costs of a shipper company are dominated by bunker-fuel prices. In particular, fuel is often the only variable when ships are chartered for fixed terms. As with airlines, there is an increasing tendency to hedge forward with swaps beyond annual budget periods. The shipping business is a long-term business: freight contracts of around 10 years' duration are common, and ship owners are therefore used to dealing with long-term risk. Long-term derivatives are a natural means of managing the oil price risk in such contracts, and although shipping companies tend not to hedge as large a percentage of their total consumption as airlines, they tend to hedge for longer periods. Whereas airlines have no traditional alternative risk-management tools, the shipping industry has used "bunker adjustment clauses" for many years to hedge oil price risk. It is only because such clauses are much less efficient and flexible that ship owners are switching to OTC derivative transactions.

Transport companies

Like other sectors of the transportation sector, road haulage firms are exposed to diesel fuel prices. The biggest barrier to their participation in the OTC markets is the fragmentation of this risk. This is continually evolving, and larger publicly quoted road and rail transportation companies are faced with fragmented and diverse client bases, facing very "airline"-like risks.

Many consumers are very small firms or independent truck owners working on a contract basis, contracts are based on spot costs, and the price risk is thus spread relatively thinly.
Power companies
Power generators using gas (indexed to either gas or oil prices), oil and coal are exposed to fluctuations that comprise a very large proportion of their variable cost base. The ability of generators to vary their power prices is very limited, particularly when selling to the household sector. Some companies have started hedging their fuel exposure, but without an adequate reference price mechanism there has been no development of the financial derivatives markets in the UK. Many acknowledge that the regulator is against such innovations, and in oil and gas they remain very significant participants.
Industrial groups
Firms with a high energy consumption (for example, metal-smelting and –refining companies, cement manufacturers, glassmakers) are increasing their use of swaps to manage fuel oil exposures. Some of these firms, such as metal producers, are experienced in managing other commodity price risks. The indexation of natural gas in Europe and Asia to the oil price has presented these companies the means to perfectly hedge their supply of gas.
Chemical companies
Petrochemical producers are typically exposed to naphtha price fluctuations but, apart from a few companies, this sector has yet to use swaps to any significant degree.
Financing organizations
Banks and institutions that provide development finance for oil projects often carry a risk that is related to oil price. This may be because repayment is linked directly to the oil output of the completed project or, less directly, because credit risks associated with new projects are dependent on the forward price of energy.
Companies may also link oil swaps directly to bonds, warrants or other securities.
Poor returns on conventional assets have stimulated significant interest from investors.
A brief summary of the financing structures associated with energy derivatives follows below.
Hedge funds
There is also a specialist fund management market that uses certain commodity market instruments such as oil swaps. They are famous for leveraging their available capital to take very significant positions in the very liquid swaps and futures contracts for WTI, Brent and NYMEX Henry Hub Natural Gas However, in 2003, it was clear that these positions moved to far less liquid contracts such as gasoline, jet and regional natural gas.
Investors
This market grew rapidly in response to poor yields in the equity and bond markets from 2000 to 2003. The volatility in energy has generated savings products with returns of 7% to 45%, depending upon the type of risk taken. In the briefest terms, these investments essentially isolate interest income on the deposits and, the discounted "strip" is used to purchase options on the suggested index. Funds from investors are used to buy a zero-coupon bond that guarantees return of principal at the horizon. The difference between the price of a discount bond and the funds received from investors is used to purchase energy derivatives.
The changing value of the options represents the yield on the investment. As the investors are concerned about the outcome and not the instrument, quite sophisticated combinations of options are often employed. Titles such as "range accrual note", "enhanced yield" and "commodity tracker" have become the bywords in high-end investments.

OIL TRADING GLOSSARY

American Style Option an American-style option may be exercised at any time during its lifetime, up to and including the expiration date.
Arbitrage A method of trading a security or commodity in which the trader attempts to profit from differences in price between two or more markets. The usual objective of arbitrage is to acquire a commodity on one market and sell it on another at a higher price.
At-the Money An option whose strike is the same as the prevailing market price of the underlying rate or price.
Back Month Contracts Any exchange-traded derivatives contracts apart from the nearest, or front, contract month.
Backwardation When the price of nearer (typically prompt or spot) crude underlying commodity or instrument trades at a premium to the same commodity or instrument traded further forward. Commonly referred to as an inverse market.
Barge Motored or motorless vessel used to carry oil products, often along a river. Barges vary in capacity, mainly from 1,000 to 5,000 tons.
Barrel A unit of measurement most used for crude oil. 2. A barrel of crude oil is equal to approximately 42 US gallons or 159 litres.
Basis is most used as a yardstick for measuring differences in price.
If the accepted price of a given commodity is $100, then a price of $105 for the same commodity is five percent higher than basis.
Basis Risk The risk that the value of a futures contract (or over-the-counter hedge) will not move in line with that of the underlying exposure. Also, the risk that the cash-futures spread will widen or narrow between the times at which a hedge position is implemented and liquidated.
Black-Scholes Model An option-pricing model initially derived by Fischer Black and Myron Scholes in 1973 for securities options and later refined by Black in 1976 for options on futures.
Blending Sometimes crudes are blended near source when the same storage terminal or pipeline is used. An example is Brent Blend – a blend of crudes from various fields in the East Shetland Basin. Also used to create components for gasoline.
Book The total of all forward positions held by a trader or company.
Book Transfer, Book out the transfer of title of a cash commodity to the buyer without a corresponding physical movement.
Call option, put option Calls and puts, as they are commonly called, are types of derivative financial securities traded privately and on stock markets which set a fixed price for a stock, bond or other commodity and an expiry date after which the owner of the option can no longer buy the commodity (call option) or sell it (put option).
Cap A supply contract between a buyer and seller, whereby the buyer is assured that he or she will not have to pay more than a given maximum price.
Carrying Charge, the total cost of storing a physical commodity, including storage, insurance, interest, and opportunity cost.

Cash-and-Carry Arbitrage A strategy in which a trader generates a riskless profit by selling a futures contract and buying the underlying to deliver into it. The futures contract must be theoretically expensive relative to the underlying. If the futures are theoretically cheap compared to cash, the trader could sell the underlying and buy the futures – reverse cash-and-carry arbitrage.
Commodity Future A futures contract on a commodity. Unlike financial futures, the prices of commodity futures are determined by supply and demand as well as the cost-of-carry of the underlying. Commodity futures can, therefore, either be in contango (where futures prices are higher than spot prices) or backwardation (where futures are lower than spot).
Commodity Swap 1. Enable both producers and consumers to hedge commodity prices. The consumer is usually a fixed payer and the producer a floating payer: if the floating-rate price of the commodity is higher than the fixed price, the difference is paid by the floating payer, and vice versa. Usually only the payment streams, not the principal, are exchanged, although physical delivery is becoming increasingly common. 2. Executed to hedge risks which cannot readily be hedged with futures contracts. This could be a geographical or quality basis risk, or it could arise from the maturity of a transaction.
Contango Description for an energy market where the anticipated value of the spot price in the future is higher than the current spot price. When a market is in contango, market participants expect the spot price to go up. The reverse situation is described as backwardation.
Contracts for differences (CfD) A type of bilateral contract arrangement in which an energy producer or seller receives a fixed price for energy plus an adjustment value to cover any differences between the agreed-upon fixed price and the actual market price of the energy at the time it is delivered.
Crack Spread 1. A calculation of the worth of a barrel of crude oil in terms of the value of its refined products such as gasoline and heating oil. 2. Crack spreads may be based on a variety of refinery models and also depend on the type of crude input. 3. Expressed usually in dollars and cents per barrel of crude. To calculate the spread, the cents per gallon product prices are multiplied by 42 (gallons per barrel) and subtracted from the crude oil price. For example, when heating oil futures cost $0.40 per gallon and NYMEX light, sweet crude oil is priced at $12 a barrel, the heating oil crack spread in dollars per barrel = $0.40 x 42 = $16.80 – $12 = $4.80.
Crude Oil A full-ranging hydrocarbon mixture produced from a reservoir after any associated gas has been removed. Among the most commonly traded crudes are the North Sea's Brent Blend, the US's West Texas Intermediate (WTI) and Dubai.
Delta Hedging An option is delta-hedged when a position has been taken in the underlying that matches its delta. Such a hedge is only effective instantaneously, because the option's delta is itself altered by changes in the price of the underlying, interest rates, the option's volatility and time to expiry. A delta-hedge must, therefore, be rebalanced continuously to be effective.
Derivatives 1. Types of securities that have no real value of their own, but whose value depends on, or is derived from, some other value such as a prevailing market price, stock value or market index. Typically, the "other value" isn't established, and will only be known at some time in the future. 2. Commonly used in the energy industry as risk management instruments. Properly used, they can provide insurance against interest rate or energy price hikes, improve the

investment quality of a utility's issues of bonds or other securities, or offer any number of other benefits.

European Option An option which may only be exercised on its expiration date.

Exchange of Futures for Physical (EFP) The conversion of a futures position into a physical position via simultaneous buy/sell transactions.

Exchange of Futures for Swaps (EFS) The conversion of a futures position into a swaps position via simultaneous buy/sell transactions.

Forward A method used for trading commodities that will be delivered to the buyer at a specified time in the future. Forwards differ from futures in that they are usually customized for the buyer, they are not traded on exchanges, and they may not be subject to the same regulations as futures.

Futures contract When an agreement is made to acquire goods or services on the futures market, the buyer and seller enter into a futures contract. This contract assures the seller that the buyer will pay the agreed-upon price for a predetermined quantity of the commodity. In return, the buyer can lock in a price for the commodity regardless of the market price when the commodity is delivered.

Hedge Ratio The ratio, determined by the option's delta, of futures to options required to establish a position which involves no price risk.

Historical Volatility The annualized standard deviation of percentage changes in futures prices over a specific period. It is an indication of past volatility in the marketplace.

Implied Volatility A measurement based on the premiums of market traded options of the expected price range of the underlying commodity.

Integrated Hedge A hedge which combines more than one distinct price risk. For example, crude oil is usually priced in US dollars. A producer of crude oil whose home currency is the Deutschmark would be exposed to both US dollar currency risk and crude oil price risk. A possible integrated hedge would be a quanto product, which would hedge the price of crude oil in Deutschmarks.

In-the Money An option that can be exercised and immediately closed out against the underlying market for a cash credit. The option is in-the-money if the underlying futures price is above a call option's strike price, or below a put option's strike price.

Mark-to-Market To calculate the value of a financial instrument (or portfolio of such instruments) at current market rates or prices of the underlying. Marking-to market on a daily (or more frequent) basis is often recommended in risk management guidelines.

Notional Value The underlying principle value of either an exchange-traded or over the-counter transaction.

Out-of-the-Money An option that has no intrinsic value. For calls, an option that has an exercise price above the market price of the underlying future. For puts, an option that has an exercise price below the futures price. The opposite is in-the money.

Over-the-Counter (OTC) A deal that is a customised derivative contract usually arranged with an intermediary such as a major bank or the trading wing of an energy major, as opposed to a standardised derivative contract traded on an exchange.

Paper Market A market for contracts where delivery is settled in cash, rather than by delivery of the physical product on which the contract is based.

Put-Call Parity The payout profile of a portfolio containing an asset plus a put option is identical to that of a portfolio containing a call option of the same strike

on that same asset (with the remainder of the money earning the risk-free rate of return). This can be used to arbitrage a position.
Put option An option that gives the buyer, or holder, the right, but not the obligation, to sell a futures contract at a specific price within a specific period of time in exchange for a one-time premium payment. It obligates the seller, or writer, of the option to buy the underlying futures contract at the designated price, should the option be exercised at that price.
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Quanto Product An asset or liability denominated in a currency other than that in which it is usually traded. Since the combined exposure to the asset and to the foreign exchange rate will change continuously, the structures must be dynamically hedged.
Reference Price In an energy derivatives contract, the settlement price of the contract based on a particular location or particular blend of the commodity.
Repo Agreement To buy (or sell) a security while at the same time agreeing to sell (or buy) the same security at a predetermined future date. The price of the second transaction determines the repo rate, the interest rate earned on the security between the two transactions. In a reverse repo the buyer sells cash in exchange for a security.
Risk Management Control and limitation of the risks faced by an organization due to its exposure to changes in financial market variables, such as foreign exchange and interest rates, equity and commodity prices or counterparty creditworthiness. This may be because of the financial impact of an adverse move in the market variable (market risk), because the organisation is ill-prepared to respond to such a move (operational risk), because a counterparty defaults (credit risk) or because a specific contract is not enforceable (legal risk). Market risks are usually managed by hedging with financial instruments, although a firm may also reduce risk by adjusting its business practices (see natural hedge). While financial derivatives lend themselves to this purpose, risk can also be reduced through judicious use of the underlying assets, e.g., by diversifying portfolios.
Risk Measurement Assessment of a firm's exposure to risk.
Roll-Over Risk The risk that a derivative hedge position will be at a loss at expiry, necessitating a cash payment when the expiring hedge is replaced with a new one.
Settlement The combined process of billing and payment for products and/or services. Accounts are not said to be settled until both customer and supplier have everything to which their agreement entitles them, and that includes all payment to the supplier and all receipts and other materials needed by the buyer.
Speculation The opposite of hedging. Holding no offsetting cash market position and deliberately incurs price risk in order to reap potential rewards.
Swap A collection (portfolio) of forward contracts that is usually tailored to balance a particular situation. A swap can be used to ensure that a set of contracts is reasonably well insured against sudden changes of value in one or more of the component contracts, or to guard against market conditions that could adversely affect the value of one type of contract in a portfolio.
Underlying The variable on which a futures, option, or other derivative contract is based.
Value-at-Risk (VaR) 1. The worst loss expected to be suffered over a given period of time with a given probability. The time period is known as the holding period and the probability is known as the confidence interval. 2. Value-at-risk is not an estimate of the worst possible loss, but the largest likely loss. For example, a firm

might estimate its VAR over ten days to be $100 million with a confidence interval of 95%. This would mean there is a one-in-twenty (5%) chance of a loss larger than $100 million in the next 10 days. In order to calculate VAR, a firm must model both the way the relevant market factors will change over the holding period and the way (if any) in which these changes are correlated between market factors. It must then evaluate the potential effects of these changes on its portfolio at the desired level of consolidation (by asset class, group or business line, for example).

Volatility 1. A measure of the variability of a market factor, most often the price of the underlying instrument. 2. The annualized standard deviation of the natural log of the ratio of two successive prices, the actual volatility realized over a period of time (the historic or historical volatility) can be calculated from recorded data. 3. One of the variables that must be specified in the Black-Scholes model of option pricing: a vanilla or non-exotic option will cost more when volatility is high than when it is low. However, volatility is the only one of these variables whose value must be estimated. The estimate used (known as the implied volatility) can be derived from the prices of options in the market and the known input variables. However, the Black-Scholes model also assumes that volatility is constant, which is not true. New techniques have been developed to cope with volatility's variability, including mean-reverting models and stochastic volatility models.

Section II

OPTIMIZATION TECHNIQUES FOR GASOLINE BLENDING & SUPPLY CHAIN MANAGEMENT OF OIL-REFINERY OPERATIONS

Ventured by

RIK CHOUDHURY

Abstract

This thesis presents a Linear Programming formulation that addresses the simultaneous optimization of the supply chain distribution and blending problem in oil-refinery applications. Depending on the problem characteristics as well as the required flexibility in the solution, the model can be based on continuous-time domain representation.

The proposed optimization approach is oriented towards providing an effective and integrated solution for both the supply chain distribution and the blending problem. In order to provide convenient solutions for all circumstances, different alternatives to cope with infeasible problems are presented in detail. The method is presented by solving real world refinery problems with very low computational requirements.

Key words: oil products; blending; linear programming; optimization

INTRODUCTION

Modern optimisation techniques have challenged organisations such as petroleum refining industry to rethink the way they conduct business both internally and externally. Supply Chain Management (SCM) is one such business function that has benefited substantially from optimisation software advances and solutions. The primary goal of SCM is to maximise profit by integrated management of material and transactional flows within a business and to customer and partner companies. The supply chain of a typical petroleum refining company involves a wide spectrum of activities, starting from crude purchase and crude transportation to refineries, refining operations, product transportation and finally delivering the product to the end user. The nature of the value chain is such that its economics are extremely complex and heavily linked. For example, the process of selecting the right crude oil is linked not only to the transportation costs involved in delivering it to the refinery, but it must take into consideration the need to balance the dynamic behaviour of the whole refinery network in different scenarios, the capabilities and constraints in converting the crude into products, stochastic nature of prices, increasingly restrictive environmental legislation as well as the product volume.

This whole process is usually described by massive amount of operational data and decision-making processes. These situations call for detailed planning over a specific period - typically one year. Often the production plans are further broken down into feasible operations throughout time with detailed schedule of each activity and event in the refining operations. The scheduling horizons span from a few days to weeks, depending on information availability and uncertainty, and decisions are taken on hourly basis.

The use of mathematical programming (MP) in the detailed planning in the petroleum refining industry spans well over half a century. However, usage prior to the invention of the electronic digital computer was limited to small problems that could be solved by hand. Dantzig's invention and development of the simplex algorithm in 1947 really created the area of linear programming (LP) and blending of gasoline turned out to be the most popular application in the petroleum industry. Later, usage of LP was extended to a grassroot design and configuration selection, capital investment analysis, long-range operations planning, supply and distribution planning. The limitations to progress are the matrix size capacity of the computer or the time required to get a solution or both and the accuracy of LP results which depend on the validity of input data. Refinery planners have therefore solved complex refinery-planning problems by decomposing into subproblems and, to date, this is reflected in the way some refineries operate its planning, central engineering, upstream operations, refining, supply and transportation. In most cases, the refinery-planning problem is decomposed into three subproblems - crude supply, refining and blending, and production. Among the mathematical methods commonly used by operations research analysts in modelling system and organizations are the following: mathematical programming (linear, nonlinear, integer, dynamic, goal programming etc), network modelling, inventory modelling, queuing theory, game theory, simulation, forecasting and others.

The blending problem are typical for the oil refining industry where various types of fractions and components are blended to produce different types of gasoline and other oil products.

The gasoline blending is critical aspect in oil refinery operations. The economic and operability benefits associated with obtaining better-quality and less expensive gasoline blends, and at the same time making a more effective use of the available resources, are numerous and significant. The main objective in oil refining is to convert a wide variety of crude oils into valuable final products such as gasoline, jet fuel and diesel. The major challenge lies on generating profits for a large process with high volumes and small margins. The general structure of this process comprises three major sections: (1) crude oil unloading and blending, (2) production unit scheduling and (3) product blending and delivery of final products. The subproblem related to the scheduling, blending, storage and delivery of final products, which is generally agreed as being the most important and complex sub-problem. Its importance comes from the fact that gasoline can yield 60-70% of total refinery's profit. On the other hand, the complexity mainly arises from the large number of product demands and quality specifications for each final product, as well as the limited number of available resources that can be used to reach the production goals.

This paper is focused on the gasoline blending and profit maximisation of oil refinery operations. The objective function was the minimization of the total operating cost, which comprises waiting time cost of each vessel in the sea, unloading cost for crude vessels, inventory cost and changeover cost.

The gasoline blending problem has also been addressed with several optimization tools. The main objective is to find the best way of mixing different intermediates products from the refinery and some additives in order to minimize blending cost subject to meeting the quality and demand requirements of different final products. The term quality refers to meeting given product specifications.

Some of the common assumptions are: (a) fixed recipes for different product grades are predefined, (b) component and product flowrates are known and constant and (c) all product properties are assumed to be linear. The major issue here is related to non-linear and non-convex constraints with which the computational performance strongly depends on the initial values and bounds assigned to the variables.

The oil products are manufactured by blending two or more different fractions whose quantities and physicochemical properties depend on the crude oil type, the way and conditions of processing. The quality of the oil products (fuels) for sale has to comply with the current standards for liquid fuels, and the produced quantities have to comply with the market needs. It is in producer's interest to do the blending in an optimal way, namely, to satisfy the requirements for the oil products quality and quantity with a maximal usage of the available fractions and, of course, with a maximal profit out of the sold products. The optimization of refinery products blending is accomplished by applying linear programming.

DEFINING THE PROBLEM

Linear Programming is an optimization problem *of* maximizing or minimizing the objective function which variables called decision variables must satisfy a set *of* linear constraints. The first step is to define the problem that has to be solved, which includes specifying the objectives that have to be achieved and the aspects that must be studied before the problem can be solved. The Crude Oil Refinery processes *dif*ferent types *of* crude oil to manufacture different oil products for the market. These refinery products are manufactured by blending various tractions produced by primary or secondary crude oil processing, which number, quantity and physical-chemical properties depend on the crude oil type, the way and conditions *of* processing.

The problem to solve is how to do the blending *of* the desired products in order to maximize the sales revenues, while still maintaining an adequate. level *of* products quality and market supply. The solution *of* the problem involves identifying a number *of* aspects that affect the achievement *of* the objectives:

1. Types *of* products needed by the market.
2. Products ex-refinery sales prices.
3. Minimal quality *of* the products that has to be achieved.
4. Market demand.
5. Available fractions to be blended into oil products.
6. Physical-chemical properties *of* all the fractions to be used as blending components.
7. Mathematical methods for estimating physical- chemical properties *of* the blended products.

DATA COLLECTING AND PROCESSING

After identifying the aspects that affect the problem, the next step is to collect the needed data and to estimate the values *of* all parameters necessary to develop and evaluate a mathematical model *of* the problem. The analysis *of* the main aspects, which could be evaluated, gives the following:

1. There are 8 products needed by the market that could be produced by the refinery: liquefied petroleum gas (LPG), three types *of* motor gasoline - leaded regular, leaded premium and unleaded premium, two types *of* diesel fuel (D1 and D2), extra light heating oil (EL) and fuel oil (FO).

2. The maximal retail as well as ex-refinery sales prices *of* oil products are under the authority *of* the government, and they are the same all over the country. Some *of* the products are being sold by weight (LPG, FO) and some by volume (gasoline, diesel fuel, EL).

3. The minimal quality *of* oil products is defined with the standards for liquid fuels that are currently in force in the country.

4. The refinery product slate has to comply with the market demand, defined by the Energy balance *of* the country and the quantities *of* oil products supplied on the domestic market in the past.

5. As a result *of* the hydroskimming structure *of* the refinery and the current way *of* operation, there are 8 fractions available for blending: propane- rich fraction (F-C3), butane-rich fraction (F- IC4), light naphtha (LN), reformate (R), kerosene (K), light gas oil (LGO), heavy gas oil (HGO) and residual oil (RO). Their quantities could be derived from the material balance *of* the processing units. The reformate is the most important fraction for gasoline blending. Unleaded gasoline requires higher reformate octane quality and consequently, different reforming unit operation conditions in comparison to leaded gasoline. So, two different ways *of* operation *of* the reforming unit have to be defined and the material balance *of* all the processing units have to be related to the reformate quantity.

FORMULATING THE LINEAR PROGRAMMING MODEL

The linear model should describe completely the decision we have to make what quantity of what fraction should be blended in what product in order to maximize the sales revenues from the oil products, given the available crude oil and the restrictions from the current standards *for* liquid *fu*els, market demand and material balance of the processing units. The decision variables could be defined as follows:

Gcij - quantity of fraction i to be blended into product j *for* operating conditions c, *for* i = 1,2, ..., *8;j* = 1,2, ... , 8; c = 1,2, where c = 1 means operating conditions of the reforming unit *for* production of leaded gasoline, and c = 2 *for* unleaded gasoline. Taking in account the nature of the products that have to be blended and the accepted technology of production, the blending scheme could be presented in a matrix form as in Table 7. The presented scheme defines 39 decision variables. Now the objective function (sales revenues)

can be defined as follows:

OBJFN = '[Ccij,gGcij where: *ccij,g* – product sales price per weight.

The values of the decision variables have to satisfy three sets of linear constraints, which have to describe the limited resources or possibilities. The first set of constraints is defined by the requirements of the current standard for the minimal quality of the blended products and by the physical-chemical properties of the available fractions. Different products have to satisfy different constraints.

MATHEMATICAL MODELS

Assumptions

For simplicity of the problem, some assumptions are taking into consideration: (1) For simplicity, energy balance of processing units will not be considered. (2) Only continuous variables that are linear will be included; decisions that involve discrete variables like deciding which processing unit serves which processing unit will not be considered. (3) The LP problem is deterministic within the planning horizon. (4) Only specific key component in crude or blended oil fix the property of crude and blended oil.

CONTINUOUS TIME REPRESENTATION

The model in the previous section is based on a discrete time domain representation. To generate more flexible schedules capable of maximizing the plant performance without significantly increasing the model size, a continuous time representation will be utilized for the model. However, special attention must be paid to the limited storage capacity

since continuous time representation tends to make the inventory constraints much more difficult. The main idea here is first to partition the entire time horizon into a predefined number of sub-intervals. The size of each sub-interval will depend on the product due dates. For instance, the first sub-interval will start at the beginning of the scheduling horizon and finish at the first product due date. The second one will be extended from the first up to the second product due date. A similar idea is applied to the next sub-intervals. Then, the number of sub-intervals will be equal to the number of product due dates. In this way, the starting and ending time of each sub-interval is known in advance.
Once the sub-intervals are defined, a set of time slots with unknown duration are postulated for each one. The number of time slots for each sub-interval will depend on the sub-interval length as well as the grade of flexibility desired for the solution. Time slot starting and ending times will be new model variables, allowing the production events to happen at any time during the scheduling horizon. Figure 5 shows a diagram illustrating the main features of the proposed continuous time domain representation. In this case, four product demands with different due dates are to be satisfied, which means that 4 subintervals are predefined. Then, nine time slots can be postulated for the entire scheduling horizon, where two timeslots are defined for each one of the first three sub-intervals whereas three are allocated to the last one.

THE PROFIT MAXIMISATION & SUPPLY CHAIN DISTRIBUTION PROBLEM

The refinery problem is solved by linear programming using AMPL. "AMPL is a comprehensive and powerful algebraic modelling language for linear and nonlinear optimization problems, in discrete or continuous variables. Developed at Bell Laboratories, AMPL lets you use common notation and familiar concepts to formulate optimization models and examine solutions, while the computer manages communication with an appropriate solver."

Mathematical programming is a technique for solving certain kinds of problems — notably maximizing profits and minimizing costs subject to constraints on resources, capacities, supplies, demands, and the like. AMPL is a language for specifying such optimization problems. It provides an algebraic notation that is very close to the way that you would describe a problem mathematically, so that it is easy to convert from a familiar mathematical description to AMPL. We will concentrate on linear programming in this part of the thesis. This thesis addresses one of the most common applications of linear programming: maximizing the profit of some operation, subject to constraints that limit what can be produced. The separation of model and data is the key to describing more complex linear programs in a concise and understandable fashion. The model describes an infinite number of related optimization problems. If we provide specific values for data, however, the model becomes a specific problem, or instance of the model, that can be solved. Each different collection of data values defines a different instance.

Given: *P*, a set of products

a_j= tons per hour of product j, for each j $\in$P

b = hours available at the mill

c_j= profit per ton of product j, for each j $\in$P

U_j= maximum tons of product j, for each j $\in$P

Define variables: X_j= tons of product j to be made, for each j $\in$P

$$\text{Maximize: } \sum_{j \in P} c_j x_j$$

$$\text{Subject to } \sum_{j \in P} (1/a_j) X_j \le b$$

$$0 \le X_j \le u_j \text{ for } j \in P$$

Basic production model in algebraic form.

PROBLEM DESCRIPTION

The configuration of the integrated refinery planning problem is illustrated in Fig. 1. The problem statement is summarised as follows

Given:

- a set of crude oils,
- a set of storage tanks,
- a set of blending tanks,
- a set of final products,

and

• necessary data needed.

Determine:

• number of final products that should be made,

• revenue from final product,

• cost of all purchased materials and

In order to:

• maximise the total profit made during the planning horizon.

Subject to:

• crude supply constraints,

• refining process constraints, and

• product distribution constraints.

In the prevalent problem presented in the thesis is a series of crude oil is procured by an oil refining company having different cost and profit margins. The refinery processes & manufactures to produce four distinct products. The market position of the products as per their demand is given in the problem. The proportion of each type of crude that goes in the manufacturing of the products is also mentioned. The refinery processing capacities for the different crudes are presented. The task at hand is to find a way to maximise the profit margin of the refinery meeting the market demand. The maximal profit possible under the given restrictions prevalent in an oil refinery.

Table 1. Crude inputs, Product demand & Product manufactured in the refinery.

Solving a Refinery Problem						
	Type of Crude or Process					Product Demand
	A	B	C1	C2	D	
Profits on Crudes	10	20	15	25	7	
	Products Product Slate for Crude or Process					
Gasoline	0.6	0.5	0.4	0.4	0.3	170
Heating Oil	0.2	0.2	0.3	0.1	0.3	85
Fuel Oil	0.1	0.2	0.2	0.2	0.3	85
Lube	0	0	0	0.2	0	20
Total Crude	100	100	C1+C2 = 200		100	

Crude Symbols	Crude Types	Cost/bbl	Profit/bbl	Specific Gravity(60F)
A	Arabian Light	33.8	10	0.764
B	Iranian Heavy	61.51	20	0.687
C1	Kuwait	51.35	15	0.7
C2	Dubai	67.01	25	0.712
D	Bonney Light	44.5	7	0.864

Table 2. Crude types, costs, physical properties & profits.

The objective function to maximize for this problem comes from multiplying each product by its

profits and summing up or

$$\pi = 10*A + 20*B + 15*C1 + 25*C2 + 7*D.$$

Product Demand Constraints:

The total gasoline from crude A is 0.6*A, from B it is 0.5*B, it is 0.4*(C1+C2), etc. To make sure we satisfy the B it is 0.5*B gasoline market then our gasoline constraint must be

$$170 < 0.6*A + 0.5*B + 0.4*C1 + 0.4*C2 + 0.3*D.$$

Similarly, our constraints for heating oil, fuel oil and lubes are

$$85 < 0.2*A + 0.2*B + 0.3*C1 + 0.1*C2 + 0.3*D,$$

$$85 < 0.1*A + 0.2*B + 0.2*C1 + 0.2*C2 + 0.3*D, \text{ and}$$

$$20 < 0.2*C2.$$

In addition, we cannot use more crude oil than we have at our disposal, so the crude oil constraints are

A < 100,

B < 100,

C1 + C2 < 200,

D < 100.

RESULT

AmplStudio Modeling System - Copyright (c) 2003-2010, Datumatic Ltd

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MODEL.STATISTICS

Problem name : Refinery

Pathname : C:\Program Files (x86)\OptiRiskSystems\AMPLStudio\Bin\Refinery profit optimisation

Model Filename :"Refinery.mod"

Data Filename :"Refinery.dat"

Date : 5:29:2011

Time : 18:56

Constraints :4

Nonzero Constraints :3

Variables :5

SOLUTION. RESULT

'Optimal solution found'

FortMP 3.2j: LP OPTIMAL SOLUTION, Objective = 10200

DECISION.VARIABLES

	Variable	Activity	U bound	Reduced Cost
1	Crude A	100	100	10
2	Crude B	90	90	20
3	CrudeC1	90	90	30
4	CrudeC2	100	100	40
5	CrudeD	100	100	7

Numerical Results

The profit maximisation problem outlined in this section was implemented in the modelling system AMPL and solved using FortMP 9.1 solver on a SUN Fire V20Z with two AMD 2.46 GHz/8 GB RAM processors. The data input into all the case studies are displayed in Tables 1 & Table 2. Table 3 shows the results.

Solution Analysis

Number of constraints Number of Number of Max. CPU	*Number of variables*	*Number of constraints*	*Max. profit ($)*
4	5	3	10200

Modelling the integrated refinery-planning problem in AMPL modelling environment. AMPL does not necessarily increase the size of the problem. We assume that the configuration of the integrated refinery network already exists. Therefore, the decision variables that are discrete or binary in nature are avoided.

REFERENCES

Betchel Corp. PIMS (Process Industry Modeling System). User's manual, version 6.0. Houston. TX. 1993.

Booner and Moore Management Science. RPMS. (Refinery and Petrochemical Modeling System). A system

description, Houston, TX, 1979.

Glismann K., Gruhn G. "Short-term scheduling and recipe optimization of blending processes" *Comp. Chem. Eng.,*

25, 627, 2001.

Grossmann I.E., Van den Heever S.A. and Harjunkoski I. "Discrete optimization methods and their role in the

integration of planning and scheduling," *AIChE Symposium Series No. 326*, 98, 150, 2002

Ierapetritou M.G., Floudas C.A. "Effective continuous-time formulation for short-term scheduling. 1. Multipurpose

batch processes. *Ind. Eng. Chem. Res.*, 37, 4341-4359, 1998.

Kelly J.D., Mann J.L. "Crude-oil blend scheduling optimization: An application with multi-million dollar benefits.

Honeywell Hi-Spec Solutions. Personal Communication. August 2002.

Kelly J.F. "Formulating production planning models" *Information Technology.* 43, January 2004

Lee H., Pinto J.M, Grossmann I.E., Park S. "Mixed-integer linear programming model for refinery short-term

scheduling of crude oil unloading with inventory management. *Ind. Eng. Chem. Res.* 35, 1630-1641, 1996.

Moro L.F.L, Zanin A.C., Pinto J.M. "A planning model for refinery diesel production" *Comp. Chem. Eng.*, 22,

S1039-S1042, 1998.

Pinto J.M. and Grossmann I.E., "Assignment and sequencing models for the scheduling of chemical processes" *Ann.*

of Oper. Res., 81, 433-466, 1998.

Quesada I., Grossmann I.E., "Global optimization of bilinear process networks with multicomponent flows" *Comp.*

Chem. Eng., 19, 1219-1242, 1995.

Reklaitis G.V. “Overview of scheduling and planning of batch process operations” Technical report, *NATO*

Advanced Study Institute, Antalaya, Turkey, 1992.

Rigby B., Lasdon L.S., and Waren A.D. “The evolution of Texaco blending systems – from Omega to StarBlend.

Interfaces, 25, 64, 1995.

Shah, N. Single- and multisite planning and scheduling: Current status and future challenges. *AIChE Symposium*

Series No 320, 94, 75, 1998

Jia Z., Iearapetritou M. “Mixed-integer linear programming for gasoline blending and distribution scheduling”. *Ind.*

Eng. Chem. Res., 42, 825-835, 2003.

CONTINUOUS TIME REPRESENTATION

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