A Review of Factors Determining Crude Oil Prices

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Abstract
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This purpose of this thesis is to form a general understanding on price formation of crude oil in the short and the long run. It is motivated by the recent record increase and subsequent crash in crude oil prices. The impacts of the price changes were broad and altered industrial activity, consumer behavior and political power globally. Understanding the factors behind these changes is important for commercial investments and public policy making.

Academics, analysts and politicians seem to disagree on what is the main driver for the oil price development. Usual explanations are resource scarcity, cartel behavior, commodity speculation and market conditions. This paper examines these central arguments based on their theoretical background and observations on the oil market. It aims at explaining recent events and describing main drivers for future price development.

Economic theory on exhaustible resources provides a framework for long run price development based on increasing scarcity. While it does not explain recent crude oil price changes, it shows that prices of exhaustible resources are bound to rise even with perfect competition. Extensions to the theory provide possibilities for analyzing increasing costs and market power. More accurate models are however also much more complicated and thus not easily applicable to price analysis.

Recent high prices were often blamed on speculation, but physical and financial arbitrage constraints limit speculators' possibility to drive prices. If the oil price was being driven higher than the market equilibrium, there should have been clear increase in oil inventories as supply was kept away from the market. When prices reached record highs, inventories were on unusually low levels, implying the contrary. Further studies on market participants' behavior also do not support market manipulation. Recent price changes were most likely due to an initially booming and finally crashing demand, which was almost inelastic to prices because of the lack of substitutes. Demand reactions were further dampened by government subsidies and on the other hand taxes, which made the price changes seem smaller to consumers. Oil producers reacted by trying to pump as much oil as possible leading to higher costs. Supply limiting cartel behavior, which was common in the 20th century, was not observed in the past few years. While the market has now loosened, it is bound to tighten again as demand growth recovers and oil field investments have stalled due to low prices. If realistic substitutes do not emerge, there will be further market crunches ahead.

KEYWORDS:
Crude oil, oil price

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1 Introduction

1.1 Background and motivation

Easy availability of energy has been a key driver of growth and industrialization in the 20th century. Bulk of this energy has been generated from non-renewable fossil fuels. The current global economy is relying on these fuels as much as ever, most notably oil. Fast logistics is the key for success of modern manufacturing industry. People live far away from their work and thus rely on automobiles for commuting. Production of countless household and industrial goods is using oil-based plastics as raw materials. We are dependent on oil.

Oil prices have been very volatile in recent years. Volatility in oil prices does harm in many ways. Both developing and developed countries are affected. Spiking high prices affect poor people more directly because fuel costs are significant in food and transportation prices, which are necessary spending. High oil costs also hit economies on a macro-level and have been triggering factors in economic cycles. Temporary low prices on the other hand delay necessary energy investments in current and alternative sources, which are needed for securing supply in the future. Changing prices also make it harder for consumers to learn new consumption patterns and look for substitutes. Adding to supply and cost issues are environmental concerns, in which oil also has a central role.

Changes in oil prices shift political balances around the world. Oil exporters gain power with high prices, but face severe difficulties when prices drop. Control over oil sources has historically driven many countries into war. In August 1941 the United States placed an oil embargo over Japan, which blocked 80% of its oil supply. Five months later Japan joined the Second World War with the oil embargo being one of the central motivators. Both Persian Gulf Wars were also at least partly motivated by securing oil supply. In addition to these, natural resources are at stake in many conflicts around the world.

Despite the large global impacts of oil prices, there seems to be little consensus about the most important price drivers and the source of recent volatility. Opinions differ from limited supply capacity to abuse of producers' market power and systematic securities' speculation. There are also many views on when oil is running out and many interpretations of the practical consequences of the continuing exhaustion. In comparison to many other markets, there is relatively little information available about fundamental factors. Production costs for example are highly guarded secrets and cannot be easily figured out for an outsider. The lack and asymmetry of information makes the industry even more mysterious and understanding it critically important.

1.2 Objectives and contribution

My objective in this paper is simply to understand what factors determine oil prices. I approach the question from many angles, both theoretical and practical. Along the way I also try to present simplified answers to the following questions: How does the oil market work and who are the participants? What has happened in the history of oil? What is the optimal way to extract oil? Does OPEC use significant market power? Does the securities market drive oil prices? Why did the prices rise to record highs in the past years and why did they drop? What is the difference between market fundamentals on the short and on the long run?

My contribution is to combine the different and partly unrelated theoretical realities of different parts of the oil supply chain into one understandable paper. The resulting paper is an analytical review into literature and evidence on the oil market. It presents the market and its underlying fundamentals to a reader who has no experience on the market or in advanced economics. It also reflects my path from gathering high-school level background data and learning about the basics of the market, to taking the role of a junior economist and looking into the theoretical limits and equilibriums concerned, and eventually weighing different factors in a way a commercial market analyst might.

1.3 Related research

Underlying economic theory on exhaustible resources is solid and expanding. The principle idea of Hotelling (1931) has been expanded by many, such as Solow and Wan (1976) on extraction costs, Pindyck (1978) on exploration, and Slade (1982) on technological progress. Issues concerning market power have been studied for example by Stiglitz (1976), Salant (1976), and Gilbert (1978). The resulting literature has been reviewed notably by Krautkraemer (1998) and more recently Gaudet (2007).

General theory on market price bubbles has been meritoriously reviewed by Brunnermeier (2008) and basics of commodity arbitrage can be found in finance literature such as Hull (2003). More specific analysis on the oil exchange can be found for example in Borenstein (2008).

After the high prices of past years many working papers emerged to explain them and the market in general. These are for example Hamilton (2008) and Mitchell (2006). At the time of writing many papers did not yet take the consequent price drop into account in their analyses.

Besides academic literature, there are also many organizations such as the International Energy Agency of the OECD-countries and the Energy Information Administration of the United States Department of Energy, which release many periodical reports and analysis on the market. Some reports have also been created for more specific needs such as the Hirsch report (2005) on global depletion and the Commodity Futures Trading Commission Task Force report (2008) on commodity speculation. Many books have been written on certain specific market factors, such as Simmons (2005) on Saudi Arabian oil reserves.

1.4 Limitations and challenges

This paper is a broad review of issues surrounding oil prices and thus does not go in-depth to many of the factors. Understanding the ”big picture” is emphasized over details. My analysis focuses on crude oil prices, thus prices of refined oil products are not analyzed directly, but only through the demand they reflect on crude oil. The undoubtedly interesting and important dynamics between crude oil, natural gas and coal prices is left out of the analysis as well. While analyzing the prices I focus mostly on microeconomic concepts. Macro-side consequences, such as supply shocks are not considered. Even though extremely topical, externalities such as pollution or other emissions and their price effects through taxation or allowances are also left out to keep the paper in reasonable focus.

Finding reliable data on the oil market proved to be surprisingly difficult. Unlike the equity markets, publicity of information is not efficiently enforced and many interesting numbers and backgrounds remained hidden. Most notably information about production costs, detailed production numbers, and OPEC quota compliance were not reliably available thus limiting numerical analysis. Also available information differed sometimes significantly from source to source.

One of the largest challenges was the changing market conditions during my analysis. I started studying the subject when crude oil prices hit all-time highs and am now finishing my analysis after the prices have dropped to 20% of that level and the economy is in a recession. While this change was interesting to witness, it made writing this paper somewhat more challenging. Unfortunately many academic analyses on what happened did not make it to this paper or even out to the public yet.

1.5 Definitions of key concepts

This paper is about the world oil market, but as mentioned I concentrate especially on the crude oil market. For sake of simplicity I will make no distinction between actual crude oil and the so called non-crude liquids, which are together often called “crude oil” in the press and popular sources, even though the technically more correct term would be “liquids”. In many sections I will use just "oil" or "petroleum" when referring to crude oil (or actually liquids). Petroleum should not be confused with gasoline or petrol, which are names for the refined oil-based fuel running automobiles, or other oil products.

I use oil price in both singular and plural, depending on whether I am describing the concept of a price or the actual different crude oil prices around the world. In practice this distinction makes very little difference, as most of the concepts introduced in this paper apply to all crude oil prices with the same mechanisms and regional differences are evened out through freight routes and differing qualities.

When describing resource theory, I use the terms "exhaustible", "non-renewable", and "depletable" interchangeably, even though some might argue that there are technical differences between them.

When talking about oil supply I mean crude oil production, i.e. the process of extracting petroleum out of the ground and processing it to a transportable form. The production of oil products, on the other hand, is referred to as refining (also "manufacturing" is used in some industry sources). Crude oil demand can be understood by either demand coming from oil refiners, which are the actual buyers, or end users that consume the refined oil products. I will separate the two interconnected demands in parts where it is relevant, but generally consider the overall price effect broadly equal.

1.6 Structure

Coming up with an appropriate structure for this paper turned out to be challenging. As there is no clear empirical part, a traditional division between theory and empirics would have split relevant chapters too far from each other. One possible division would have been according to the chronology of oil prices, as different factors have driven the prices in different time periods. Another possibility could have been dividing the whole paper into short-term analysis and long-term analysis, as fundamental factors differ significantly in different time frames. This would have led to having many duplicate parts though.

The chosen representation is a compromise between many things. In chapter 2 I first describe the oil market and its participants in an objective way to build the basis for further analysis. The chapter can be skipped if the reader is already familiar with the market or wishes to concentrate only on the analysis. Next I go through different concepts affecting the price in chapter 3 in the order of the oil supply chain: starting from the ground to the producers and going through the exchange to end at the consumer. I present theory and analysis together for each subchapter. In the end in chapter 4 I conclude my analysis and sum up issues to be taken into account in the future.

2 Description of the World Oil Market

The broad definition of the world oil market consists of a long and wide chain of numerous different economic actors acting on multiple markets. Crude oil resides mostly underground in deposits that are hard to reach and whose ownership is highly sought after. The deposit is extracted by a national oil company or a private company that has acquired necessary rights from the government. Before it can be transported, oil has to be separated from water, natural gas, and other extracted side products.

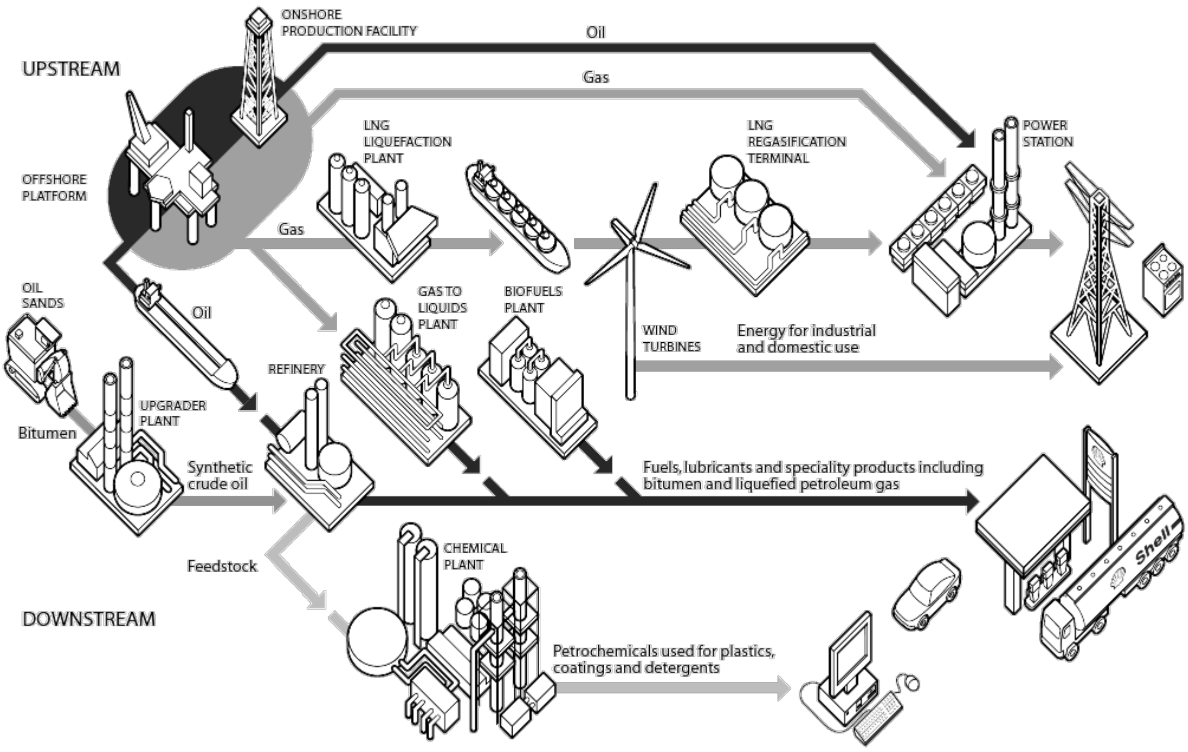

Figure 2.1: Oil (and gas) supply chain (Shell 2007)

Crude oil is then sold to refiners on spot markets around the world. It arrives at the refineries usually by a tanker ship or through an oil pipeline. The refiners use a vast array of chemical methods to refine crude oil to various different oil products. These products are then sold on further markets to industrial users and retailers. Finally the end products reach consumption in the form of transportation fuel, heating, electricity, plastics or numerous other oil-based products.

In the following subchapters I will describe the oil market in more detail. I will go through supply and demand drivers and trends as well as introduce central market participants.

2.1 The commodity

Crude oil is arguably the most important natural resource in the world. As mentioned before in the introduction, it is present all over the world in many sectors as a provider of transportation, heat, electricity or raw materials.

2.1.1 Origin

According to the generally accepted theory of fossil fuels, crude oil (as well as other hydrocarbons natural gas and coal) has formed over hundreds of millions of years from ancient organic materials in sediment layers of the Earth's crust under high temperatures and pressure. More specifically crude oil and natural gas have formed from prehistoric plankton and algae on ancient seafloor, whereas coal has formed from remains of prehistoric plants on land. (Encyclopædia Britannica 2008)

The formation process leads to one of the most central points of economic analysis about oil – its exhaustibility. Currently the human race is consuming oil millions of times faster than it is naturally created, making crude oil practically non-renewable.

There exists also another theory for oil formation. The abiogenic petroleum hypothesis states that crude oil is formed in deep carbon deposits, possibly as old as the Earth itself. This theory suggests that biological life forms are not the source of oil, and that there could be much more oil in the ground than current estimates suggest. One of the most interesting suggested proofs for the theory is the recently observed existence of the natural gas methane in Titan, a moon of the planet Saturn, where it could not have been formed through biological processes. (Glasby 2006)

Even though this theory has currently very little proponents (Glasby 2006), it is worth mentioning as it would change the fundamentals of future oil supply if it were true. In this paper I will still consider the abiogenic oil hypothesis false, and view crude oil as a fossil fuel whose exhaustion is a cause of concern.

2.1.2 Oil grades

Crude oil reservoirs around the world differ significantly in availability and quality. The main attribute for crude oil is its viscosity (thickness). Viscosity is measured by "API gravity", which is an industry standard developed by the American Petroleum Institute. Oil reserves are classified by API gravity into light, medium, heavy and extra heavy oils. Beyond extra heavy oils there are oil sands (also tar sands), which contain very thick oil-based bitumen and oil shales, which contain solid oil-based kerogen. Both of these non-liquid sources can be heated and processed (with high costs and reduced energy efficiency) into liquid oil. Extra heavy oils, oil sands and oil shales are often also called non-conventional oils, because their extraction requires methods that differ from the more traditional drilling of the lighter grades. (SPE 2007)

Another important quality factor is the sulfur content of the oil. So called "sweet" crude oil has a low sulfur content, which means that it is more environmentally friendly and thus requires less processing to meet environmental standards. This makes it also more valuable than "sour" crude oil with a higher percentage of sulfur. The third important attribute is the physical location of the oil source. Depth and qualities of local rock formations play an important role in the extraction costs of oil reserves. (Simmons 2005)

Understanding that crude oil is not homogenous and that the physical and geological properties differ between different oil sources is necessary for the economical analysis. The availability of easy to reach light and medium oil sources make current oil prices possible, while when considering non-conventional oils extraction costs rise to levels that are currently uneconomic. In addition to extraction, lighter fuels are also cheaper and more versatile to be refined further to oil products.

Table 2.1: Oil Grades (data: Alboudwarej et al 2006)

Oil Grade	API Gravity	Percentage of global proven reserves (9-13 trillion bbl)
Light	> 31,1°	30%
Medium	31,1° - 22,3°	
Heavy	22,3° - 10,0°	15%
Extra Heavy	< 10,0°	25%
Oil sands and oil shales		30%

2.1.3 Non-crude liquids, biofuels and synthetic substitutes

Refined oil products can also be produced from sources other than crude oil. The before mentioned non-crude liquids are hydrocarbons that come as side products in different phases in crude oil or natural gas production and are liquid in normal atmospheric pressure. Many of these liquids are of high quality and can be used as raw material in refineries in the same way as light or medium crude oil. The use of these side products is increasing as production technology advances and efficient recovery is focused on.

Maybe the currently most prominent alternative source to drilled crude oil comes from the nature in the form of biofuels. Often classified to either bioethanol or biodiesel, these fuels are made from a range of different plants and can power many types of modern combustion engines with little or no modifications. Biofuels have quickly gained popularity and also some notable production after the oil price hikes in recent years. They are also considered more environmentally friendly as their life cycle releases less green house gases to the atmosphere. The most recent opposition has risen from the fact that biofuel production partially competes with food production, which has been claimed to be one of the factors behind recent growth in food prices. Nevertheless research in biofuels continues and studies suggest that in the future it may be possible to grow biofuels in areas where food could not be grown, thus removing the problem of competition. (IEA 2007)

Oil products can also be made synthetically through chemical processes. The most notable process is the so called “Fischer-Tropsch synthesis”, which can produce petroleum substitutes from coal or natural gas. Synthetic processes are currently not widely utilized, as they are still relatively expensive and environmentally unfriendly. They still appear in many future projections of the aviation industry, especially military aviation, as electrical engines or biofuels do not currently offer enough power for aircraft jet engines. (Encyclopædia Britannica 2008)

In this paper I will consider non-crude liquids as a part of crude oil. Many statistical sources also include but do not separate them in their oil figures. Synthetic substitutes are currently only of interest when thinking about the upper cost limits in the oil supply curve and I will return to that later. Biofuels are usually only economically viable with government support based on climate issues. Thus they fall out of the scope of this paper.

2.2 Reserves

Demand for oil and suitable extraction techniques started to emerge in the mid-19th century. In the following 150 years many great oil discoveries were made around the world. During the last decades however, new oil field discoveries have become scarcer and of lower quality. New oil fields are often found in deep waters or consist of non-conventional oil grades. Many industry sources have estimated that most of the high quality and easily available oil fields have already been discovered (Simmons 2005).

Oil discovery and reserve development is a long and complicated process. The size of discovered oil reserves is a matter of great uncertainty. Sizes are determined based on various geological methods that yield probabilities, which are further classified by technical and economical feasibility.

The largest estimate of the whole field size is called *petroleum initially in place* (PIIP, or OOIP: *original oil in place*). It describes the total volume of oil inside the reserve. Of this oil only a fraction is usually recovered. *Estimated ultimate recovery* (EUR, or *the recovery factor*, or *the basin potential*), as the name says, represents the fraction that will probably be recovered using current knowledge during the life of the reserve. According to Simmons (2005) EUR ranges from as little as 5% to even 80% depending of the viscosity of the oil and qualities of rock formations. For example typical Saudi Arabian light crude fields have an EUR of 20% - 45%. These reserve size figures are often criticized as they are based on very broad estimates. Simmons (2005) states that initial PIIP estimates are often over- or underestimating the reserve by even 60% - 80%. He goes as far as saying that the estimates are “not far from educated guesses”.

The size of oil reserves is naturally also very important for market participants analyzing the oil price and estimating values of oil companies. Therefore industry organization, foremost the World Petroleum Council (WPC) and the Society of Petroleum Engineers (SPE) have defined more detailed guidelines for oil reserve classification. The newest revision of the Petroleum Reserve Management System is from 2007.

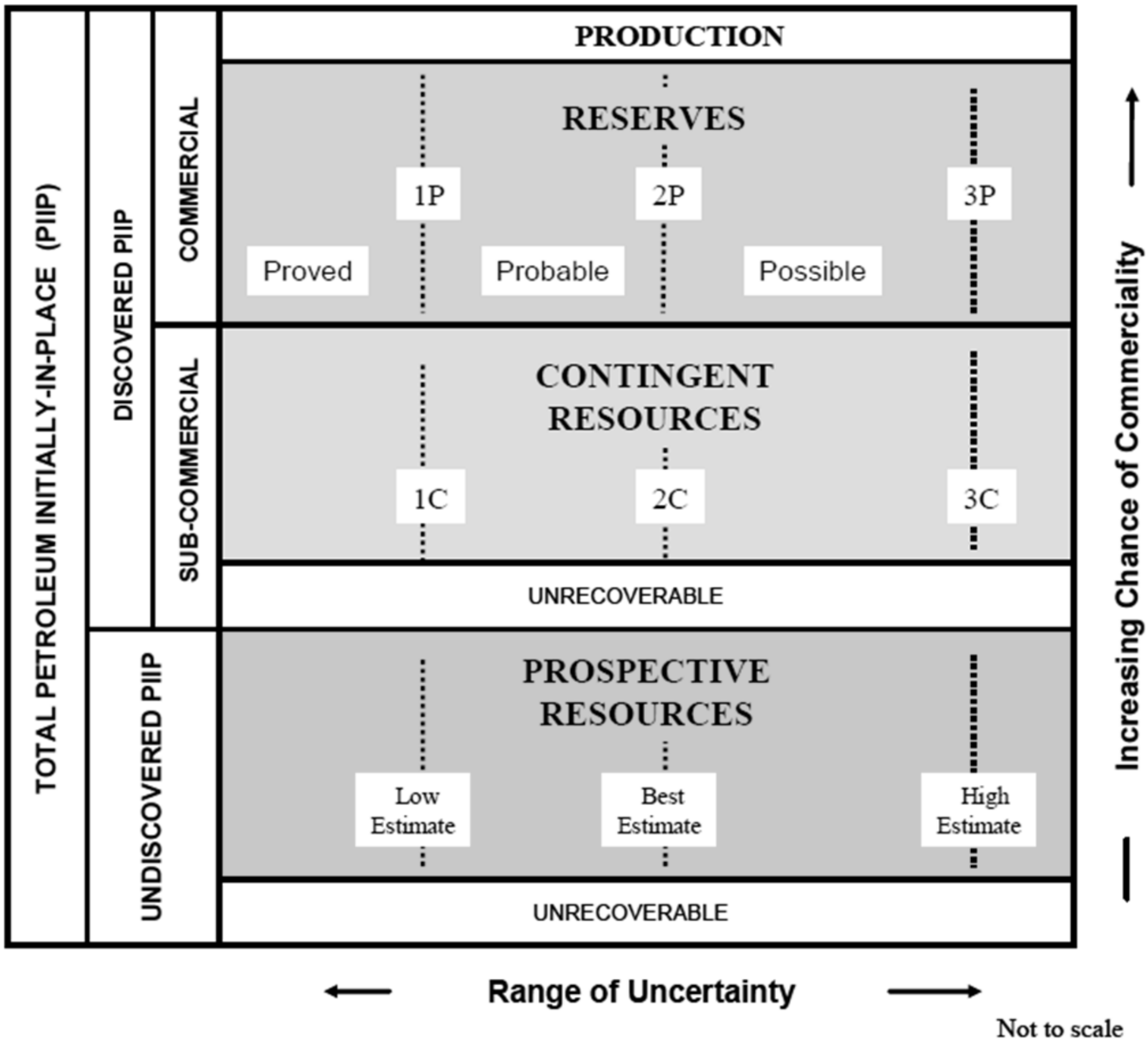

Figure 2.2: Oil resource classification (SPE 2007)

The above figure describes the classification of the petroleum resource management system. According to the system, PIIP is divided into three subgroups: reserves, contingent resources, and prospective resources. Reserves are further divided into proven, probable and possible reserves. These three are often shortened to 1P, 2P, and 3P representing recovery probabilities of 90%, 50%, and 10% accordingly. Proven reserves, or 1P, are “the reserves” that oil companies are to report according to the rules of the United States Securities and Exchange Commission (SEC). Proven reserves can also by further divided to developed and undeveloped ones depending on whether they have built capacity for production.

Estimated ultimate recovery is not usually a clear aggregate of any of these subgroups. It is best understood as a figure that contains all already produced oil and remaining reserves that are currently technologically and economically viable. Proven reserves, as well as EUR, are both affected by the changes in crude oil price. Higher prices enable oil to be extracted with higher costs from places that are harder to reach and thus allow larger reserve estimates.

According to Simmons (2005) individual oil fields vary significantly in size. There are over 4000 producing oil fields in the world, but 20% of global production comes from only 14 so called “super giant” fields. Saudi Arabia is an extreme example where 90% of production comes from five fields. One of them, worlds largest oil field Ghawar, accounts alone for 60% of Saudi production, and for over 6% even globally.

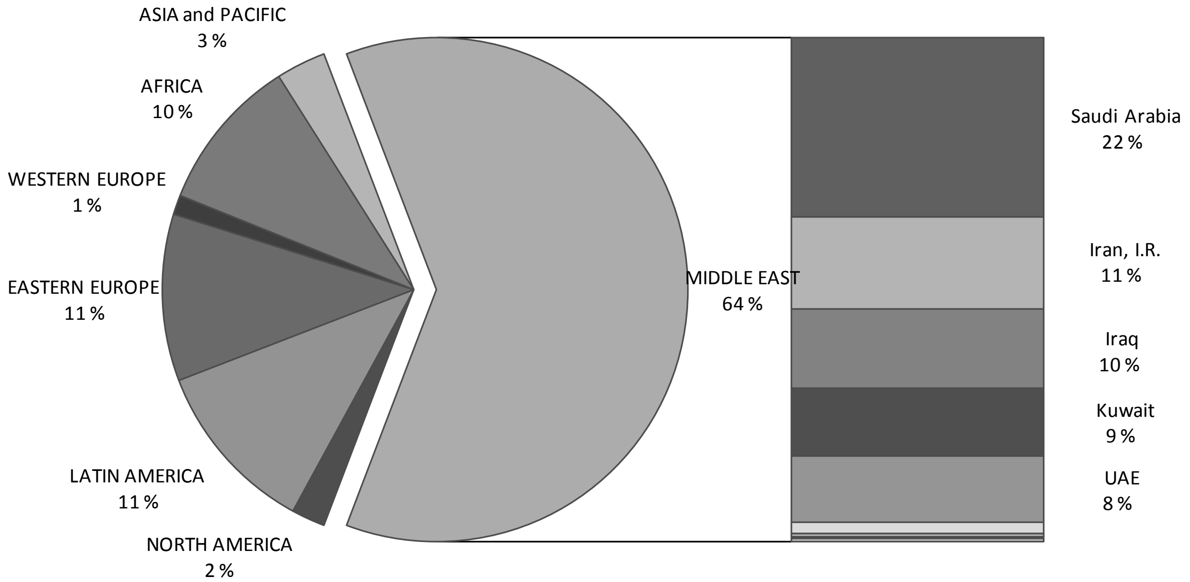

Figure 2.3: World proven oil reserves 2007 (data: IEA 2007)

The above figure clearly shows how unevenly oil reserves are distributed globally. Middle East dominates the figure with a share of over 60%, from which Saudi Arabia represents alone globally over a fifth. As mentioned earlier, reserve estimates are not very reliable. Additionally, reports of national reserves may be biased at least in less open economies, as oil ownership equals political power. Reported Saudi reserves for example have remained exactly the same for many years, even though they produce over 3% of their reserves annually (BP 2008). Thus above reserve distribution should be interpreted critically.

2.3 Supply

Before the 1970’s the oil business was dominated by seven western companies. These “Seven Sisters”, as they were called, operated around the world and were involved in most significant oil field developments (Simmons 2005). After the oil crisis in the 1970’s and following political developments, oil production around the world has been nationalized to a large extent. Today multinational companies control only 5% (Simmons 2005) of global oil reserves, but have remained as important partners in refinement and new oil production projects. I choose to examine oil production by country, which in most cases corresponds precisely to the national oil company.

2.3.1 Oil producers

The largest oil producers are roughly the countries with the largest reserves, although developed economies have managed to utilize their reserves more effectively and have a lower reserves-to-production ratio. In 2007 total world crude oil production averaged at 81,5 million barrels per day, amounting to a total of 3,9 billion metric tons total (IEA 2007).

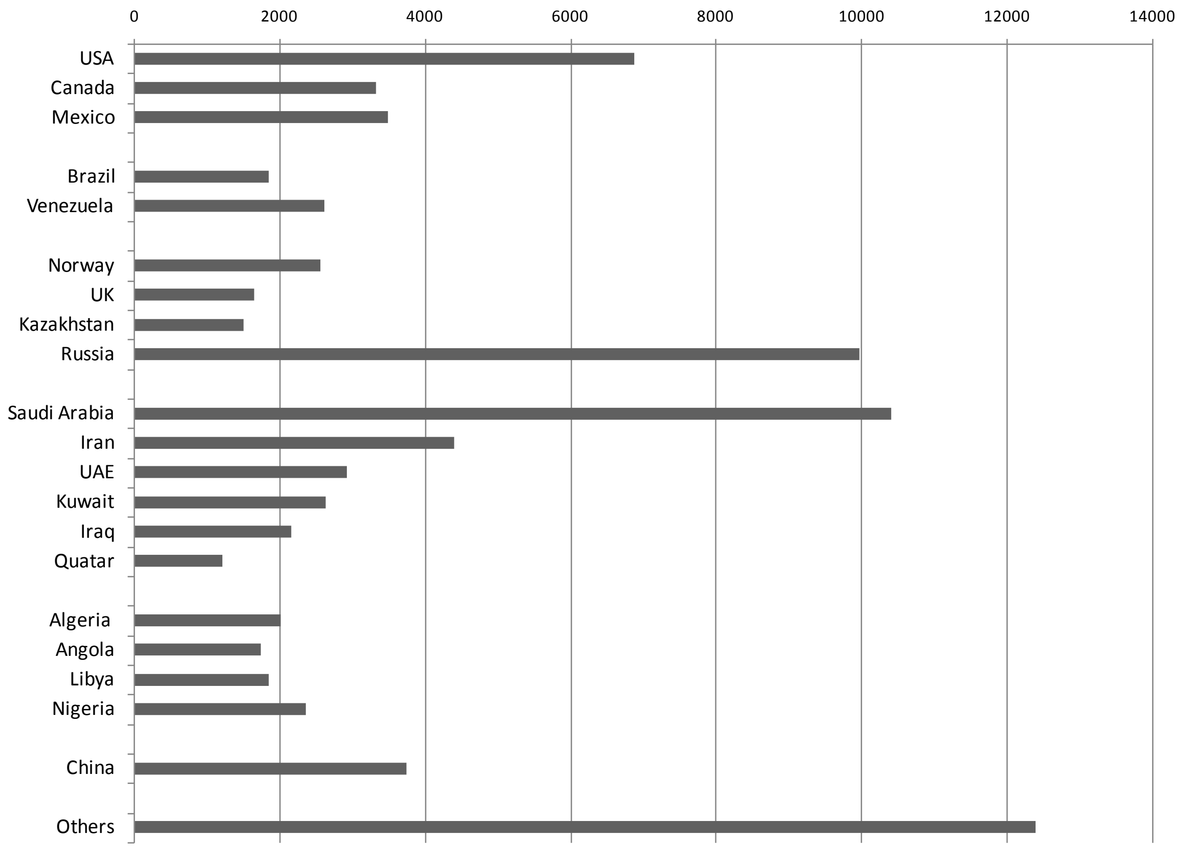

Figure 2.4: Oil production in thousands of barrels per day in 2007 (data: BP 2008)

The Middle Eastern producers dominate in production numbers as they do in reserves. It is notable that especially Russia and the United States produce at a very high rate despite their relatively lower reserves. Many developed countries have once produced at higher rates, but are experiencing production decline because of depleting and degrading reserves.

Since the 1970's some of the most notable oil exporters have furthered their interests through OPEC, the Organization of Petroleum Exporting Countries. OPEC represents over half of worlds oil exports (OPEC 2008) and is usually regarded the single most powerful player in the oil market. Other oil producers are very loosely represented through the IEA (International Energy Agency), which is a sister organization of and sharing the same developed member countries with OECD (Organisation for Economic Co-operation and Development). It is notable that such significant producers and/or consumers as Russia, China and India are not members of either of these organizations.

I will return especially to OPEC in later parts of this paper regarding historical developments and the role of market power.

2.3.2 Extraction technology

The romanticized image of oil production with crude oil raining down after bursting from vast underground lakes is unfortunately misleading. In reality crude oil is located inside porous rock formations, which vary in accessibility and porosity[1]. In most cases the formations have varying amounts of natural gas on the top parts, crude oil in the middle and groundwater below. These rock formations are found in varying depths underground or under the seabed. (Simmons 2005)

As new reserves are found oil indeed flows to the surface with its own pressure and the assistance of the groundwater pressure below it. The natural pressure however declines in a few years and it needs to be sustained artificially. This is usually done by injecting (pumping) water into the reserve. For example the Saudi Arabian national oil company ARAMCO currently injects twice the volume of water into its fields as it extracts oil from them. The process is often referred to as secondary recovery. The extracted material is a mixture of water, natural gas and oil, all of which need to be set apart in separation facilities before the products can be transported and sold. The amount of water depends on the age of the reserve and the rate at which it is extracted (new water injected). If the extraction rate is too high, water may also flow past some oil and leave it practically unrecoverable. (Simmons 2005)

1 Porous rocks can best be understood as rocks with holes or bubbles of oil in them. These bubbles intersect each other in many points and thus allow the oil to flow through the rock.

As oil producers have learned more and more about the decline and problems of oil reserves, they have also developed new technologies to ease extraction. Advances in offshore drilling technology have made many new reserves accessible. Modern drilled oil wells consist of branching vertical and horizontal pipes, which can be guided towards parts of the reserve that were impossible to reach before. Rock formations are studied with three-dimensional seismic and magnetic instruments, while in the earlier days of oil discoveries studies were based only on test drilling and visually observed surface formations. (Simmons 2005, IEA 2007)

One of the most promising technologies is referred to as EOR, or Enhanced Oil Recovery. It achieves higher recovery rates than traditional secondary recovery, by pumping CO2 or other gases into the oil well. As with water injection, CO2 increases pressure but it also dissolves into the crude oil and increases viscosity. CO2 injection is expensive, but it also has interesting environmental implications enabling the greenhouse gas to be returned to where it came from. This is called CCS, Carbon Capture and Storage. (IEA 2007)

The above mentioned challenges and technologies concern conventional oil reserves. Non-conventional sources, such as oil shales and oil sands require even more complicated processes including crushing, warming and distillation. This naturally makes them also clearly more expensive to extract. (Shell 2007)

These geological realities give insights to the nature of the resource and are important to understand when studying crude oil production. The complexity of infrastructure involved also explains the far reaching time frame of oil field investments and long lead times for new production. Issues like oil reserve decline and technological progress can also be analyzed in the framework of economic theory. I will return into these issues and their theoretical presentations in following chapters.

2.3.3 Transport and refining

Extracted crude oil is transported to buyers' refineries and storage tanks usually by oil tankers or pipelines, while trucks and trains are used more with refined oil products. Refineries process crude oil through many distillation cycles, which yield in a variety of oil products. As described earlier, lighter and sweeter oil grades are easier to refine into premium products and are thus more valuable.

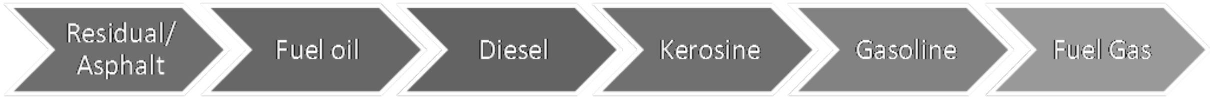

Figure 2.5: Main oil distillates from heaviest to lightest (data: Shell 2007)

I will not go further into the refining industry in this paper. It is however important to note that crude oil is always just a raw material for oil products, which are then consumed by end-users creating demand.

2.4 Demand

Crude oil demand is driven by the demand for aforementioned refined oil products. There are large regional differences, with the developed OECD countries representing 57% of world demand. The demand comes also from many sources, but the two main sectors: transportation and industry represent 85% of the total globally.

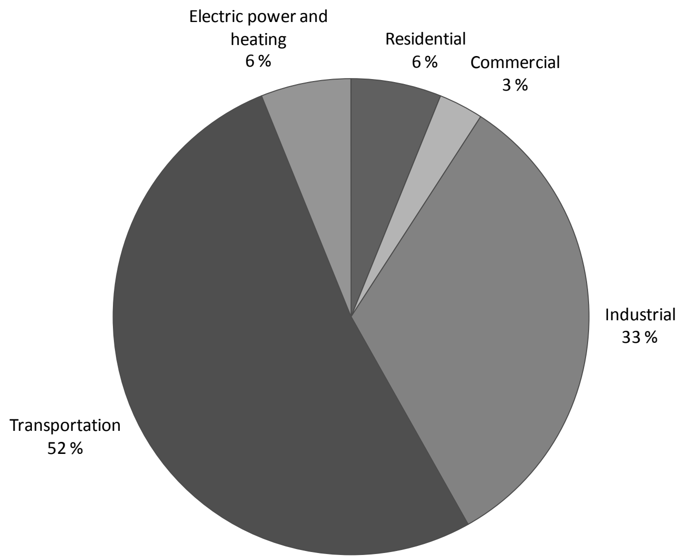

Figure 2.6: Crude oil demand by sector 2007 (data: EIA 2007)

It is notable that industry uses also many other sources of energy, but transportation is almost solely dependent on crude oil products for its energy needs.

2.4.1 Transportation demand

The transportation sector is clearly the largest user of crude oil products globally. It is also the largest in practically all individual countries regardless of the standard of living. It includes road, rail, air, and water transportation. The sector can be roughly divided into personal and industry driven transportation, which are both driven by population and economic growth. As economic activity grows, industrial output grows and transportation demand increases for raw materials as well as manufactured goods. This trend has been further emphasized by the development of global logistic networks. Increased personal incomes and urbanization have increased the demand for transportation also on the personal level. (EIA 2008)

The transportation sector is currently completely dependent on oil products, which represent 98% of the sector's energy use. Long periods of low fuel prices have led the transportation infrastructure and industry to be built around oil products. Even with higher oil prices substituting technologies have had hard times to gain foothold. Growing oil prices have also increased focus on the fuel economy of transportation vehicles. Developments in fuel economy are still constrained by availability of technology and capital. Consumer trends play also a role in private transportation. (EIA 2008)

2.4.2 Industrial demand

The industry sector has two different uses for oil products. Firstly, they are used as energy to generate power or heat for industrial processes. Secondly, they are used as raw materials for manufactured products such as plastics, industrial chemicals or asphalt. Industrial output is generally driven by economic growth as mentioned earlier.

Industry is not as dependent on oil as transportation is. Its energy needs can be easily substituted with a variety of power generation methods. Energy efficiency can also be improved by developing new technologies. As a raw material, oil is harder to substitute. Recent materials research and improvements in recycling have still lowered industry dependence in developed countries. (EIA 2008)

2.4.3 Other sectors' demand

The remaining three sectors; electric power and heating, residential demand and commercial demand, account for the remaining 15% of oil products consumption. In the case of oil products, energy use in residential and commercial sector means locally heating, cooling, lighting and cooking. Electric power and heating on the other hand are centrally produced and distributed. (EIA 2008)

Energy is produced locally mostly in developing countries. Because of easy availability and transportation, oil products are the energy of choice especially in remote areas. Central electricity and heating are linked to the standard of living and are thus used more in developed countries. Oil is very insignificant in central electricity generation and even though there are not as many substitutes for heating, oil is losing share to other fossil fuels because of relatively high prices. (EIA 2008)

2.4.4 Demographics and Geography

Even though the sectors and their order remains mostly the same around the world, demand differs much regionally. Developed western economies consume significantly more oil products per capita than developing countries.

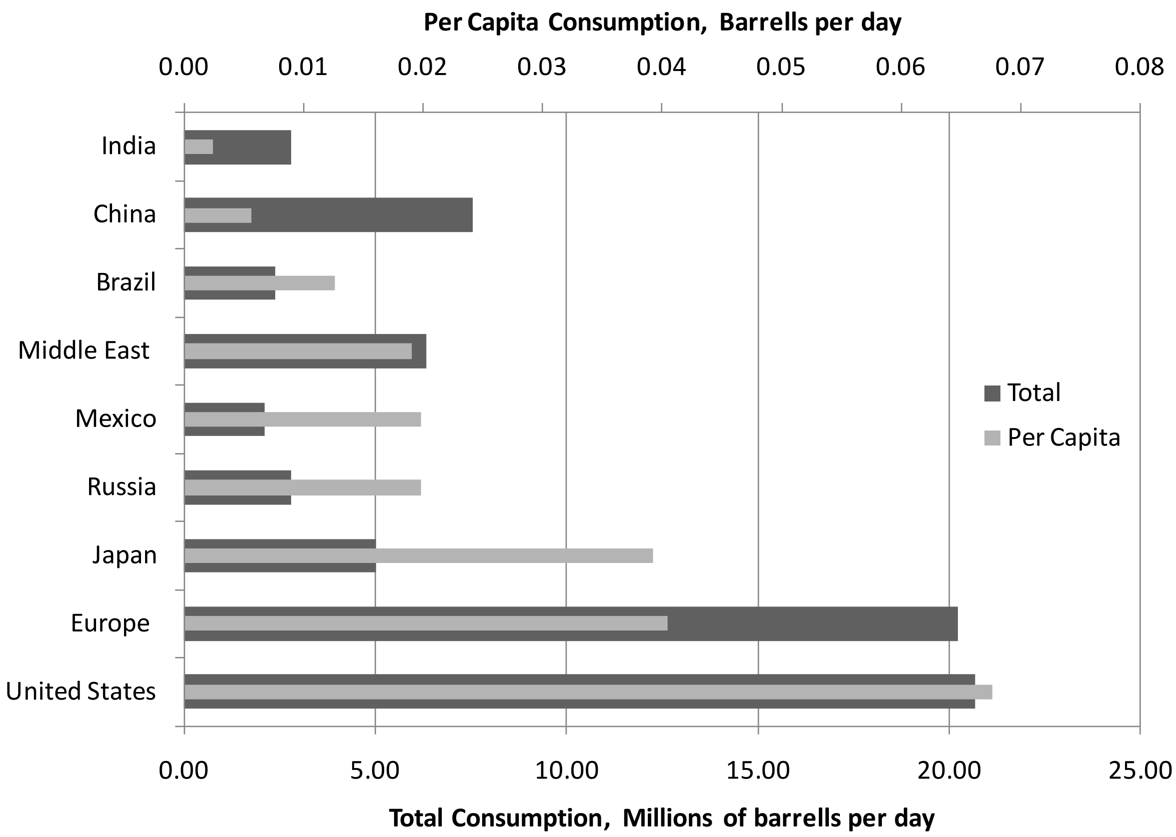

Figure 2.6: Oil consumption in selected countries in 2007 (data: BP 2008, EIA 2008)

Even large producing OECD countries are net importers because of their proportionally high demand. Developing oil producers on the other hand often subsidize their domestic oil to boost demand and harbor economic activity. This is true also for some developing net importers, most importantly China. Developed countries especially in Europe on the other hand have laid heavy taxes on oil products.

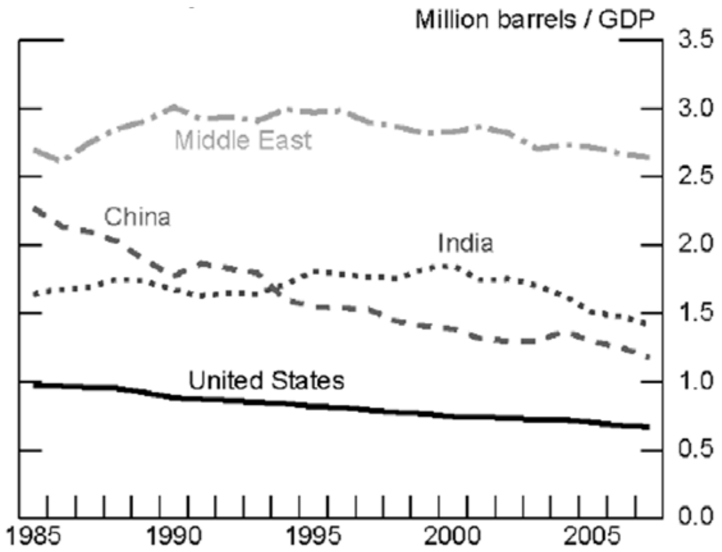

Figure 2.7: Oil intensity of GDP (ITF 2008)

Oil demand has developed hand in hand with global economic growth for decades. It is however anticipated that the relationship is loosening in the future. Oil intensity of the GDP has been already falling in OECD countries, as well as some developing countries, in past decades. (ITF 2008) This may be a result of individuals starting to prefer efficiency over luxury in transportation, and development of more efficient processes in industry. These ecological trends and efficiency increases can lead to the decrease of oil demand's income elasticity in the future.

2.5 Exchange

Oil suppliers and buyers meet on commodity exchanges. Commodity exchanges trade in options, futures and physical delivery of crude oil and various oil products. There are currently two major exchanges in which oil is traded: the New York Mercantile Exchange (NYMEX) in New York City and the Intercontinental Exchange (ICE) in London and Atlanta. Oil is traded in numerous different qualities, but three light oil blends are regarded as benchmarks representing also major oil production areas: West Texas Intermediate ("WTI", United States), Brent Blend (North Sea, Europe) and Dubai Crude (also "Fateh", UAE, Middle East)[2]. These benchmarks' prices are heavily correlated; WTI and Brent have been almost equal for decades, with their spread for twenty years averaging at $1.44 in favor of WTI. The OPEC Reference Basket is often seen as a fourth central benchmark. It is not an oil blend itself but a weighted average of 13 blends across OPEC member countries. Unlike the three primary benchmarks, the OPEC basket includes also some heavy oils. (NYMEX, ICE 2008)

2.5.1 Participants

The Commodity Futures Trading Commission (CTCF), an agency of the US government monitoring the NYMEX, classifies participants in the exchanges into two main categories: commercial and non-commercial. Commercial participants include oil producers, oil refiners (-manufacturers), oil traders and swap traders. These participants are in the market either to trade oil or to hedge their business-related risks in oil. Non-commercial participants on the other hand do not have a direct business-link to oil and are thus often called speculators[3]. These are further split into two sub-groups, namely hedge funds and floor brokers. (ITF 2008)

2.5.2 Spot and Futures contracts

The spot price of crude oil is not actually a current price, but a one-month forward agreement, also called "front month". This is due to the nature of oil, which requires time for the physical delivery, unlike currencies or securities. In the NYMEX for example, trading for the spot delivery closes three business days prior to the 25th calendar day of the month preceding the delivery. The commodity is then to be delivered by the end of the delivery month according to further details. The oil is made available at an announced location and the buyer transports it then further with his own cost. After the close date, the market will continue trading for the next spot month. (Borenstein 2008)

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[2] All of the major oil benchmarks (as well as practically all minor ones) are denominated in US Dollars. This is due to the history of the industry and helps price comparisons across markets. The significance of the denomination has been under debate in the press and has also stemmed discussion about the foreign policy of the United States. To address this issue the Republic of Iran opened its own oil bourse on the free-trade-zone of island Kish on the gulf of Persia. The Iranian oil bourse accepts all major currencies except for the dollar. (Reuters 2007) Because of the obvious political motivations, economics impacts of developments like these are hard to evaluate.

[3] The classification into commercial and non-commercial participants is not completely interchangeable with the division to hedgers and speculators, as also commercial traders may participate in some speculation even if their main transactions in the market are risk-driven hedging. (ITF)

Delivered spot contracts represent only a small amount of trading volumes on commodity exchanges. Most liquid contracts can be also settled in cash between the counterparties. During the past five years, only 2% of all traded contracts resulted in physical delivery (ITF 2008). Futures contracts are standardized exchange traded forward contracts. Unlike forwards, which are paid at the time of delivery, futures are “marked-to-market” meaning that they are settled and paid in the end of each trading day during the contract period. The daily settlement reduces the default risk of the other participant. The NYMEX trades oil futures for the next nine years. There are contracts for each month of the five first years and two monthly contracts per year for the following four. All of these contracts do not however necessarily exist if there is no trade in them. (NYMEX 2008, Pindyck 2001)

2.5.3 Market information

For the spot and futures markets to be efficient, all information should be equally available to all market participants. This is however not the case in reality. NYMEX and ICE provide data about exchange prices and regulators keep track of derivative positions, but information about more fundamental factors is missing. While oil demand is constantly forecasted along with other economic forecasts by national and international institutions, oil supply, capacity, costs and reserve information are scarce. This is due to the fact that, as mentioned earlier, the clear majority of oil is produced by national oil companies, who do not generally disclose their detailed production data. Usually only broad aggregates are reported.

The International Energy Agency (of OECD) and Energy Information Administration (of the US Department of Energy) as well as many financial institutions gather public data into periodical publications. Unfortunately some of their sources, especially OPEC, are neither specific nor reliable (Hamilton 2008). Some specialist companies such as Petro-Logistics also provide intelligence on oil production. They gather their data for example by literally tracking tankers and estimating their loads by the draft of their hull. According to Hamilton (2008), even OPEC uses third party sources in their reporting, instead of numbers provided by member countries themselves. Marginal production costs are one of the key issues in price forecasting, but unfortunately they are maybe the most guarded secrets of national oil companies. Some researchers have also tried alternative approaches. The most famous one is probably Simmons (2005), who estimated the production capacity of Saudi Arabia by going through and aggregating numerous reports from engineering research papers. While production capacity may be figured out with thorough investigation, the actual size of oil reserves is still practically impossible to estimate from an external point of view.

All in all, production information of the most important commodity in the world is scarce and some of it is not freely available. Forecasting is hard as even sizes of oil reserves or built production capacity cannot be reliably verified. This raises doubt that oil market participants may be trading with asymmetric information, theoretically leaving room for market bubbles and other inefficient and unfair behavior. I will analyze this possibility further in a dedicated subchapter.

3 Analysis of price factors

As stated before in the introduction, the aim of this thesis is to understand the structure and central drivers of the oil market. To reach this goal I will examine different views of oil price formation and their theoretical basis. After going through the relevant history of the market I will present Hotelling's theory on exhaustible resources. In the following subchapters I will use Hotelling's framework as a reference to understand the long term nature of the market. I will further introduce shorter term concepts on market equilibrium conditions and price bubbles. Lastly I will analyze short and long term equilibriums based on presented concepts and specific market features.

The analysis is organized in the form of a stylized oil supply chain. It starts from long term questions of oil ownership, market power and production planning. Then it deals with short term issues in the actual marketplace where trade is made. Lastly it presents oil demand drivers and matches them with short and long term supply. I will introduce theoretical concepts, empirical evidence and analytical reasoning side-by-side for each of the given topics. Before further analysis however, I will now take a look at the observed time series of crude oil price and related history of the market.

3.1 Historical price developments

The history of oil prices can be divided roughly into three different periods: a calm beginning when oil supply was totally adequate for all demand needs, a middle period when political events and market power shaped the price path, and the present period where the effect of politics is decreasing and the price is affected by more fundamental factors in supply and demand. While it is pretty clear that oil price development cannot be forecasted statistically based on historical prices, it is interesting to examine different periods in the time series.

3.1.1 History of oil before the 1970's

The history of oil dates back at least four thousand years. Oil was first found in oil pits throughout the Middle East and used in construction, lighting and medicine. First oil wells were drilled in ancient China over two thousand years ago. The history of modern oil began in the mid-19th century when significant breakthroughs in drilling and distillation technology were made. Driven by demand for kerosene lighting, the industry began growing. For many decades gasoline was just a byproduct of refined kerosene. After the invention of the internal combustion engine and further by the first automobiles, gasoline became the main product. Demand for transportation grew in the industrializing world and the oil market boomed alongside, even though electric light bulbs made kerosene lighting obsolete. Oil demand was further increased by the World Wars, where motorized transport played a key role. It was with warfare when oil's strategic significance was first realized. (Encyclopaedia Britannica 2008)

In the mid-20th century seven international oil companies dominated oil production and refinement. The "Seven Sisters", as they were called, were:

- Standard Oil of New Jersey (renamed later Esso and merged with Mobil)
- Royal Dutch Shell
- Anglo-Persian Oil Company (renamed later BP)
- Standard Oil Co. of New York (renamed later Mobil and merged with Esso)
- Standard Oil of California (renamed later Chevron)
- Gulf Oil (merged later with Chevron)
- Texaco (merged later with Chevron)

At that time the United States was the largest oil producing country in the world. Prices remained low because oil fields of that time were still their young phase and production was cheap. New advances in extraction technology, scale benefits, and increased competition actually pushed nominal oil prices down for long periods of time. Actually still in the 1960's most industry analyst suggested that oil prices would continue slowly falling and stay down "for ever". (Simmons 2005)

At the same time major oil discoveries were made in the Middle East, which would eventually become world's leading oil region. All major oil companies had ventures around the world, and their dominance of the industry was indisputable. As mentioned earlier, private oil companies account for only 5% of present day oil production. This is largely due to events of the 1970's that proved oil's power as a political asset and started the nationalization of oil resources. (Simmons 2005)

3.1.2 Political events affect prices in 1970 – 2000

In 1973 Arab states Egypt and Syria attacked US-backed Israel in what would be called the Yom Kippur War. This was in continuation for the Six-Day War fought in 1967, where Egypt and Syria lost territories to Israel. The Israelis were short on weapons and supplies making them reliant on the west, if they were to win the war. Saudi Arabia had created a close relationship with the United States through oil ventures at that time. Their King Faisal was however not happy that the US supported the Israelis in a fight against their fellow Arabs.

When the United States announced that they would re-supply Israel with weapons, King Faisal decided to use the “oil sword”. He gathered ten fellow Arab oil ministers and they quickly announced a collective supply reduction of 5%. This was the first time that OPEC rose into public knowledge. Saudi Arabia would itself cut production by 10% and place the United States and the Netherlands (a major oil shipping hub) to an oil embargo. Saudis also quickly nationalized 20% of their national oil company ARAMCO. In the following years they further increased the share to 60%, and soon to 100%. Other OPEC-members would follow their example.

The cut did not represent a large share of global production at that time, but it was enough to send the oil price soaring from a little over $4 to approximately $10 per barrel in just one month. Other oil producing countries did not have excess capacity to compensate for the production drop. This was the first time when the oil market showed its inelasticity, a feature that would continue to move prices from then on. Another reason for the strong price reaction was psychological. Market participants had to start thinking about oil in a completely new and different way. The 1970’s brought politics to the oil market and the dependence on production from Middle East materialized. (Simmons 2005)

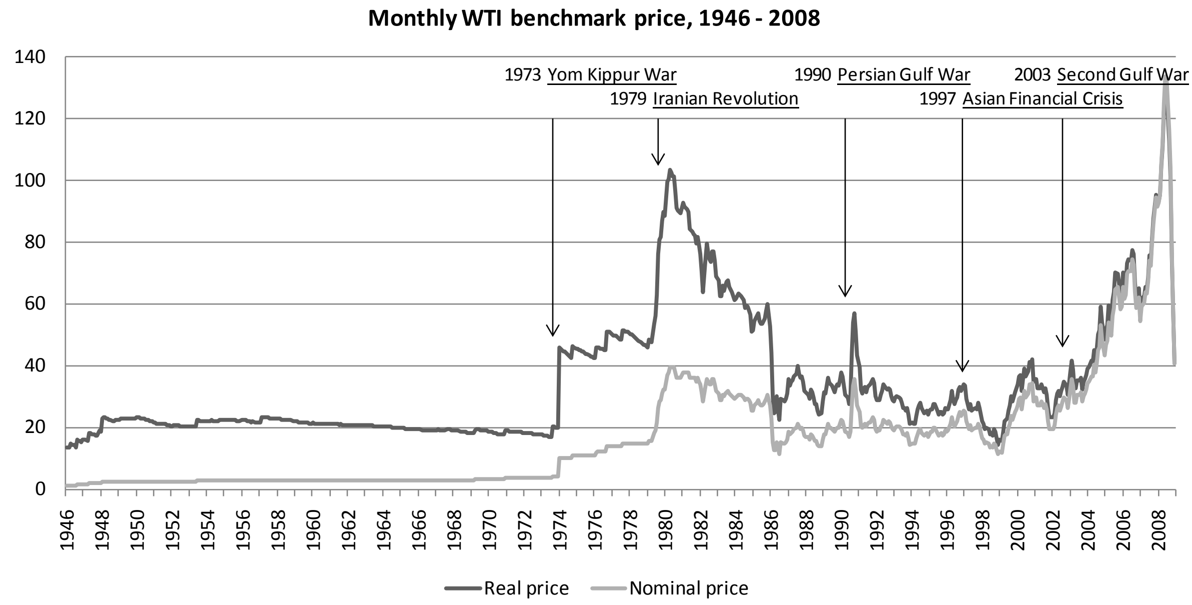


Figure 3.1: Nominal and real oil price and political events 1945-2007 (data: BP 2008, Bureau of Labor Statistics 2009)

The oil price was to rise even higher. In 1979, Iran was shaken by a revolution, which disrupted production. The new government didn't manage to stabilize production before Iraq attacked Iran starting the Iran - Iraq War in 1980, which would last for eight years. Both Iranian and Iraqi production was significantly affected. Oil price had already been rising from the last crisis to about $18. The war caused it to jump to a high of $40 (over $100 in 2008 dollars).

In the following years the oil price decreased steadily, as a result of decreasing demand, and increasing competition as capacity was again available. OPEC was unable to act as a group to keep production down, as they had managed to do in 1973. Saudi Arabia started to unilaterally cut back its production in 1982, but other OPEC members did not follow. The dramatic price drop happened in 1986, when OPEC again failed to reach an agreement, and the Saudis decided to begin full production again resulting in a price war with the oil price falling under $12. As a result, OPEC's ranks were tightened again, and the price recovered to around $18 for the next few years.

In 1990 Iraq invaded Kuwait, which led to the Persian Gulf War, and the oil price bounced again to $35. Saudi Arabia however compensated for the production distortion rather quickly, and the Gulf War, even though it was a major political event globally, didn't affect oil prices as much as previous crises.

The first major demand-side event in the history of crude oil prices was the Asian Financial Crisis that begun in 1997. The promising increase in oil demand from Southeast Asian countries resulting from the “Asian economic miracle” suddenly turned to a decrease. Nominal GDP’s in the region decreased tens of percents from ’97 to ’98. Oil price dropped momentarily to as low as $8. The price drop also partly triggered the Russian financial crisis in 1998, as Russia’s main exports were (and still are) crude oil and natural gas.

3.1.3 The new oil market 2000 -

In the 21st century oil prices increased to new records as well as crashed with a record speed as the current economic crisis hit in fall 2008. The role of politics or market power has however been much smaller this time around. The Second Gulf War in 2003 had only a small and short effect in the price even though the conflict is still not over in 2009. OPEC on the other hand actually increased production as prices were rising in 2003 – 2008.

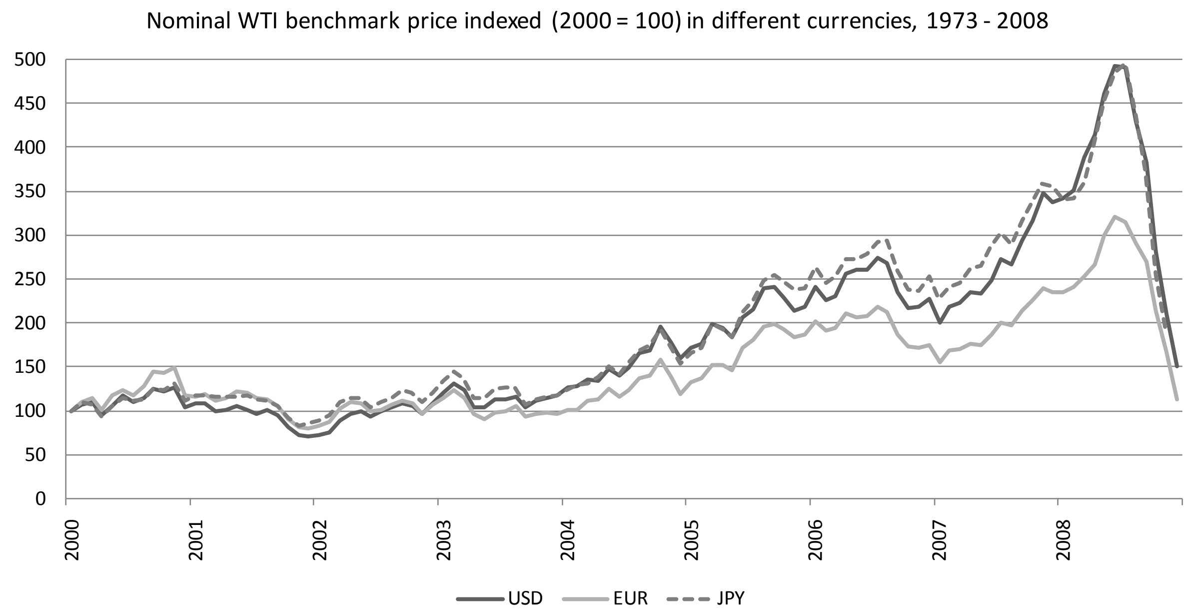


Figure 3.2: Nominal WTI price in different currencies, 2000-2008 (data: BP 2008, Bank of Japan 2009, European Central Bank 2009)

Before the crash of 2008, the depreciating dollar was often raised as an explanation for the rising prices. In the above graph we can see that the price change was not as extreme in Euros. The comparison is still not that simple. There are many reasons why currencies and traded commodity prices are not independent of each other, but I will not go into that in detail. It is however clear from the graph that prices were driven up also by other factors. In the following subchapters, I will look into possible explanations.

3.2 Basic resource theory

Economic theory provides a good starting point for understanding oil price developments. Hotelling's theory on exhaustible resources (1931) can be considered the basic theory for understanding fundamental factors in long-term price development of depletable commodities. Despite its significance, the theory didn't get much attention before the oil crisis in the 1970's. This was because adequacy of natural resources for sustained growth wasn't a main concern before the Second World War and also because Hotelling's work was considered mathematically difficult for the economics of that time. After the oil crisis however, Hotelling's theory became the basis for following papers and is still one of the central works in the field. (Gaudet 2007)

3.2.1 Hotelling's rule

The idea of the theory can be best understood by comparing a stock of exhaustible resources with a more general description of a capital asset in a market economy. The value of a capital asset is dependent on the rate of return it yields to its owner. In his primer to Hotelling's theory Gerard Gaudet (2007) divides the rate of return into three factors:

1. Marginal productivity or dividend rate
2. Change of characteristics over time
3. Rate of change in the asset's market value

For the asset market to be in equilibrium, the rate of return (comprised from the three components) needs to be equal with the return of selling a marginal unit of the asset and investing it in a riskless bond. In other words: the rate of return must equal the rate of interest (this statement does not take into account risk and associated reward for the sake of simplicity).

Exhaustible resources, like oil, are different from many industrial assets. Holding them in stock is not productive and thus does not yield any dividend. Also their physical characteristics do not generally change over time. (The overall quality of a mine or an oil well might still degrade over time, but I will return to that later.) Left as the only source of return is the third component: the rate of change in the resource's market value. (Gaudet 2007)

The marginal value of the resource in the ground is often called the in situ value or scarcity rent. In practice it is the opportunity cost of extracting the resource instead of leaving it in the ground. In this case, the in situ value of the exhaustible resource is simply its price on the market minus its extraction costs. The in situ value can be written as

$$\pi(t) = p(t) - c(t) \tag{1}$$

with *p(t)* as the current market price, *c(t)* the unit extraction cost and π(t) the in situ value at date *t*.

Hotelling's rule states that the growth rate of the in situ value of an exhaustible resource must equal the interest rate

$$\frac{\dot{\pi}(t)}{\pi(t)} = r \tag{2}$$

where *r* is the risk free interest rate. This reflects the opportunity cost of the alternative interest yielding the interest rate r.

It is simple to estimate the growth in the market price of the natural resource, if we assume that extraction costs do not depend on the extraction rate and are invariant over time. This gives the following equation for change in market price

$$\frac{\dot{p}(t)}{p(t)} = r\left(1 - \frac{c}{p(t)}\right) \tag{3}$$

This should lead to a situation where the market price grows first slower than the interest but, as the share of the extraction costs gets smaller and smaller, approaches the interest rate over time.

For most exhaustible resources however, this has not been an observed price path. According to Gaudet (2007), price changes during the last hundred years for copper, lead, zinc, coal, petroleum, tin, aluminum, nickel, and natural gas have been very volatile, but have not followed changes in interest rates. There are no significant observed trends that would suggest behavior according to Hotelling's rule, as the mean price changes are not significantly different from zero. This observation still does not mean that Hotelling's theory should be abandoned. To explain more realistic price paths, the theory needs to be refined by adding more factors.

3.2.2 Degradation cost

One important factor affecting the extraction costs over time is the accessibility and/or quality of the resource. This is linked to the second component of asset valuation, which accounts for the resource stock's change of characteristics over time (Gaudet 2007). As a resource is extracted, it gets harder to reach and becomes of lower quality. This "degradation cost" (Solow and Wan 1972) can be though as "going deeper into a mine" or "drilling deeper into an oil well" towards the last and worst pieces of the resource. Lower quality can also be thought of as the need for further (costly) refinement to reach the same homogenous marketable good. As degradation is very common in the real world, Krautkraemer (1998) considers this form as being the "basic" formulation of Hotelling's rule.

It is now useful to go beyond the simple opportunity cost -explanation of Hotelling's rule and show it's derivation through maximal utility. The goal in the problem is to maximize the resource stock owner's utility over all future time. The utility of the owner at any point in time is the profit he gets from the amount of resources extracted at that time, which is defined as $\left(p(t) - c\big(s(t)\big)\right) q(t)$. The following is the maximization problem with the integral over profits discounted to their present value

$$\begin{gathered} max \int_0^\infty e^{-rt} \left(p(t) - c\big(s(t)\big)\right) q(t)\, dt \\ \dot{s}(t) = -q(t) \\ s(t), q(t) \geq 0 \end{gathered} \tag{4}$$

where *s(t)* is the remaining resource stock, which is depleted at speed *q(t).*

The Hamiltonian function[4] of this problem is

$$H(q, s, t, \lambda) = e^{-rt} \left(p(t) - c\big(s(t)\big)\right) q(t) - \lambda(t) q(t) \tag{5}$$

With the shadow price (current opportunity cost or in situ value) and its time dynamics

$$\begin{gathered} \lambda = e^{-rt} \big(p - c(s)\big) \\ \dot{\lambda} = e^{-rt} \big(c'(s) q\big) \end{gathered} \tag{6}$$

[4] The Hamiltonian is a central function of optimal control theory. For further details see for example Kamien and Schwartz (1991).

When denoting the current in situ value as $\pi(t) = \lambda(t)e^{rt}$, it can be solved to Hotelling's rule with degradation costs[5]

$$\frac{\dot{\pi}(t)}{\pi(t)} - \frac{c'\big(s(t)\big)q(t)}{\pi(t)} = r \qquad (7)$$

For the owner of the asset, this implies that extracting a marginal resource now will make extracting future resources more expensive. It can be seen from the equation that the in situ value will grow with a rate less than the interest. Depending on the cost function it may also decrease.

The central take-away of the Hotelling's rule is that even with perfectly competitive markets, it is natural that prices of exhaustible resources exceed their marginal extraction costs. Resource scarcity leads to the existence of a positive scarcity rent, which cannot be completely eliminated by trying to make the market more competitive. I will get back to market power later.

Degradation as presented previously applies for identical pools of resources that become more expensive and of lower quality during their lifetimes. On an aggregate level however, it can be assumed that many resource pools exist simultaneously with different quality or age, and thus different extraction costs. It is then economically reasonable to deplete the lowest-cost one first and then start sequentially extracting the higher-cost ones (Herfindahl 1967, Solow and Wan 1976). When considering two pools, in situ values of both pools will then grow at the rate of interest, but the low-cost one will be more valuable than the high-cost one. Market prices remain still same for both, as the extracted end product is assumed homogenous. In this case the owner of the high-cost pool will find it profitable to hold on to his resource, until the low-cost pool has been depleted. When the low-cost pool is exhausted and the high-cost pool starts producing, the extraction costs will instantly jump to the higher level. The in situ value has then grown on at a rate less than the interest (Dasgupta and Heal 1979), but the market price has kept on continuously growing.

In oil production, degradation of oil fields is maybe the most central extraction problem of all. As described in chapter 2, advanced extraction technology is trying to keep up with degrading oil fields. This indeed raises extraction costs significantly as Hotelling's refined rule suggests. Testing this version of Hotelling's rule in the oil industry would be very difficult though.

[5] For the complete solution see Appendix 1.

Extraction costs for most large producers are not public information, the degradation function would differ significantly depending on the oil field, and maybe most importantly: there is no public consensus on the sizes of initial oil stocks. Testing the theory with rough assumptions might be possible as an experiment, but falls out of the scope of this paper.

Previous concepts offer an explanation for rising oil prices, but do not explain why prices have remained stable or even decreased at some long periods of time. This requires further expansions of Hotelling's model.

3.2.3 Technological change

Another important issue is technological progress. Extraction technology should develop over time making extraction cheaper. By defining the extraction cost as $c(t) = ce^{-\alpha t}$, exogenous technological progress will lower extraction costs at the rate α. Hotelling's rule for market price growth takes the following form

$$\frac{\dot{p}(t)}{p(t)} = r\left(1 - \frac{c(t)}{p(t)}\right) - \alpha\frac{c(t)}{p(t)} = r - (r - \alpha)\frac{c(t)}{p(t)} \qquad (8)$$

where the market price change is the weighted sum of the interest rate and the cost reduction achieved from technological progress. When the share of cost is high, the rate of technological progress will dominate price movement, but when the share of cost is lower, the price will move closer with the interest rate. This would explain a U-shaped price path that has been observed with some commodities (Slade 1982).

As mentioned in chapter 2, oil extraction technology has developed significantly from the days of first oil discoveries. New technological methods are developed constantly and the newest wells are technically much more advanced than a few decades ago (Simmons 2005). This hasn't still stopped the oil price from rising. Combining technological progress with significant degradation costs might in theory justify initial price decreases and eventual high prices.

3.2.4 Price paths

According to equations presented above, prices of exhaustible natural resources should rise steadily over time. The price path implied by Hotelling's theory can be best illustrated by the following figure.

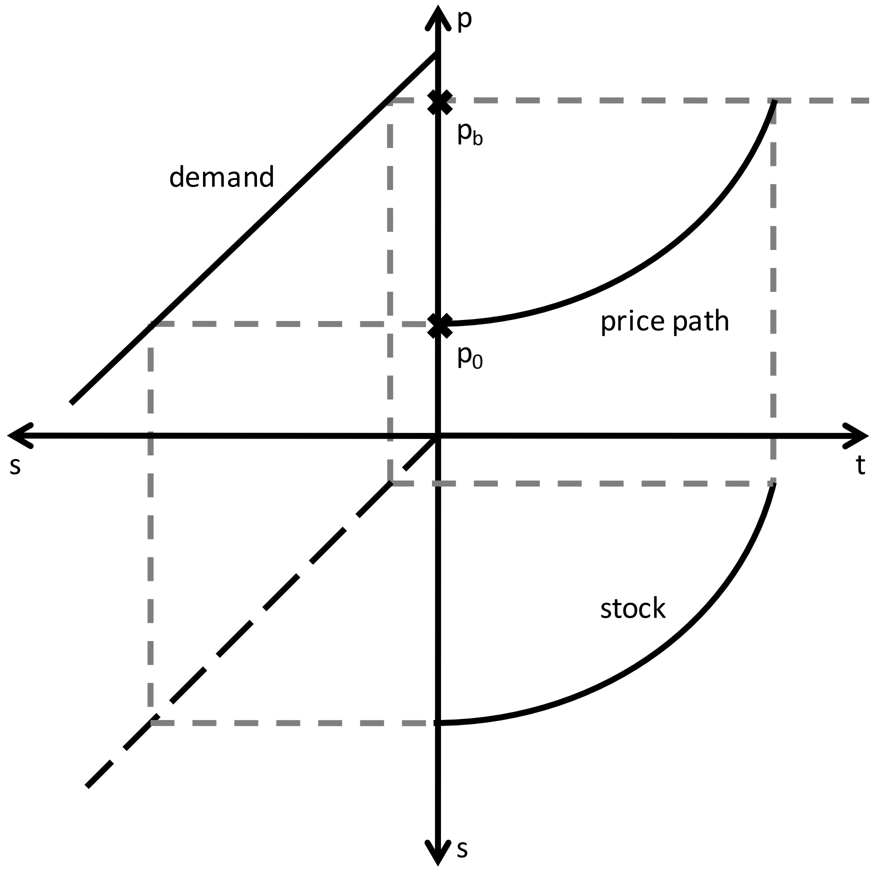


Figure 3.3: Illustration of a Hotelling's price path

As time passes by, the resource is extracted, its stock decreases, and its price increases at a speed that is close to the rate of interest. This continues until the backstop price p_b is reached. The backstop price represents the price of a substitute for the resource. For oil it can be thought as for example the cost per energy unit of switching to an infrastructure of electric cars running on nuclear power. After the backstop price is reached, production stops. In the end there might be some resources left in the ground, but it is not economical to extract them anymore, as the backstop substitute is cheaper.

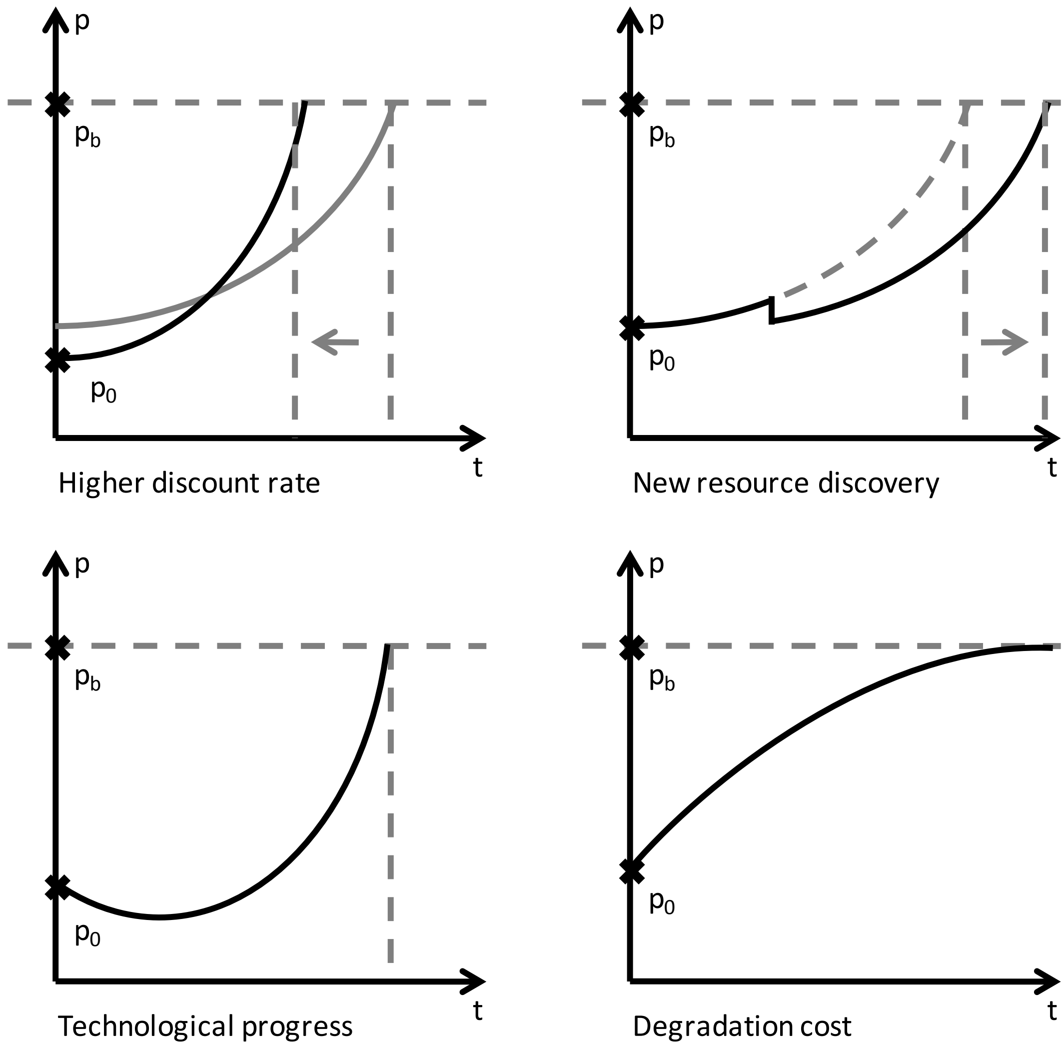


Figure 3.4: Hotelling's price paths in different cases

The figures above illustrate the price path in different kinds of cases based on previous theoretical concepts. The first figure shows how a higher interest rate causes the stock of resources to be exhausted in a shorter time period. The starting level for the price is lower because otherwise the backstop price would be reached "too soon". In the second figure a new resource discovery is made after production has already started. It "resets" the price path at that time point and a new path is formed based on the total remaining stock and the interest rate. In this case the time period for extraction is longer. Further new discoveries would lead to a saw-like shape. Besides technological progress, new discoveries are thus also one explanation why real life oil prices have not always been rising. The third case presents an example of technological change that lowers costs and causes a U-shaped price path as Slade (1982) suggests. Basically a series of new resource discoveries and changes in technology might explain more realistic looking paths. The last example is a price path of extraction with degradation costs. The price never reaches the backstop as it gets more and more expensive to extract the last units of the stock. In this case the supply is so low in the end that consumption shifts to using the backstop simultaneously as it is needed to satisfy demand. The shape of the path depends on the shape of the cost function. With linear increasing costs the price path will be concave as pictured above. Although all of these cases are extreme simplifications of reality, they provide good tools to analyzing real life price paths.

This presentation of Hotelling's important theory was scaled down to suit the scope of this paper and thus is just a scratch on the surface. An important extension, namely market structure, will be discussed in the next subchapter and revisited again later on with more on backstop technologies, but many important aspects of resource economics are left out from the theoretical part. Some of the most central ones include uncertainty, investments, externalities and taxation.

Hotelling's rule and the theoretical concepts around it provide necessary tools to understanding the basic long-term fundamentals of oil extraction. In the growing world economy, with imperfect markets, vast technological advances and political interests it is not sufficient to understanding the whole picture. In the following subchapters I will try to get deeper into these other affecting issues.

3.3 Market power

The crude oil market does not consist of numerous small and equal producers, as Hotelling's rule would require. Many producers are relatively large and thus at least have the potential to use some market power. The Organization of petroleum exporting countries (OPEC) is often viewed as the strongest player and accused of manipulating prices and using power as a cartel. OPEC itself strongly disagrees with being called a cartel, but does frequently announce production quotas, that can be interpreted as cartel agreements.

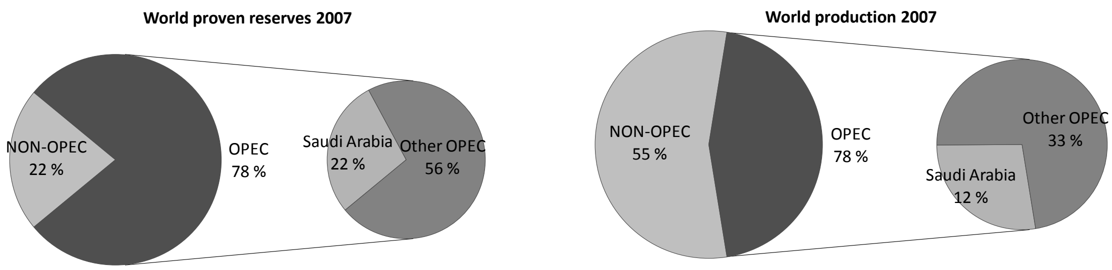


Figure 3.5: OPEC's share in reserves and production 2007 (data: IEA 2007)

Many academics and experts disagree whether OPEC is driving prices higher for their own benefit or just stabilizing the market with their capacity (Mitchell 2006). In the following I will go through some adjustments to Hotelling's rule that help to understand how market power could change producers' price paths. I will also discuss more practical evidence behind production decisions.

3.3.1 Hotelling on market structure and imperfect competition

Hotelling's framework, which was introduced in the previous subchapter, can also be used to address imperfect competition. Gaudet (2007) describes the situation where the resource stock is owned by a monopolist. To a monopolist the value of the resource stock in ground equals its marginal profit on the market, which is less than the in situ value. As the asset markets are still required to be in equilibrium, the rate of return of the resource stock must equal the rate of interest. The value of the resource stock in ground is now dictated by the rate of change of the monopolist's marginal profit, not the rate of change in the in situ value. By assuming constant marginal costs, we can get the following equation for the rate of growth in market price (Stiglitz 1976)

$$\frac{\dot{p}(t)}{p(t)} = r\left(1 - \frac{c}{\eta(t)p(t)}\right) - \frac{\dot{\eta}(t)}{\eta(t)} \tag{9}$$

where $\eta(t)$ is the ratio of marginal revenue to price. If costs are assumed negligible, the equation becomes simpler.

The introduction of a monopolist leads to a slower price growth than on a free market, even if the ratio of marginal revenue does not change, as the marginal revenue is lower than the price and thus the weight of the rate of interest is smaller. This means that even if the elasticity of demand remains unchanged, the market price will follow a flatter path than in a competitive market, unless marginal extraction costs are insignificant. Another change from the free market situation is that the difference between market price and marginal revenue will change over time. If η grows over time, the difference will decrease and hence further flatten the price path. As the gap between market price and marginal revenue is inversely related to the price elasticity of demand, the flattening will happen if elasticity increases over time. An elasticity increase would realistically occur on the long run, when substitutes for the resource are introduced. (Gaudet 2007)

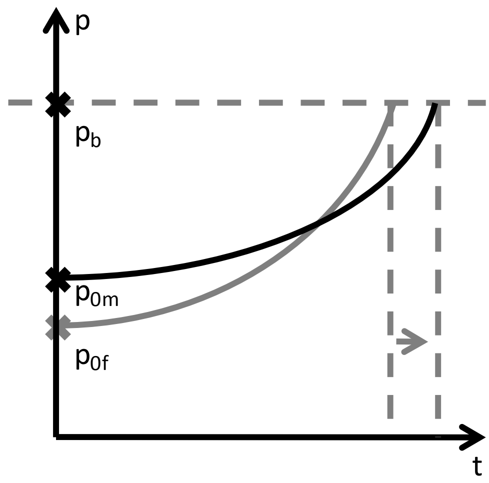


Figure 3.6: Price path with a monopolist

The stock of natural resources available for extraction will determine the absolute level of the price path. The market equilibrium requires that both the price under free competition and the price under monopoly are the same at the date of resource exhaustion. In effect the monopoly market price will initially be above the price on the competitive market but eventually become below it, assuming that resource stocks are the same. This means that a monopolist will exhaust the initial resource stock slower than perfect competition, with a flatter price path. A monopolist may also use his power by choosing a lower initial stock than price-takers, if determining the size of the stock is costly (Gaudet and Lasserre 1988). Even in that case, the price path will be flatter than under perfect competition. (Gaudet 2007)

Even though he didn't formally analyze it, Hotelling himself made the remark, that oligopolistic competition is more realistic than a monopoly in most markets for nonrenewable resources. The before described price path flattening effect will be present also in an oligopoly as it is due to the use of market power in general (Gaudet 2007). Oligopolistic competition with nonrenewable resources is however otherwise much more complex than either perfect competition or a sole monopolist. It's a dynamic and strategic game, where producers react to each others' stocks and production choices over time.

Studying market power and oligopolistic markets in the context of Hotelling's model was largely inspired by the oil crisis of the 1970's and OPEC's perceived leading role as a user of market power. The usual market description in these studies consists of OPEC as the dominant cartel player and of other producers as a competitive fringe. The first of many analyses of this problem was made by Salant (1976), in which he used the Nash-Cournot equilibrium concept where players ignore their choices' effects on other players. In this equilibrium the competitive fringe takes as given the price path of the dominant player and chooses its production accordingly, while the dominant player takes the fringe's production as given and chooses its price path (Gaudet 2007).

Another branch of studies (for example Gilbert 1978) is also based on the assumption of a dominant cartel versus a competitive fringe, but considers the cartel as a Stackelberg leader. Now the cartel understands its actions' impacts on the fringe and takes this into account in its decisions. The fringe acts as the follower and chooses its production path based on the leader's production. The cartel acts as the leader and determines its production path by taking the fringe's assumed reaction as given. The important difference here from the Nash-Cournot case is that now the cartel can manipulate the fringe's production decisions. (Gaudet 2007)

These models have given important tools and points of view to understanding the mechanisms of imperfectly competitive markets of non-renewable natural resources. Their limitations, on the other hand, have shown that there is still much work to be done for creating an accurate model describing all the dynamics of the market. One of the most apparent limitations is that both above described oligopoly interpretations are functions of only initial resource stocks and time. These are often called "open-loop" strategies and require credible commitment from the players throughout all time to the whole price and output paths. If players do not have required capacity to commit to the path, the reached equilibrium may not hold on different resource stocks. It may also be that players would change their chosen path if they would be allowed to reconsider it at some future time. In terms of game theory, the reached equilibria are not generally subgame perfect and may also be time-inconsistent. (Karp and Newberry 1993, Gaudet 2007)

Another way to look at the problem is to use so called Markovian strategies, where the extraction rate is a function of current, rather than initial reserves. In these strategies producers make decisions as time goes by, which leads into feedback equilibria (feedback loops, closed-loop equilibria). These are called Markov perfect Nash equilibria as they form a Nash equilibrium both in resource stocks on the solution path and resource stocks out of equilibrium. Solving these equilibria for a natural resource game is however hard with many theoretical and computational issues (Gaudet 2007). Groot et al (2003) have managed to derive a Stackelberg feedback equilibrium by setting constant marginal cost and linear demand, but much research still remains to be done.

The situation is easier if we assume that there exists no dominant player, but a limited number of equal producers who make simultaneous decisions. This case can be then examined as Cournot competition in a dynamic setting, leading to an open-loop game. It is in many ways similar to a static game, because players condition their decisions in the beginning of the game. The dynamic nature of its variables makes it still crucially different, even though it is an open-loop game. Benchekroun and Gaudet (2003) give an example where production is taxed for a finite time period in the game. A static game would change for the period of the tax and return to its original state after the tax is lifted. In a dynamic game on the other hand, temporary taxes would change the state of the game permanently and players would try to anticipate possible effects. This would mean that they change their open-loop paths also before and after the taxation period.

Gaudet (2007) suggests, that because of features as the one described above, open-loop strategies are not a good way to analyze depletable natural resource extraction. It is very likely that producers gather new information as time goes by and change their production accordingly. As with the cartel-fringe structure, a closed-loop Markovian equilibrium is more adequate to describe also an oligopoly with equal players. Solving this kind of feedback equilibria is comparably difficult as in the case of a cartel and competitive fringe. In contrast to the basic Hotelling's rule, decisions are not based on the initial situation, but on decision rules that are interpreted dynamically. A player knows his own reserves and can observe other players' reserves by assuming that they follow some rule in their production decisions. If extraction costs are assumed to be constant, Hotelling's rule can be sketched as

$$\frac{\dot{\pi}(t)}{\pi(t)} + s\left(\vec{X}(t), \pi(t)\right) = r \tag{10}$$

where s is the strategic decision function including $\vec{X}(t)$, which is the vector of all producers' stocks remaining at a certain time. While the idea of this new formulation is simple, the details of the decision rule (function) are unknown. As not even the sign of the component is known, no conclusions about its effect on the price path can be made (Gaudet 2007).

3.3.2 OPEC's role

As mentioned before, the crude oil market is often said to consist of the cartel OPEC and a competitive fringe of other producers, who react based on OPEC's decisions. While in the changing world it is unlikely that OPEC would decide their production on an open-loop basis, even complicated feedback equilibria in exhaustible natural resources include the underlying feature of increasing in situ value in relation with the interest rate. Strategic decision rules that affect production in addition to the interest rate are hard to formalize, but the significance of market power used to drive prices can be better understood by looking at evidence from the market.

Since the oil crisis of the 1970's OPEC has been blamed for rising oil prices. While OPEC denies that it is a cartel, it often announces changes in members' "voluntary production restraints". These quotas represent approximately 45% of current global production and 55% of crude oil exports (OPEC 2008) and thus changes in them signal use of market power.

OPEC's quota announcements have often been reported widely in the news accompanied by political comments and criticism. This has also led to quick movements in crude oil futures' prices anticipating changes in production (Hamilton 2008). The credibility of OPEC's announcements was indisputable in the 1970's. Also after the price war between OPEC members in 1986 coordinated actions were again resumed (Simmons 2005). For 1990's oil prices seemed thus to be negatively correlated with OPEC production.

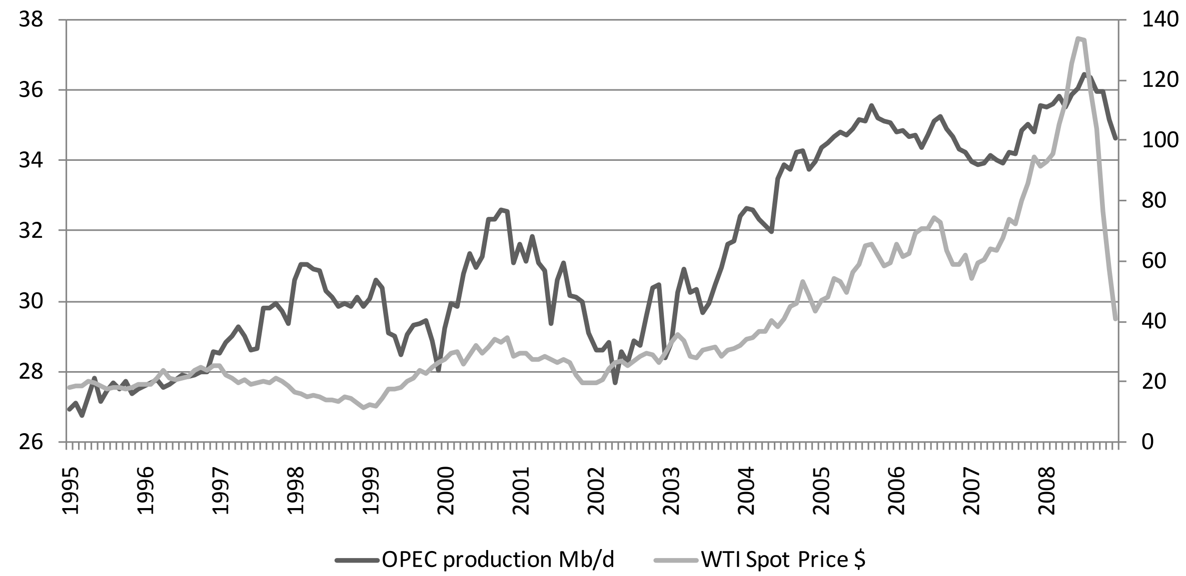


Figure 3.7: OPEC production and WTI oil price (data: EIA 2009)

After 2002 however, the price trend seems to have lost its connection with OPEC production. While small adjustments show negative correlation, the main observation is that even though OPEC reached its highest production in decades it was not enough to counter the price increase.

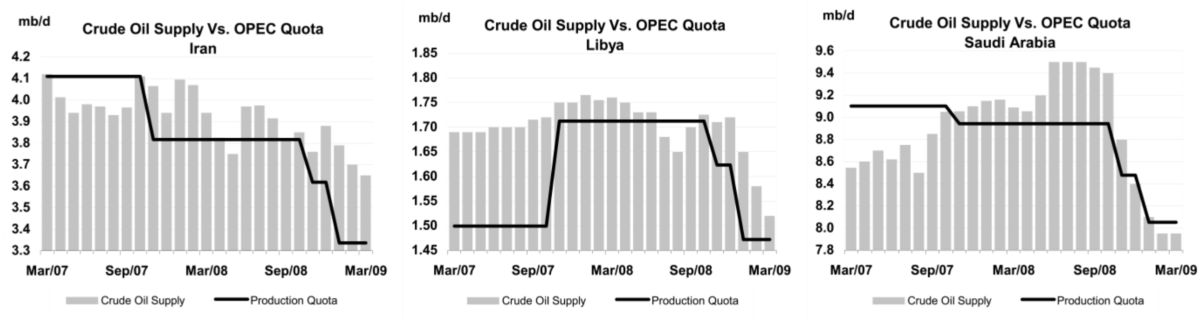


Figure 3.8: Quotas and production from selected OPEC members (IEA 2009)

Hamilton (2008) has studied OPEC's quota announcements from the past five years. While OPEC production numbers are not generally accepted as reliable, he finds that based on third-party production numbers, quotas are systematically inconsistent with actual production. This can be also seen from recent data in the above pictures. Some members overproduce and some stay below the quota for long periods. Hamilton (2008) notes that during the five year period the causality seemed to be sometimes reversed; production changes happened first and it seemed as quotas were just adjusted accordingly. In 2006 OPEC stopped reporting quotas as production levels and announced just changes to previous production.

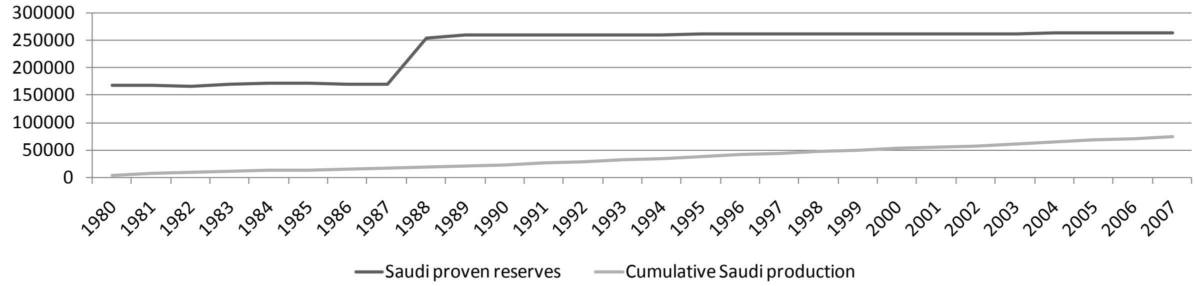


Figure 3.9: Saudi Arabian announced reserves and cumulative production 1980 – 2007 (data: OPEC 2008)

We can also question OPEC's credibility by looking at member countries' reserve announcements. Their proven reserves seem to increase exactly by the amount of production annually, as changes in the sizes are almost nonexistent. The above figure shows Saudi Arabian announced reserves, which have not changed even though they have simultaneously produced significant amounts of them.

To be able to use market power, OPEC needs two things: excess capacity to stabilize the market and internal discipline to limit production. For the past five years, Saudi Arabia has been the only OPEC member that has had excess capacity at its usage (Hamilton 2008). It is also clearly the largest member, so its production has also impact on the market alone. One way of viewing the issue of market power, is to think of Saudi production as the only one with power, and regard other producers as competitive. This was mostly the case in the price war of 1986. Saudi capacity has been used in many instances to compensate for production cuts elsewhere. This has undoubtedly had positive impacts on oil price stability. The Saudis did not however manage to stabilize the prices in the past years. There are two reasons that could explain why: they could not or they did not want to. I will return to production capacity and incentives in later parts of the paper.

3.4 Distortions in the exchange

Understanding Hotelling's theory and observing the evidence of production and market power is not enough for understanding movements in the oil price. Between reaching from producers to consumers, oil passes through the marketplace, where many parties with differing interests, assumptions and information trade with it and its derivatives. Theory and empirical evidence have shown that asset prices can contain bubbles, where the price does not correspond to its fundamental value based on supply and demand. Many physical issues also create arbitrage possibilities when oil changes owners. Therefore it is important to examine, how oil prices could be affected by distortions in the marketplace.

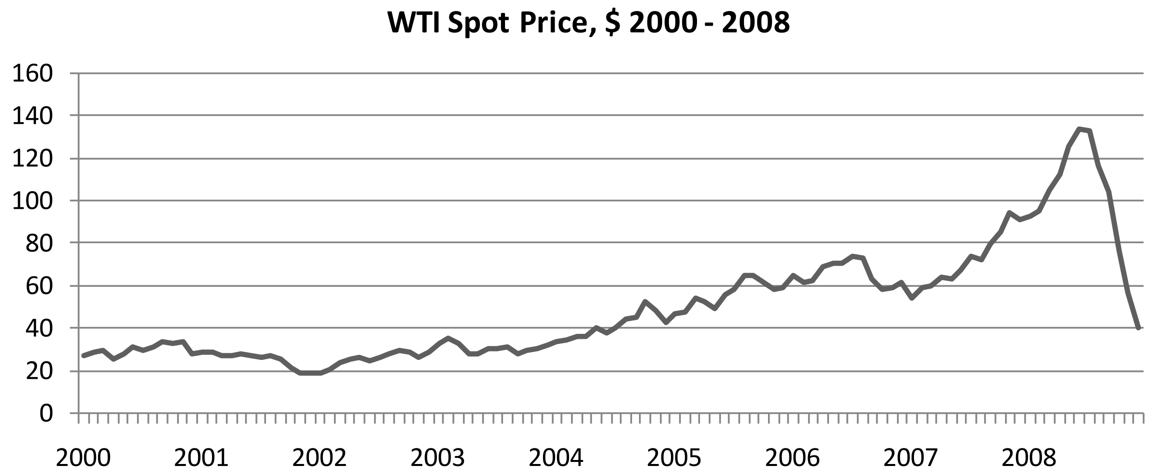


Figure 3.10: WTI price development in the 21st century (data: EIA 2009)

Recent changes in oil prices have been often blamed on speculators, who trade on oil futures. Oil price was said to be artificially driven up, without justification from fundamental factors. The market for oil derivatives has indeed grown significantly in recent years. Oil, as well as other commodities, is however different from most securities. Unlike shares, which are held for dividend or growth in value, oil is "consumed at the spot" (Hamilton 2008), which means that supply and demand are met constantly on the marketplace and once physical oil is sold in the spot market, it rarely returns to be sold again.

The exchange in oil is thus constrained by arbitrage conditions in storage and futures markets, which are both required to be in equilibrium for arbitrage to be unprofitable. In the following I will go through the arbitrage conditions, possible situations when markets could divert from them, and empirical evidence about speculators' actions in the oil market.

3.4.1 Storage and futures arbitrage

If an investor had a view that oil prices were rising strongly, he could borrow money, buy oil now, put it into storage, and sell it later with a profit over loan interest. This would require the price to be

$$P_{t+1} > (1+i)(P_t + C_t) \quad (11)$$

where C is the cost of storage and i the interest rate. As investors do not know the future for sure, P_{t+1} would rather be represented by the price expectation $E_t\ P_{t+1}$, which is based on current information. If other investors shared the same information and view, everyone would start buying oil from the spot and storing it which would increase the spot price. As all oil would be going into storage, the expectation of the future price would decrease as there would be more oil available in the future.

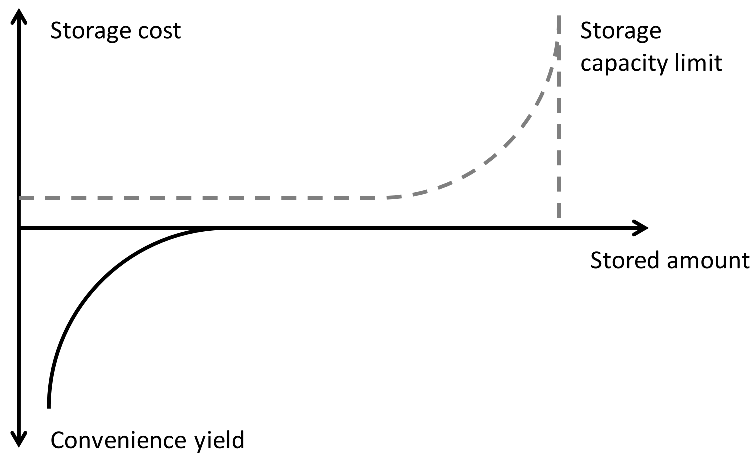


Figure 3.11: Storage cost and convenience yield compared to stored amount

If on the other hand the inequality would be reversed and storage would be clearly unprofitable, we might think that there would be no storage at all. This is however not completely true as there are also other gains to storage besides price speculation. The so called “convenience yield” can be thought as a negative storage cost, and describes the benefit of having inventories to balance short term volatility. Inventories are crucial in doing business in the oil supply chain. To capture total storage costs/benefits, physical costs, interest costs and convenience yield can be simplified into net cost of carry $C^{\#}$. A further refinement to $C^{\#}$ could be including risk premia associated in holding inventories. (Hull 2003)

Investors balancing between storage decisions create equilibrium, where they need to be indifferent between storing and not storing. This can be formulated as

$$E_t P_{t+1} = P_t + C^{\#}{}_t \tag{12}$$

If this equation does not hold, investors will start exploiting the storage arbitrage and the market will bring itself back into equilibrium.

Storing oil is not the only way of profiting from price expectations. An investor could alternatively enter a futures contract with another investor, where oil is sold on a future date at price F_t. When such a contract is done through an exchange, both parties have to set aside funds as proof that you can fulfill the contract (these are called margin requirements). If the investor manages to buy a futures contract with a price that is less than the realized spot price in the future (subtracted with costs), he makes a profit. (Hull 2003)

As before, when other investors have the same information and expectations, the market balances itself into equilibrium, where investors are indifferent between entering a futures contract as a buyer or a seller

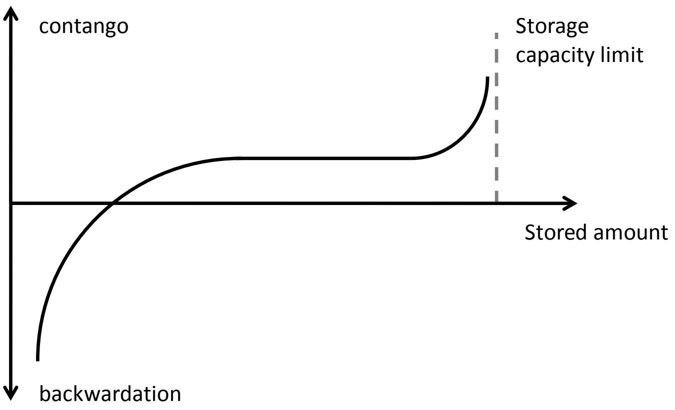
$$F_t = E_t P_{t+1} + H^{\#}{}_t \tag{13}$$

where $H^{\#}$ contains transaction costs, risk premium, and costs related to the marginal requirements.

Equilibrium in the storage market and the futures market are interrelated and are both required to hold simultaneously (Hamilton 2008). An increase in futures prices without an increase in the spot price for example, would allow an investor to store oil now and sell it on the futures market for a guaranteed profit. Thus, the storage would again continue until equilibrium is reached at

$$F_t = P_t + C^{\#}{}_t \tag{14}$$

This result would imply that futures prices are “naturally” somewhat higher than the spot price as long as net storage costs are positive. The net storage costs can be negative when inventories are low and convenience yield exceeds physical storage costs.



Picture 3.12: Equilibrium in contango and backwardation compared to stared amount

When futures prices exceed the spot price, the market is said to be in contango. The opposite of contango is called backwardation, in which the spot price is higher than futures. Because of unanticipated changes in oil supply and demand, the oil market shifts between contango and backwardation - high inventories and low inventories. This means that the market can be in equilibrium both in contango and backwardation, depending on storage levels and associated cost and convenience yield. If the equilibrium does not hold at some point of time, the market is again balanced as participants exploit the arbitrage to make profits. These short term movements are hard to anticipate long beforehand and generally are not seen as drivers for larger price trends. (ITF 2008)

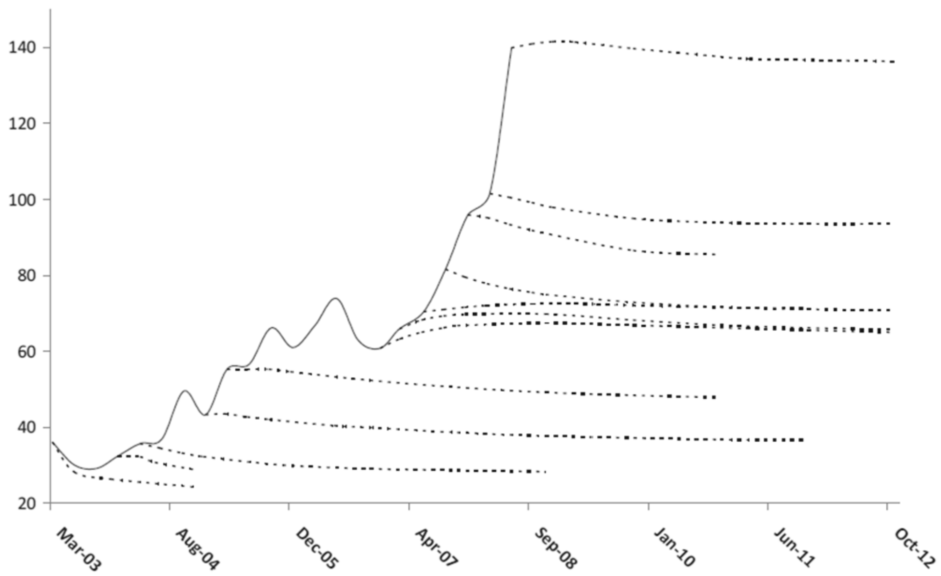


Figure 3.13: WTI futures' term structure (ITF 2008)

By looking at the term structure of crude oil futures, we can see that the changes in futures prices compared to the spot price are small, when compared to the spot price volatility over time. As the spot price rises, futures prices usually shift accordingly. This relationship has been studied extensively and Hamilton (2008) concludes that the spot price P_t is often found to be the best forecast for P_{t+1}. The described arbitrage between oil storage and futures is crucial in establishing the link between physical oil prices and prices of financial oil products. For this link to work, speculators are needed to provide liquidity and keep the markets in equilibrium.

3.4.2 Market bubbles

Previously introduced arbitrage conditions require all participants in the exchange to have homogenous information and act on it rationally. Diversion of these requirements or introduction of special constraints can lead to the market going out of equilibrium for a period of time. A longer disequilibrium, where the price continuously exceeds (or falls short) the asset's fundamental value, is often called a bubble.

Brunnermeier (2008) classifies market bubbles into four categories:

1. Bubbles where all investors are rational and have identical information,
2. Bubbles where investors have asymmetrical information,
3. Bubbles where rational and behavioral investors interact, and
4. Bubbles where investors have heterogeneous beliefs or "agree to disagree"

The first category is mostly theoretical, as constraints for bubbles under identical information and rational investors are not easily applicable to practice. In this case, a commonly known bubble will grow infinitely, which is possible only for certain assets. This rules out for example fossil fuels, as they have a backstop price at which substitutes become cheaper and demand drops to zero. (Brunnermeier 2008)

In the second category, bubble formation is based on asymmetrical information, and the existence of a bubble need not to be commonly known. An investor may realize that the value of an asset is not justified by its dividends, but he does not know if other investors know this as well. These kinds of bubbles also require certain constraints. Investors must remain asymmetrically informed also after witnessing asset prices over time. This means that prices can not contain all relevant information. For the bubble to persist there has to be also some constraints in selling or buying. Also there has to be doubt about the efficiency of the initial allocation, so that investors believe that there can be gains from trade. This kind of a bubble might form if a fund manager bought overpriced assets to make his clients believe that he has insider information. If other fund managers would not buy as well, it would seem to their clients as they had less information. This effect could be further enhanced if fund managers' compensation would not expose them to downside risks as much as upside benefits. (Brunnermeier 2008)

The third category deals with bubbles, which form in a market that has two types of investors: rational investors who act based on fundamental valuation, and behavioral investors who are affected by psychological motives. In an efficient market, the rational investors would exploit the arbitrage and stop a psychologically motivated bubble from forming. There are however many realistic risks to arbitrage, which allow a bubble to form. Fundamental risk aversion limits selling against the bubble, as there might be a simultaneous shift in the fundamentals towards the bubble leading to a larger loss than doing nothing. Another risk arises from noise traders, who may temporarily widen the mispricing. This is especially risky for fund managers, who have to be concerned also on short-run losses, as they may lead to fund outflows. This limits their willingness to attack bubbles. This is also why many arbitrage-based hedge-funds have lock-up provisions to stop fund owners from selling after short run losses. The third and maybe the most interesting arbitrage limiting risk associated to this case of bubbles is the synchronization risk. Investors gather and interpret information in search for bubbles and arbitrage opportunities. The process is however not completely identical, which leads to investors becoming aware of bubbles not simultaneously, but sequentially. Investors do not know if other investors are aware of the bubble and they have no means to credibly communicate about it. If none of the investors is large enough to attack the bubble alone, the only way to burst the bubble would be a coordinated attack. Thus, without coordination investors choose to "ride the bubble" as it is more profitable than attacking it alone. This can be also seen as one reason why seemingly insignificant news trigger large movements in asset prices: Investors take the news as a synchronization signal that they know others will recognize as well, and start trading against the mispricing. The same can be thought to apply for technical analysis. (Brunnermeier 2008)

The fourth category of bubbles form when there are heterogeneous beliefs about fundamental valuation. Investors agree to disagree about the pricing even though they have access to identical information. If short-selling constraints are introduced, bubbles may form as optimists drive prices up but pessimists cannot counterbalance them. In a dynamic setting, prices can rise even over the valuation of the most optimistic investor, if optimism and pessimism is assumed to shift between investors. According to a study by Scheinkman and Xiong (2003), short-selling constraints and investors with heterogeneous beliefs lead to high trading volumes and high volatility. (Brunnermeier 2008)

In his recent paper, Jovanovic (2007) presented a bubble that applies directly to the Hotelling's model. He used the example of high-end vintage wines, which behave like non-renewable resources. Jovanovic suggests that the market for wines can be in equilibrium while a price bubble sustained and some fraction of the stock continues to be traded infinitely while consumption is low. In the oil market however consumption is relatively high compared to storage and oil in the ground is not traded back and forth. The theory might still be more relevant when closer to the moment of resource exhaustion.

Bubble formation has been studied with empirical data and laboratory tests. Using real market data has not given conclusive answers. Rejecting the hypothesis that a bubble exists has been as hard as proving that one does not exist. Experiments in controlled laboratory environment however, have revealed much about bubble formation. Results with human test subjects differ strongly from theoretical predictions. Test subjects participate in trading actively, even if there is no fundamental reason or information asymmetry. Bubbles emerge even in tests with business professionals as subjects who are allowed short-selling. Only a futures market and repeated tests reduce observed bubble formation. These test results support the view that even experienced people are not always rational investors and do not actually rely on backward induction in decision making. The practical implication from this is that also real markets are likely to experience bubbles. (Brunnermeier 2008)

In the case of oil prices a price bubble has often been suspected. However, we should note that oil has no dividend streams, and does not generally return to the market to be resold. In this sense the concept of a bubble is valid only to those who do not take part in the production or refining of physical oil, namely speculators and arbitragers who invest in futures or physical storage. Thus a bubble would be formed between futures prices and the spot price. The oil market indeed seems to share many characteristics with the before mentioned bubble models. Information about fundamental oil drivers, such as capacity and production costs, is not reliably available, and is further made more complicated by political decisions and sometimes unpredictable use of market power. As all information is not available, many explanations about oil prices have formed, and they coexist amongst the market participants.

In this sense many oil investors agree to disagree about fundamental valuation. Especially in the past few years, the oil market has seen increasing volumes and large volatility, which also fit the theoretical prediction of a heterogeneous belief bubble.

As mentioned before however, the oil market is constrained at the spot by physical limitations: If the spot price included a bubble and actual demand would be lowered, oil storage should increase accordingly. On the other hand the oil futures market makes it possible for speculators to take positions in oil even though they never take part in physical delivery. It is thus often suggested that speculators could sustain an intentional bubble by using futures contracts. This argument contradicts with the arbitrage linkage of futures and storage that was presented earlier. Transferring the bubble to the spot price would still have to change inventory levels in most cases. I will look into evidence of this kind of speculation in the following subchapter.

3.4.3 Evidence of speculation

Speculators in the oil market are investors who do not do business with physical oil. They only care about changes in the value of oil-derived securities in comparison with their holdings. The amount of speculators in the oil market has risen significantly in the 21st century. The increase was largely due to the increase in index trading. Index traders diversify their holdings into different asset classes, oil being one amongst many. They are generally always in a long position and expect prices to rise or they exit the market. According to Masters (2008), assets in funds investing in commodity index trading strategies have risen from $13 billion at the end of 2003 to $260 billion on March 2008. These strategies are executed by holding near-term futures contracts and selling them before their expiry date. The revenue is then used to buy new futures from the following month, and the strategy continues. This is sometimes called “rolling futures contracts”.

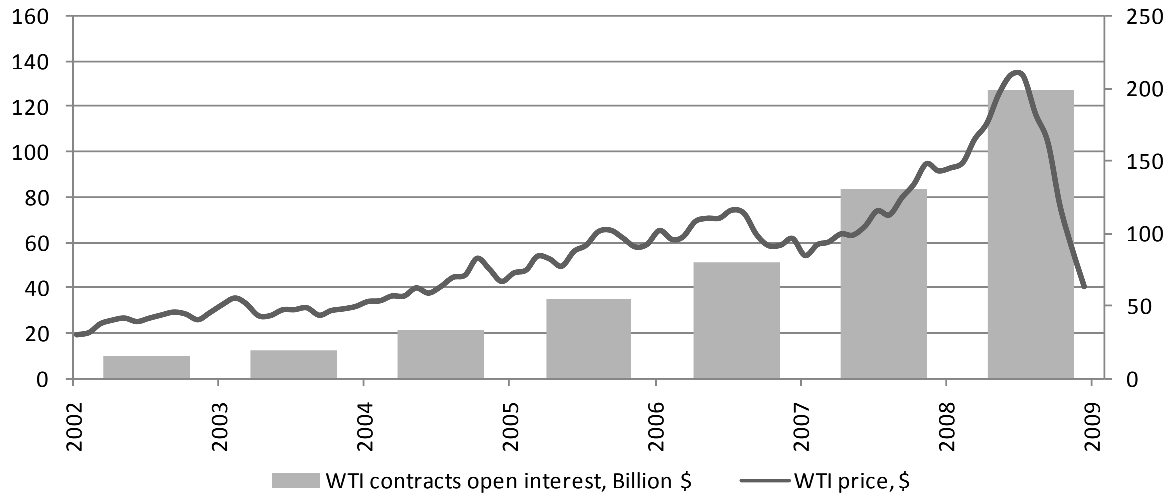


Figure 3.14: WTI contracts open interest compared to prices at NYMEX 2002 – 2008 (data: Masters 2008, BP 2008)

While index traders are in long positions, there has to be always an equal amount of short positions from other market participants, as the futures market is a zero-sum-game. If rising volumes on the buy side would drive futures prices up against fundamentals, there would be many sellers benefitting from the situation when storage arbitrage delivers profits and the bubble bursts. As with bubble theories in the previous subchapter however, this kind of a situation could last for some time as arbitrage may be limited by risk aversion and uncertainty about information. A positive bubble in futures prices should still not lead to an increase in spot prices, but an increase in oil storage. Borenstein (2008) calculates that a 30% increase in oil prices would require storing 3% of global oil supply. There is no evidence of this so far. It is still good to note that only a fraction of global oil inventories are reported publicly.

According to Hamilton (2008), there is a case in which a futures bubble could lead to spot price increases with no clear storage effects. This would be, if the spot price was completely price inelastic in the short run. Then an increase in the futures price would increase the spot price with the exact same amount. This would indeed make “rolling futures contracts” profitable as an investment and lead to an expanding bubble. In the theoretical situation of zero price elasticity however, the concept of a bubble does not make much sense. When higher prices do not affect demand, then the high price is the price that makes supply and demand match and the market is thus in equilibrium. I will return to the price elasticity of oil demand in the following subchapter, but it is good to consider that while elasticity is unlikely to be zero, very low elasticity may lead to inventories accumulating slower and arbitrage to be less efficient.

In a report by the Cabinet Office of the United Kingdom government (2008), another mechanism is suggested for transferring futures bubbles to the spot market. The report states that in tight market conditions it might be possible to drive prices higher by only having the possibility to store oil. The logic is that existing storage capacity would allow the seller to effectively use negotiating power in a situation where market prices are expected to rise, without ever having to actually use the capacity and increase storage. While there is no evidence supplied about this mechanism, it sounds theoretically plausible to some extent.

The role of speculation in oil prices has been studied by many market organizations, most notably recently the Commodity Futures Trading Commission (CFTC) of the US government, who monitors derivatives trade at NYMEX and other exchanges alike. The CFTC gathered a task force (Interagency Task Force, ITF) from different US government market regulation and energy agencies and assigned them to study speculation on the crude oil market. The ITF released an interim report of their findings in July 2008, before the price collapse of the same fall.

The report also underlines the fact that the amount open futures positions have significantly grown during the past years. Most of the growth has been due to activities by non-commercial market participants. Open interests of producers and manufacturers have not grown notably in the same time period. However, according to the report, the net long position of speculators relative to the market volume has remained steady. This could be interpreted as speculative positions being “natural” in this kind of growth. Also, most of the growth by speculators has been exhibited in spread positions, which take views on relative prices, not absolute price levels. As noted before, if the oil market would continuously divert upwards from its spot market equilibrium, there should be evidence of inventory accumulation. During the strong price growth of the past five years, inventory levels have however declined instead (ITF 2008).

The ITF report goes further and utilizes causality test, to study if position changes of different groups of market participants have preceded or succeeded price changes. This is done in order to find out if different investors indeed succeed in manipulating the price by their behavior, or take price changes as new information and adjust accordingly, as we would expect from a functioning market.

While non-commercial traders (or speculators), have correlated positively with prices, it does not prove that the direction of the causality. The causality tests do not show any significant results of position changes leading to price changes. Most groups of market participants however show significant signs of changing their position after price changes. Commercial participants seem to move towards the price change. Hedge Funds, maybe the most known speculators, on the other hand move significantly against price changes, as we might expect from an active arbitrager.

The report concludes that the price increases in the past five years are due to fundamental factors such as demand and supply developments, currency movements and market structure. According to the report, the fundamental price increase has increased interest in oil futures, thus explaining the significant volume increases. The role of speculative price manipulation is dismissed in the light of causality test results, but because of some limitations in the data and tested causalities speculation cannot be completely ruled out.

Recent price drops in the oil market have changed the picture a lot. Unfortunately the ITF (2008) report hasn't been followed up with positions and causalities in the price crash. Public evidence so far does not indicate that funds or financial institutions would have benefitted from the crash. The observation that no one generally benefitted from the crash, does not necessarily mean that there was no bubble. It merely suggests that if there was a bubble, it burst unpredictably and not by a successful attack by the speculators. It could also be possible that there was an unintended bubble element in the price resulting from heterogeneous beliefs as mentioned earlier. The price crash may have also been somewhat exaggerated because of forced selling of all asset classes, including oil derivatives, by many investors in search for liquidity.

In the light of current evidence we cannot conclude that the price increase and subsequent crash of the past five years would have been mainly a result of a speculation in oil prices. Positions in the futures markets and especially oil inventory changes do not support a bubble explanation. The possibility of extremely low price elasticity combined with storage owners' successful bargaining still remains and may have had some effect. As I will further describe in the following subchapters, the price changes were more likely mostly result of fundamental issues that were at least temporarily solved by the bursting of another bubble, namely in the private loan markets.

3.5 Short run equilibrium and inelasticity

Recently some academic and industrial sources (for ex. Hamilton 2008, IEA 2008) have suggested that the recent price increase and the even faster crash were not primarily results of producers' use of market power nor speculators' distortion in commodity exchanges. Instead price changes are explained to a large extent by the unique characteristics of the oil market, which derive from supply and demand fundamentals. As we have seen, even as prices increased almost four fold, demand did not decrease significantly, but also there were not large production increases either (EIA 2009). This sort of inelasticity in both supply and demand allow severe price volatility, while the market is in principle functioning well. I will go through aspects of the oil market that lead to its short run inelasticity.

3.5.1 Production capacity

If oil demand for some reason increases, or there is some external factor that requires production to grow, it would be natural to expect that producers increase production to match the demand. Lead times in new oil projects are however very long. It takes years for initial discoveries to be developed into producing oil fields. This means that on the short term, producers can only increase their production within the limits of existing capacity. With the high prices of recent years however, most producers seemed to have practically zero excess capacity left.

Many sources (for example IEA 2007) divide global oil production capacity to non-OPEC countries who are expected to meet demand as well as they can, and to OPEC countries who decide how much of their capacity they use to achieve a desired global price level. The part of demand that cannot be matched by non-OPEC countries is called "call on OPEC". The used term already reveals an underlying assumption that OPEC countries would have excess capacity available.

Until the recent price crash, excess capacity all over the world had been diminishing for many years. As I noted before with OPEC, Saudi Arabia has long been the only country with potential to quickly increase production significantly. In practice all increases in the "call on OPEC" were to be compensated by the Saudis if prices were to be kept stable. The Saudis have often voiced that they are committed to keep oil prices on a reasonable level (OPEC 2008), but as prices continued to rise it started to look like even the Saudis had no more capacity available to balance the market. This led to more and more expensive capacity to be taken into use, which contributed to higher prices. It would have been interesting to see how the situation would have continued in the following years, if the economic downturn had not taken the prices down.

The highest observed prices of year 2008 need not to be completely explained by production costs. In the event of a supply crunch, where production fails to match inelastic demand, prices can rise high as explained earlier. In that situation the temporal scarcity increases the price easily above any marginal costs as buyers are bidding for the limited supply of oil. If such situation persists however, substitution and arbitrage based on increasing production in the future should balance the market.

There are many explanations to why production capacity was unable to keep up with the growing demand in the past years, and I will look into them in the next subchapter with long-term prospects.

While increasing production to meet increasing demand has been hard, decreasing should always be easier. Recent evidence (EIA 2009) however suggests that oil is accumulating in storage as crude oil production significantly exceeds shrunken down demand. The reason why production is not being turned down is probably not related to technical issues, but to national budgets and politics. The public spending of many oil exporting countries is dependent on oil incomes. During the recent years national budgets were planned based on high oil prices. The increased income allowed many countries to expand their public sector, demonstrate military strength and gain regional influence.

Table 3.1: Oil prices that would balance exporters' national budgets in 2009 (Data: IEA 2009)

Country	Oil price, $
Venezuela	97
Nigeria	71
Russia	70
Saudi Arabia	62
Iran	58
UAE	51
Kuwait	48
Algeria	35

As prices have dropped, these countries need to sell as much oil as possible to get even close to their budget goals. Discounting possible higher prices in the future is not political reality because decision makers face domestic short term obligations, such as public sector wages and import payments. At uncertain economic times discount rates are higher thus also practically favoring producing rather now than later. As long as the oil price does not drop below their marginal costs, it is not in any exporter's interest to unilaterally decrease production. So far OPEC has not been able to coordinate any significant decreases since the price drops. In a way the situation corresponds to a classical prisoner's dilemma, where non-compliance to OPEC agreements would yield significant short-term gains.

At the time of writing, OPEC has announced large production cuts and there are some reports based on tanker movements that indicate actual significant decreases in OPEC production. The ability of turning prices back to an upward trend may well turn out to be the best evidence of OPEC's current market power, or the lack of it. This paper however will not reach long enough to see the results.

3.5.2 Demand reactions

As mentioned in chapter 2, transportation makes up over 50% of global oil demand. In the short term, there are practically no substitutes for oil in transportation. Individuals use transportation for many purposes, none of which they easily give up. Commuting and daily tasks account for most of the individual oil spending, but in the developed countries also leisure activities have a fair share. The share of oil expenditures in total income is however not large in the western world, and has been diminishing over past decades (EIA 2008). As oil prices went up, private consumption remained almost unchanged. While some people were thinking about reducing consumption, they had made many commitments to oil. Buying a smaller car, moving closer to the workplace or rearranging leisure activities and holidays can all be done, but are not worth the saving for everyone, and do not happen very quickly anyway. In many developed countries, such as EU members, retail oil products are also taxed so heavily, that changes in crude oil prices do not have the same magnitude on consumers as they have on the crude oil market.

In developing countries oil prices would have struck harder as the income share of oil is also higher. It is important to note however, that in many developing countries oil prices are subsidized by the government. This is true especially for China, which was the leader of the demand increase of the past decade. Governments of course paid (at least in the form of alternative income) for the subsidies, but they were not lowered even with high prices (EIA 2008), as cheap oil was seen as a crucial ingredient for economic growth and the investment in subsidies would thus pay off.

Transportation for commercial purposes felt the increase in prices heavily, as fuel costs are very significant for the transportation industry. Many companies faced financial difficulties, but a large part of the risen fuel costs were transferred to transport prices. This then became a burden for consumers in the form of higher prices for food and some other goods (EIA 2008). While the transportation industry reacted to the rising oil prices, it did not directly lead to less demand.

As described earlier, the other large oil consuming sector is industry, with an over 30% share of the world oil demand. Oil price increases of recent years hit the industry as well. Rising costs were transferred to prices to a large extent, thus again delaying price reactions. Unlike with transportation, many industrial processes can technically substitute oil for natural gas or even coal. Still it requires investments and long lead times. Also as with consumer incomes, oil costs are not a significant factor in many industrial companies.

The recent oil price crash was triggered by a sudden decrease in demand caused by a global economic downturn. Market evidence shows that the spot demand has (EIA 2009) decreased significantly. As this shock is exogenous from the perspective of the oil market and affects the whole economy, it is hard to separate price elasticity effects from demand decreases caused by crisis. While oil is now cheaper than in 2004, demand is not increasing, because demands for goods that oil is used for or transported with are expected to decrease as well as demand for personal transport. It will be interesting to see, how the economic crisis affects oil demand in the coming years. I will return to demand growth on the longer term in the next subchapter.

3.5.3 Empirical observations of short run elasticity

Elasticities are hard to determine empirically, as the only observation is the equilibrium price at a given time. Separating factors behind changes in both supply and demand is practically an impossible task. Some unique global events however allow economists to reveal price movements that can be considered resulting from an isolated factor. Hamilton (2008) takes an example from the turn of the 1980's, when first the Iranian and then Iraqi oil production dropped heavily due to the Iranian revolution and the following Iran-Iraq war as described in chapter 3.1. This led to a logarithmic oil price increase of 81,1% and a decrease in US oil consumption by 16,0% while the US GDP increased by 5,4% at the same time. From these figures, a short run demand price elasticity of -0,26 can be estimated.

In the 21st century, before the recent crash, oil prices increased much over 100% but the US oil consumption actually increased as well. While it is hard to say any numbers, it seems reasonable to assume that the short run price elasticity of demand is now even less than in the 1980's. This has been also suggested by other sources. A study by Hughes, Knittel and Sperling (2008) on US gasoline prices estimates, that while short run elasticity of demand was around -0,21 – -0,34 between 1975 and 1980, it was only -0,034 – -0,077 between 2001 and 2006.

Low price elasticity makes prices very volatile to any changes in the market equilibrium. Events like the current global economic crisis change demand and the price has to change sometimes extremely to stabilize the market. The same kinds of effects were seen for example when King Faisal used the "oil sword", decreased supply, and sent oil prices soaring as described in the history part. If demand stays inelastic for many years, prices can rise relatively quickly also without any surprising global events, as we saw during the past five years.

When looking at a longer period of time, demand becomes more elastic, as consumers and industries adjust their consumption and seek for alternative sources of energy and raw materials. Supply also responds as new investments come on line, and producers plan for coming generations according to Hotelling's principle. In the next subchapter I will look into the market equilibrium in the long run.

3.6 Long run equilibrium and dependence

We might argue that the price changes we've seen in the past five years are natural consequences of an (albeit strong) economic cycle. The inelastic nature of the oil market just caused it to react to the cycle rather violently.

On the long run the market becomes more elastic but also new constraints come into play. Large scale substitution and physical limits of oil reserves shape the long run price path. In this chapter I will look into longer term supply and demand drivers to better understand where the market might be heading.

3.6.1 Supply development

From the beginning of the oil industry up until the turn of the millennia, oil production has been able to keep up with increasing oil demand. Many oil fields have dried down, even many oil producing countries have seen their aggregate production turning into decline, but on a global scale new relatively cheap reserves have always been found to compensate declines elsewhere. During the price increase of the past five years however, it seemed that all production capacity was at use.

It is important to note here that producing at full capacity is often damaging to the oil field, as mentioned earlier in the market description. Overproducing may lead to unwanted movements of water inside the well and lead to lower amount of oil ultimately recovered. In this sense long term capacity should not be seen as the amount of built wells pumping at full speed, but as the rate that is sustainable for a long period of time and maximizes ultimate recovery.

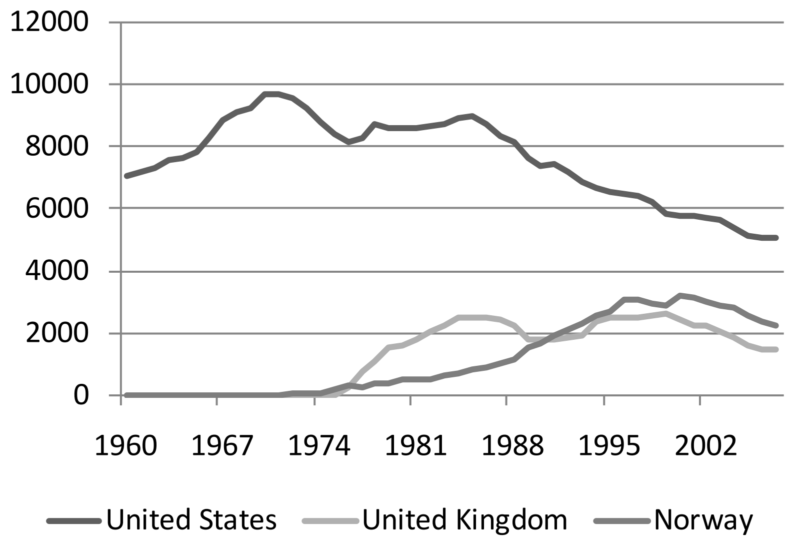


Figure 3.15: Developed oil producer's production decline (data: IEA 2007)

As mentioned, many countries' production has turned to decline. This has been especially true for developed economies, maybe because oil has been searched and found there early. The production in United States reached its highest point already in 1970. Reserves in the North Sea reached their production highs in 1999 and 2000 for the United Kingdom and Norway, respectively. Production in Middle East has been able to increase so far, but its sustainability is a big question. Simmons (2005) has studied Saudi Arabian oil fields extensively and concludes that production is likely to turn into a decline very soon, if it has not already happened. Indeed, during the high prices of past years Saudis didn't manage to increase their production, but it in fact decreased for some periods. Simmons also suggests that oil reserve sizes in the Middle East are significantly exaggerated.

Reserves, as well as production rates to some extent, are also a matter of price. With high oil prices it is economical to take some new reserves into production, which would not have been profitable before. New production is coming on line all the time, but the question is if it comes fast enough to keep up with growing demand.

After oil fields reach their highest production, they start to decline, at a relatively stable rate. These decline rates are usually observed at around 6% to 8% per year (IEA 2007). The observed decline however includes continuous investments to keep pressure up and purify the degrading oil. The International Energy Agency (2007) estimates that natural decline rates, with no investments to new technology are on average 10%.

Table 3.2: Oil investment projects coming on line in the next 10 years (data: Oil megaprojects 2009)

(thousands of barrels per day)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
OPEC												
Saudi Arabia	1150	670	365	300	330	250						3065
Angola	130		335	395	525	140						1525
Iran	115	95	255	210		530	240					1445
Nigeria	205	240	459	250	150							1304
Qatar	505	280	170	135								1090
Iraq	60	200	150		200							610
UAE	20	210	75				200					505
Algeria	100	50	190	40								380
Venezuela	75		200									275
Other OPEC	105		175	110	190							580
Non-OPEC												
Canada	100	215	125	300	185	350	210	245	162	180	50	2122
Brazil	200	460	280	200	380	300	100					1920
Russia	570	310	415	360	15							1670
Kazakhstan				300	380			850				1530
USA	335	180	110	120		150	200					1095
Norway	100	190	85	125								500
China			20	200	80							300
Mexico	173		51	74								298
Other Non-OPEC	402	560	275	140	110	100	305					1892
World total	4345	3660	3735	3259	2545	1820	1255	1095	162	180	50	22106

The above table is from an open source project that tracks oil investment plans around the world. As the table shows, there are many large ongoing investment projects to new oil production capacity. With the above table and a rough decline estimate of 5% we can calculate that global capacity will start declining after three years. Thus new capacity will be coming on line in future years to at least partly offset declining current capacity and to answer to the eventually growing demand, but it is hard to anticipate, if current investment rate will continue fast enough in the future with new projects. Current uncertainty about price and demand development has stalled many projects, and the investment environment has at least temporarily deteriorated significantly (EIA 2009). The figure below further illustrates this issue by comparing the planned capacity upgrades with the EIA (2009) long term demand forecast. The forecast takes the current economic slowdown into account and we can see that there is a large gap that needs to be filled with future investments.

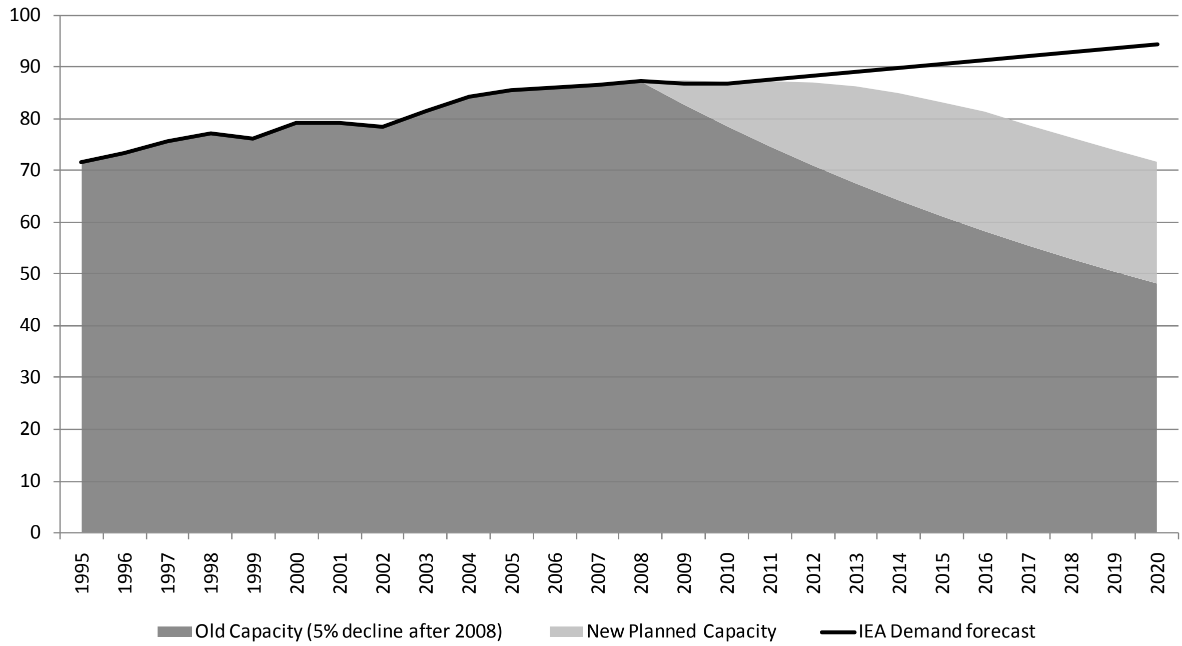


Figure 3.16: New oil projects are replacing old capacity and trying to meet growing demand (data: Oil megaprojects, IEA 2009)

As mentioned in previous chapters, more recent oil field discoveries have been in difficult locations and of lower quality. This means that extraction costs for new oil fields are generally higher than for older ones in for example Middle East and Texas. Average and marginal extraction costs are trade secrets of oil companies, but many cost estimates exist. It is generally accepted that producers in the Middle East have the lowest production costs. Marginal producers' cost estimates with current production range from \$50 to \$90 per barrel depending on the source and level (for ex. IEA 2007). For the oil price, only marginal producers matter, as they will set the fundamental price level.

The current situation might work as a reference for figuring out marginal costs. In January 2009, the prices of WTI and Brent have stabilized to around \$40 to \$45, with production and demand somewhat less than a year before. As financial asset markets around the world have crashed, accusations of speculative price bubbles have disappeared. It is reasonable to assume that price is at least close to supply/demand fundamentals. This is not necessarily contradicting previously mentioned higher marginal costs, as production has decreased, and inventories are currently much higher (actually at record highs, EIA 2009) than at the time those estimates were made. From this we can make an educated guess that we are in a part of the supply curve where it quickly gets steeper. As discussed in the previous part, the steepening may be really rapid on the short run, if inventories are low and there is not much excess capacity available.

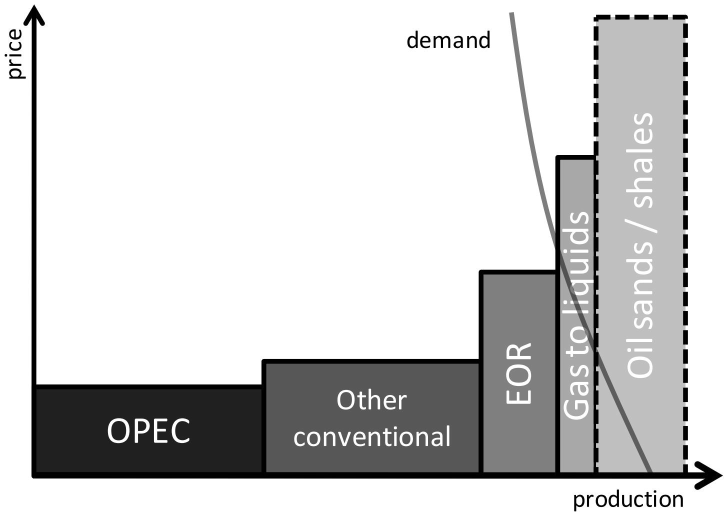


Figure 3.17: Hypothetical oil supply curve

The figure above sketches the marginal cost structure of oil production based on current existing and planned capacity. It divides production into a few categories based on marginal costs. It also visualizes that there is undoubtedly much more oil left to be produced (even much more than the figure shows), but it will get increasingly expensive. Additionally, as cheap oil fields are already in a mature phase and newer fields are more expensive, the supply curve will start moving to the left as the leftmost parts get smaller. This will shift the equilibrium to a steeper part on the curve, which then leads to higher prices. An additional issue with more expensive unconventional sources is that while their reserves are plentiful, the achieved production rates per reserves are low because of required time consuming processing (Simmons 2005).

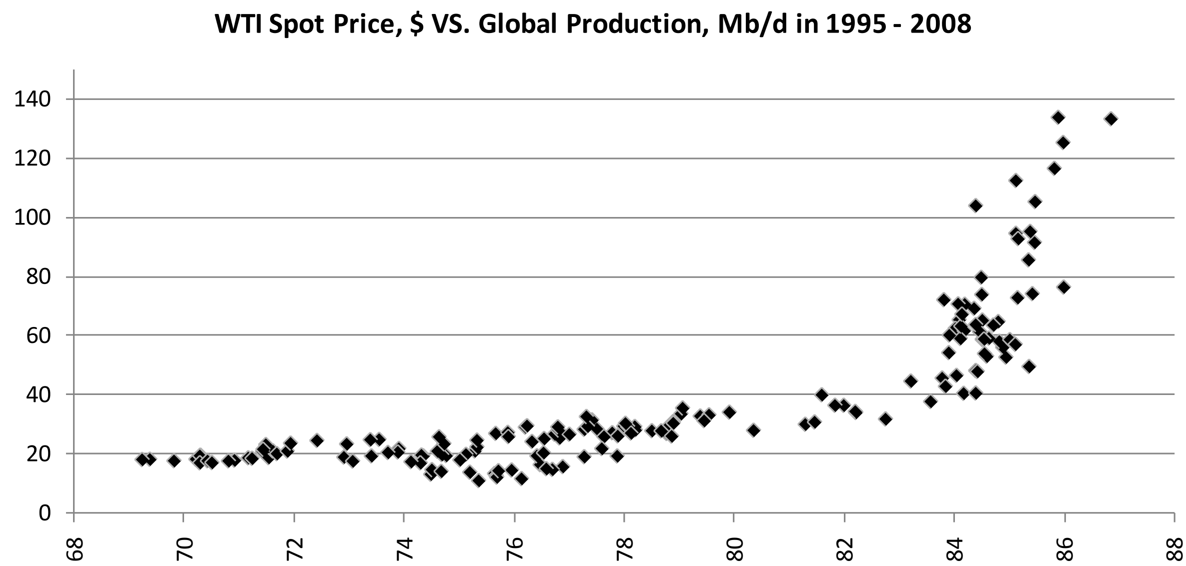


Figure 3.18: Guessing a supply curve based on historical price/production (data: EIA 2009)

One way of trying to guess a supply curve is plotting historical prices against historical production-figures as is done in the above figure. While this is not econometrically sound method, it gives some hints on the curve. If we forget all other factors for a moment and look at the figure, it seems as the first 83 million barrels per day are relatively cheap to produce, but it gets quickly much more expensive after that. Of course there are many things between production and eventual prices as described before and on the long run the market will become more elastic.

Grim analyses of the future of oil supply were much more popular when the prices were high. Still, unless long-term demand growth decreases, new cheap oil fields are found, extraction technology is significantly developed or cheap substitutes arrive, we will likely see high oil prices in the future as well.

3.6.2 Demand development

On the long run, oil demand is largely driven by the same drivers as economic growth in general. The basis of long term oil demand forecasts is thus in GDP and population growth. As mentioned in the second chapter however, oil intensity of GDP tends to fall as countries get more developed. This is through increased efficiency in industry and reduction of relative transportation spending.

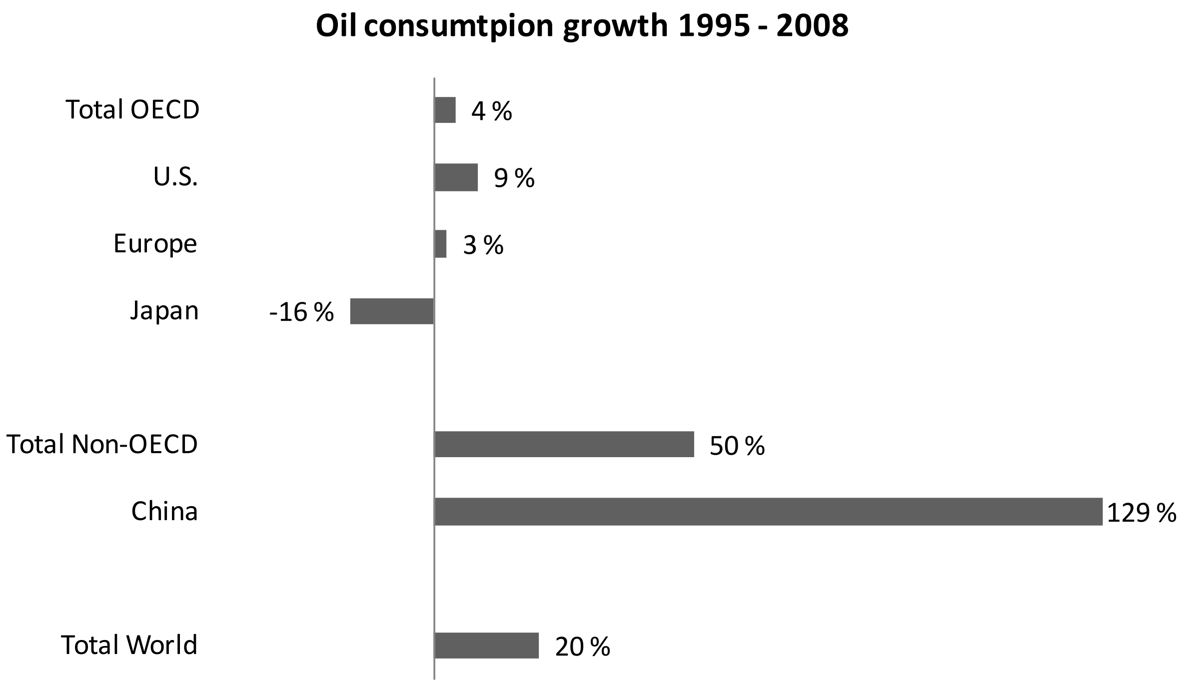


Figure 3.19: Oil consumption growth rates from 1995 to 2008 (data: EIA 2009)

As the above figure shows, demand growth has been relatively low in OECD countries with Japan as an example of significant demand reductions. Developing countries on the other hand are still on a strong growth track with China as the extreme example increasing oil demand almost 130% in 13 years.

The EIA (2008) estimates that global oil demand will grow on an annual rate of 1,2% until 2030. Their estimate for total energy demand growth in the same period is 1,6%, which means that the relative share of oil will drop. This is explained by industry switching to relatively cheaper coal and natural gas, whose demand is forecasted to grow more than the average (these commodities also have same kind of constraints as oil, but the dynamic relationship falls beyond the scope of this paper). This shift has already been happening gradually for some time and shows that on a longer run the industrial demand is indeed rather price elastic.

The key issue of oil demand also in the coming decades will be transportation. Even though not as inelastic as in the short run, forecasts (IEA 2007, EIA 2008) do not see transportation declining significantly even with sustained periods of high prices. As mentioned several times before, unlike the industrial sector, transportation does not have easy substitutes in sight. Also subsidies in many developing countries distort the price impact on consumers, thus making the price more inelastic. If oil prices increase back to last year's levels for a longer period of time, subsidies will become expensive to sustain and also demand will start reacting to the price.

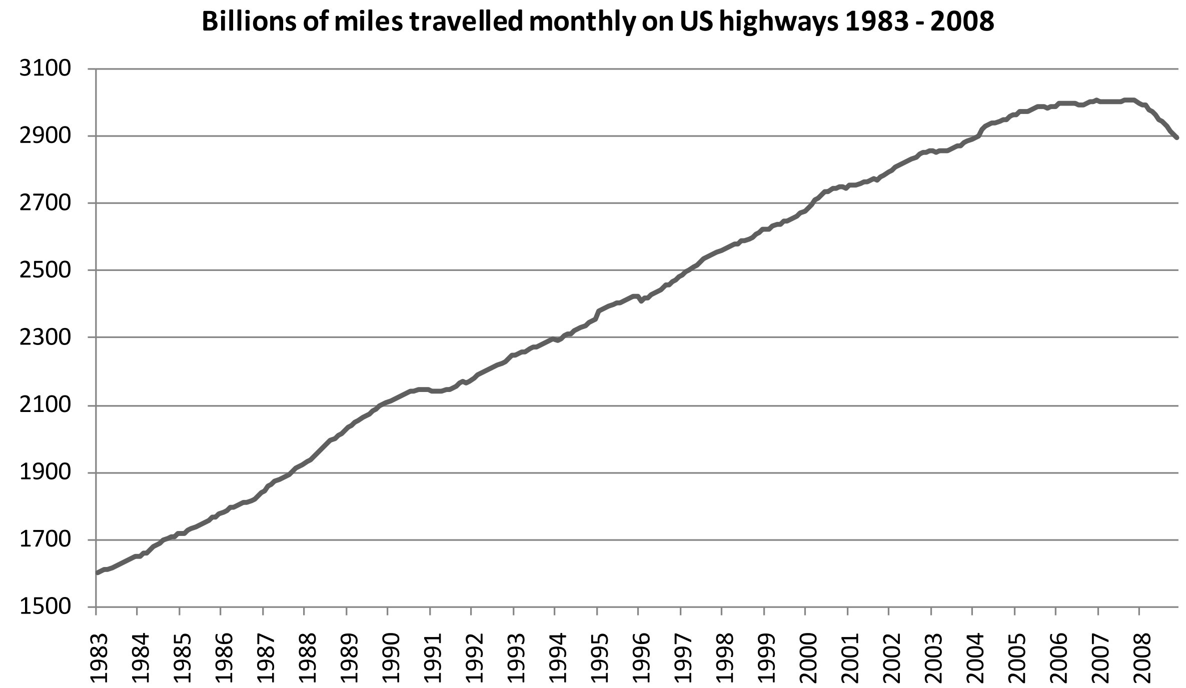


Figure 3.20: Billions of miles travelled monthly on US highways 1983 – 2008 (data: US department of transportation 2009)

The above figure is a good example of eventual elasticity in transportation. Although the very last portions of the curve were probably more affected by the economic slowdown, high oil prices were undoubtedly a factor in decreasing driving growth that had grown steadily for at least twenty five years. Despite some elasticity, it is clear that the whole global transportation system is dependent on oil on almost all levels. The only way to ease the situation is to find efficient and economical substitutes.

3.6.3 Substitutes

As mentioned above, industry has many substitutes for oil. Plastics and chemicals can be made from natural gas or even coal. Other industrial processes use oil for creating heat, which can be done with even a larger variety of substitutes. The transportation segment on the other hand does not have the flexibility, but substitution in other industries makes more oil available for transportation at lower prices (Mitchell 2006).

Oil will eventually be substituted in transportation as well. The question is if it will happen because future high prices make current substitutes desirable or because of breakthroughs in technology that make substitutes competitive also with current lower prices. Oil dependence in transportation can be divided into two issues. The first one is the direct dependence on oil as the fuel for internal combustion engines. It requires liquid oil-based fuel available around the world. It also makes Western economies dependent on the Middle East and other oil exporters. Development of electric engines running on a battery or hydrogen presents a possibility to break free from this dependence. Batteries can be charged or hydrogen produced with electricity, which can then be produced in many ways.

This is where the second dependence issue arises: even if we managed to make transportation directly independent of oil as a fuel, we still need to produce the energy somehow. Using other depletable resources such as natural gas or coal would just move the same long-term problems between similar commodities. Also producing electricity from fossil fuels centrally does not necessarily provide better efficiency than individual engines. In the case of hydrogen cars it actually reduces energy efficiency (EIA 2008). Other forms of electricity generation, such as nuclear power, hydro power or wind power are either physically constrained, more expensive, or both and thus cannot substitute for oil with current prices and technology.

Because transportation is truly addicted on oil, many policy efforts have aimed at reducing the dependency gradually. Subsidies on biofuels production have increased fuels' supply with more neutral environmental effects. Biofuels are still a very controversial solution as they compete for the same agricultural land with food production. Another solution, and the most reasonable for many reasons, is increasing the efficiency of transportation. Fuel efficiency has large variations between countries and is not necessarily correlated with standards of living. Cars in the United States consume on average almost double the fuel per kilometer as cars in Italy do (IEA 2007). This is a good example of significant efficiency gains that could be achieved by regulation without new innovations or costs. Consumer attitudes play also a large role here. With high oil prices in the past few years, fuel efficiency and electric vehicles gained much public interest. Hybrid vehicles gave an example of fuel efficiency that was economically sound, and while still running on oil they contributed to research for less direct dependence in the future. With the current economic crisis and cheap oil, talks about new (expensive) car innovations have faded to the background. There is a vicious circle: Without necessary changes in oil consumption structure we cannot restrain demand growth and achieve lower prices in the long run, but without high prices there might not be enough political momentum to get the changes going.

The mentioned challenges are real and large, but not unimaginable. One of the biggest problems in the vision of oil independent transportation is its adaptation in the developing world. While a population of electric cars running on centrally produced fusion power is a possible scenario in OECD-countries during this century, it feels very hard to imagine in the developing world. Changes like these take a very long time and during that time we may hit many new oil price spikes with their adverse side effects.

3.6.4 Producers' incentives

With the previous subchapters in mind, it is worth to think about the issues from the producers' point of view. As they are fully aware of the challenges involved, we should assume that their long term behavior is somehow affected. As we saw in an earlier part of this paper, fully competitive markets for exhaustible resources should already lead to increasing prices based on the Hotelling's rule. The use of market power leads to different price levels and time-frames but does not change the main idea.

According to Hotelling's rule, supply decisions are made by maximizing the present value of all future oil incomes taking into account alternative investments. This requires rationality and a time-frame lasting the whole life of the reserves. In reality decisions are affected by shorter term issues, which are often also of political nature as most reserves are controlled by governments. Corrupt politicians may maximize oil incomes for the current regime, or use oil to gain political power. This can range from gaining personal influence to practicing international extortion. Even honest politicians face challenges trying to balance trade accounts and national budgets as noted before.

It is unlikely that real world decision makers operate in a time-frame spanning over several generations and discount their wellbeing fairly. This is especially unsettling for many developing countries, whose economies are dependent on oil incomes. Being short-sighted could seriously harm the future generations. If decision makers do not consider future generations to be equal, they choose a higher discount rate for their Hotelling price paths. This leads to resources being exhausted faster, as seen in chapter 3.3.

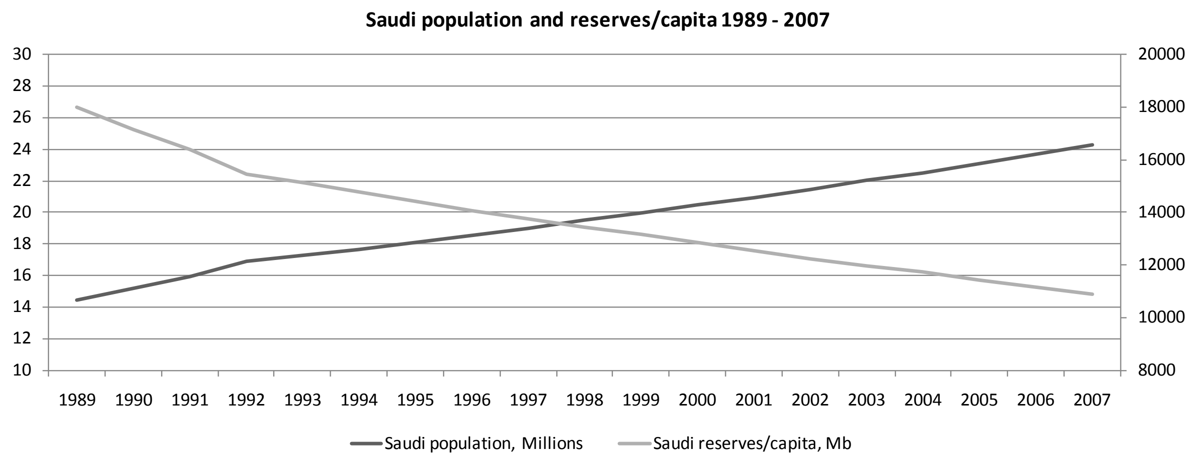


Figure 3.21: Saudi Arabia's population and reserves/capita (data: IEA 2007, IMF 2009)

Many developing oil exporting countries have experienced a population-boom alongside the oil-boom. In Saudi Arabia the purchasing power corrected GDP/capita has actually decreased during the past 20 years. Worries about future generations are thus clearly justified. In April 2008, According to the official Saudi Press Agency, Saudi Arabia's King Abdullah was quoted saying: *"I keep no secret from you that when there were some new finds, I told them, 'no, leave it in the ground, with grace from god, our children need it."* It may be that the events of the past five years were the first real global example of inevitable limits in oil production, and that producers are finally starting to take Hotelling's rule and eventual scarcity into account. On the other hand comments like these can be also political rhetoric with no real message. It will be interesting to see how the OPEC countries and especially Saudi Arabia will produce in the coming years.

One observation raises concerns of producers' different views of the world: reserves to production -ratios differ significantly between producers. Russia and Saudi-Arabia both produce approximately at the same rate, but according to their reporting Russia's proven oil reserves are less than half of Saudi-Arabia's (OPEC 2008).

Differing reserves/production ratios can be seen as results of different geopolitical aspirations, or just the undisputable dominance of Middle East. Still, also other possible conclusions can be drawn. The exhaustion rate can be seen as an indicator of the producer's view of the time crude oil has left as the world's dominant commodity. Saudis will exhaust their resources in almost 80 years at current speed, as Russia will spend less than 40 years, and the United States only 11 years (OPEC 2008). These numbers do not take into account oil field declines or discount factors, but still illustrate either differing strategies or short term thinking.

In a forthcoming paper Gerlagh and Liski (2008) present a theory that leads to a price path different from Hotelling. They describe a situation where a powerful seller and a dependent buyer bargain for a scarce resource. The buyer would like to switch to an abundant backstop resource, but the irreversible transition requires an investment and takes time to complete. Unlike the Hotelling's case, where resource supplies decrease as the price closes to the backstop, this situation makes the producers increase supplies and thus keeping prices lower than the scarcity rent would require, delaying the buyer's backstop investment decision. The buyer is compensated by lower prices, but will face increased scarcity when he eventually decides to start the time consuming substitution investment.

While this example is rather theoretical and does not directly apply to the real market, it bears many resemblances to the current situation. It also broadens thinking about motivations behind oil producers' decisions and raises serious concerns over oil scarcity in the future. If taking long term developments into account, producers have an incentive to keep consumers dependent as long as it is economically viable. This could be achieved by overproducing current production and misinforming consumers that reserves were abundant. As it happens, OPEC and especially Saudi-Arabia have been accused of doing exactly this. While the conclusion falls into the unscientific category of wild conspiracy theories and has no evidence to back it up, it still is an interesting thought.

4 Discussion

The price formation of crude oil is clearly far from simple. The basis for the price is formed by factors “below ground” – meaning scarce reserves, extraction costs and such. Still “above ground” factors, such as price subsidies, OPEC decisions and market distortions have a large role to play. Finally the end users set the demand based on their needs and alternatives.

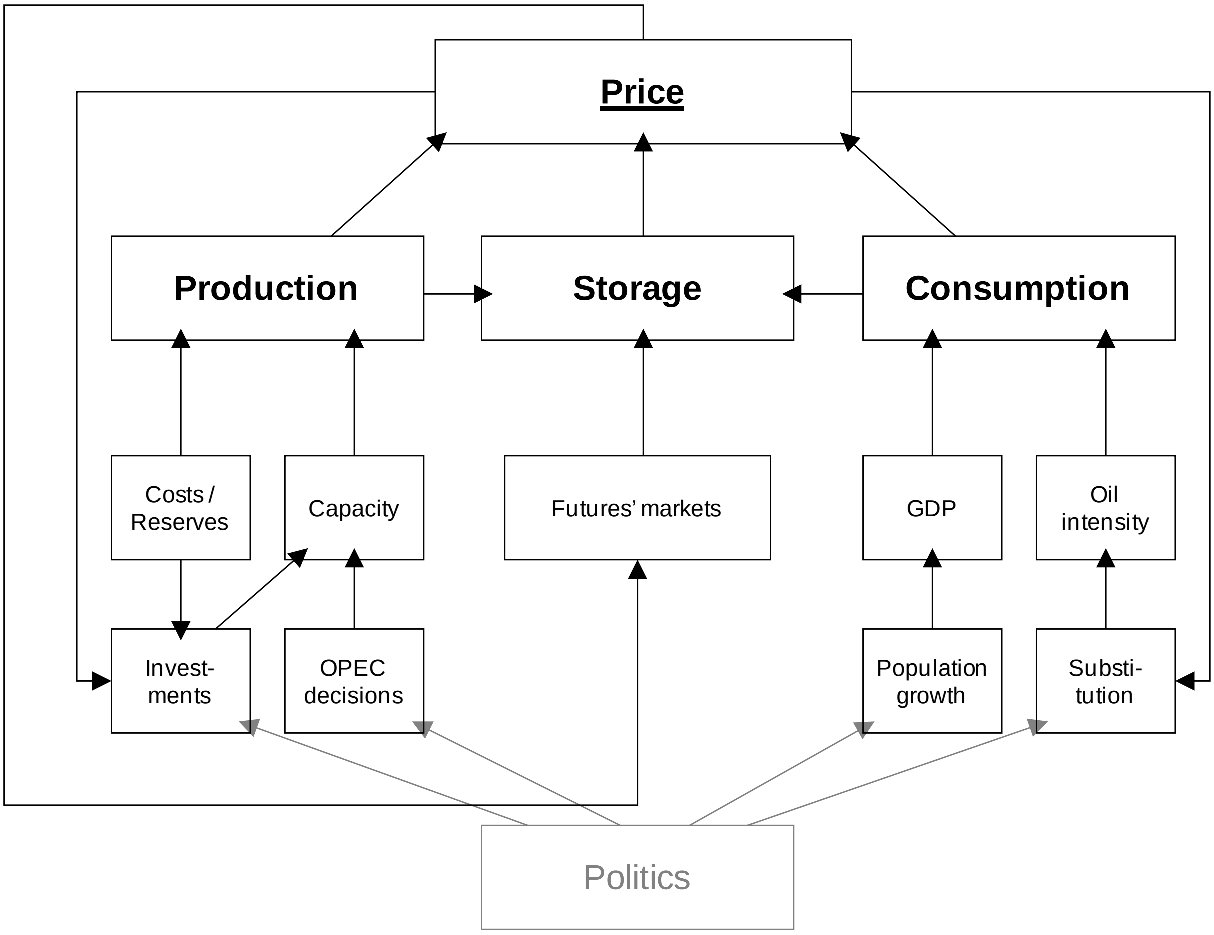


Figure 4.1: Relations between different factors affecting oil price

In this thesis I have gone through many theoretical concepts that concern the oil price. While they have not given a clear answer to how the price actually is determined, the study has been highly useful in helping to understand underlying conditions and limits. The above picture shows concluding relationships that have become apparent in this thesis. It is surely just one of many ways of presenting the price drivers.

The goal of this paper was not at any phase to forecast the oil price. I considered the task too challenging to begin with and now after the study I am convinced that it was the right choice. The difficulty in forecasting oil price lies in the great degree of uncertainty in several crucial factors. A good example of this uncertainty is the extreme jump in the annual long-term price forecasts of both IEA and EIA during the writing of this thesis. Both of the price forecasts nearly doubled their reference case estimate for the next twenty years. For example: the EIA forecasts for sweet light crude oil price for 2030 published in June 2008 was $70.45, while less than a year later in March 2009 the new version of the forecast was expecting a price of $130.43 – the prices are in real terms and taking into account the price drop of late 2008. Similar changes also happened in the IEA forecasts, although some months earlier. The reports explain the change by having obtained more precise field-by-field data on global capacity. One explanation might be that as 2008 was not a record year only in price, but also in production, we had never seen the costs of those marginal fields, because they had never before been in production. While these two public institutions clearly changed their view, other price views still exist and the future does not look any clearer than a year ago.

4.1 Conclusions from the literature review

Hotelling's theory with its extensions fits the oil market principally well. It does not however explain recent oil prices as such. Various unanticipated factors affect the price path constantly thus making it practically impossible to simplify price movements into a consistent theory. Hotelling's scarcity rent is still a valid concept and its effect should be taken into consideration when analyzing the market, especially in the future if, and when, resources are nearing depletion.

OPEC has historically shaken the market by cutting production and thus using market power. After the 1990's however OPEC's production changes have not had a clear impact on the price. In the recent price rise OPEC was in fact clearly increasing production without being able to stop prices from rising. OPEC's disputed reserve estimates and weak compliance in announced quotas further weaken the impression of a cartel in control of prices. In the first oil crisis in the 1970's OPEC emerged into public knowledge when cutting production on political motives. Throughout its history it has brought its members a lot of political attention and power. The current situation gives OPEC the chance to prove it being more than a political tool. During fall 2008 and spring 2009 OPEC has announced supply cuts to stabilize oil prices. So far there has been only a slight recovery in the prices.

The price peak in 2008 was often said to be a bubble and thus not a result of matching supply and demand. Scarce information on the oil market and participants' differing views would be theoretically good grounds for bubbles to form. Physical arbitrage constraints however set conditions on bubble formation. Speculative oil positions should lead to clear changes in oil storage. This was however not observed during the price peak. Demand was continuously met on the market, although with high prices. Tight market conditions allowed the price to rise quickly without any clear market inefficiency. Causality tests also show that there was no systematic speculator behavior driving prices up. Still speculators in general were blamed, while actually speculators are much needed in the market to generate liquidity and fight bubbles through arbitrage.

A general explanation for the high prices in the past few years is that supply capacity was not keeping up with the growing demand. Oil supply reached record highs with the help of new, more expensive production. From the previously presented investment plans we can see that there was significant new capacity coming on line in OPEC countries in 2009. The fact that these plans existed may have also discouraged investments in more expensive fields as cheaper sources in the Middle East were coming on line soon. This might have also further tightened the market. With this constrained inelastic supply prices got surprisingly high for some periods of time. Crude oil was priced not only by highest marginal costs but also by convenience yields of giving up inventory and scarcity rent of those who had inventories at the time of the crunch. Maybe even more significant than supply tightness, is the inelasticity of oil demand. For a large amount of the demand there are simply no substitutes available. Oil consumption is also often necessary for basic needs and is thus not easily given up. Taxes in western countries and subsidies in many developing countries both (although differently) further soften the price changes perceived by consumers.

4.2 Final thoughts on the future of oil prices

While prices are at low levels again, the most crucial long-term drivers remain. Oil demand will inevitably continue growing even if it is now held back for a few years by the stagnating world economy. Old oil fields will decline and new replacing capacity will cost more to produce. Surely oil will not run out, but it will become increasingly more expensive. Demand has not become any more elastic, which means that if the market tightens again we can see another price spike. The tightening could happen in clearly less than ten years as current low prices are seriously hurting investments in new capacity. It might be that the future price path looks like a steadily growing saw tooth, with the market going through consecutive crunches and crashes.

When serious substitutes start to emerge, demand is bound to become more elastic. This is mostly important for the transportation sector, where currently practically no fuel alternatives exist. Current developments in electric cars seem very promising, but they would only solve the problem of dependence “at the pump”. The approximately same amount of energy needs to be created in some way and currently the most likely way would be burning coal for electricity. While coal is cheaper and somewhat less scarce, it emits clearly more greenhouse gasses and is likewise non-renewable. It seems that even if we manage to get rid of oil dependence, we will have more problems ahead.

In the current environment OPEC is in a big role. For investments in oil capacity to happen efficiently, oil price needs to be on a stable level or a steady trend. To balance market disturbances, excess capacity from OPEC is needed to compensate. OPEC countries face a situation where it is beneficial for them to keep the world dependent on oil as long as possible by stabilizing prices. Recent high price levels have however already pushed forward significant efforts in research for substitutes. We are thus heading towards more balanced mix of energy sources. I hope that we will get there before oil dependence causes larger problems.

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6 Appendix 1: Complete derivation of Hotelling's rule with degradation:

$$max \int_0^\infty e^{-rt} \left(p(t) - c\big(s(t)\big)\right) q(t)\, dt$$

$$\dot{s}(t) = -q(t)$$

$$s(t), q(t) \geq 0$$

$$H(q, s, t, \lambda) = e^{-rt} \left(p(t) - c\big(s(t)\big)\right) q(t) - \lambda(t) q(t)$$

$$H = e^{-rt} (pq - c(s)q) - \lambda q$$

$$\frac{\partial H}{\partial q} = e^{-rt} \big(p - c(s)\big) - \lambda = 0$$

$$\frac{\partial H}{\partial s} = e^{-rt} (-c'(s)q) = -\dot{\lambda}$$

$$\frac{\partial H}{\partial \lambda} = -q = \dot{s}$$

$$\lambda = e^{-rt} \big(p - c(s)\big)$$

$$\dot{\lambda} = e^{-rt} (c'(s)q)$$

$$\pi(t) = \lambda(t) e^{rt}$$

$$\dot{\pi}(t) = r\lambda(t) e^{rt} + \dot{\lambda}(t) e^{rt}$$

$$\dot{\pi}(t) = r\pi(t) + c'(s)q$$

$$\frac{\dot{\pi}}{\pi} - \frac{c'(s)q}{\pi} = r$$

$$\frac{\dot{\pi}(t)}{\pi(t)} - \frac{c'\big(s(t)\big) q(t)}{\pi(t)} = r$$