Vienna University of Technology

Diploma Thesis

Impact Parameters on World Oil Prices

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Abstract

The complexity of oil price trajectory is the reason to try to postulate a set of parameters impacting the oil price behaviour. The major objective of this thesis was to establish such an systematic set of impacting parameters that should be able to facilitate the process of oil price modelling and additional forecasting, although it is not supposed to suggest the optimal specification of the price rule. The problematic of this study concentrates on three basic tasks. First, the explanation of crude oil market structure and subsequent analysis of oil market fundamentals. Second, search for impact parameters used in previous studies of oil price modelling. Third, the systematic categorization of obtained impact parameters by means of microeconomic analysis of crude oil market fundamentals.

Zusammenfassung

Das Verhalten der Ölpreise ist sehr komplex und deswegen wäre es wichtig eine systematische Reihe der Einflussparameter zusammenzufassen, die das Verhalten der Ölpreise erklären lässt. Ziel dieser Arbeit war die Reihe der Einflussprameter so aufzustellen, dass diese zum Zwecke der Modellierung und Vorhersage dienen kann auch wenn sie dabei keine optimale Lösung auf die Frage der Preisspezifikation suggerieren soll. Die ganze Problematik dieser Studie konzentriert sich auf drei glundlegende Aufgaben. Erstens, die Erklärung der Struktur des Ölmarktes und darauffolgende Analyse der grundlegenden Preisdeterminanten. Zweitens, die Suche nach Einflussparametern, die in bestehenden Modellen der Preisgestaltung eingesetzt wurden. Dritens, die systematische Kategorisierung der zusammengefassten Parameter mit Hilfe einer mikroökonomischer Analyse der grundlegender Marktrelationen.

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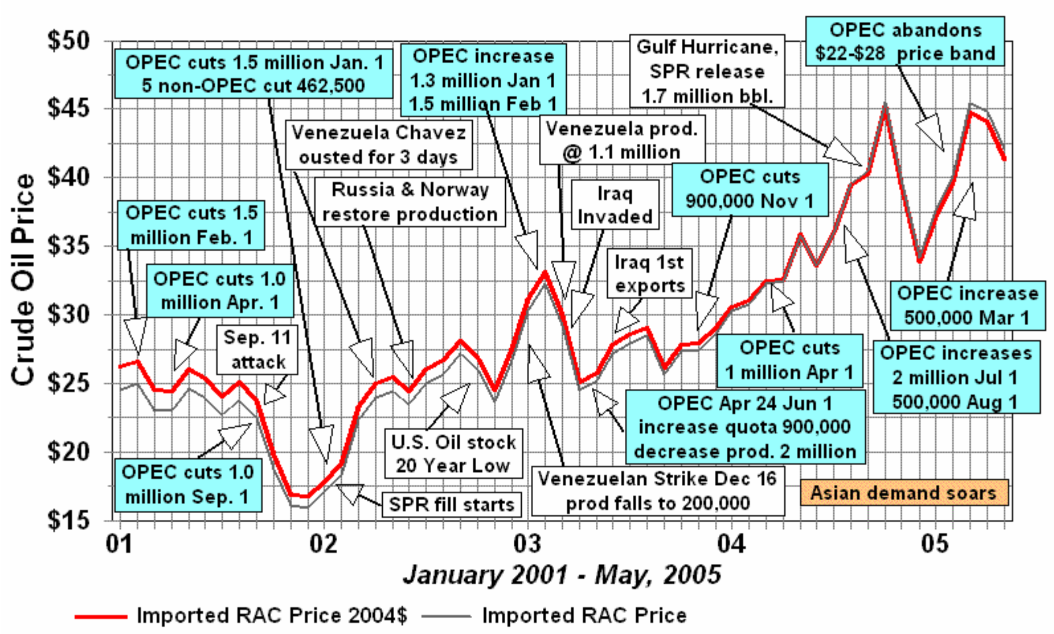
1 Introduction

Forecasting crude oil[1] prices is experienced as a complex endeavor. Its complexity relates to some unpredictable characters not only in economic but also in political aspects.

Oil prices react in a very complex fashion to changes in market conditions resulting from the impact of a complex set of determining parameters. Postulating the rules describing the oil price behavior would be of exceptional importance for the issue of forecasting. *See Figure 1 illustrating recent oil price development!*

Figure 1: *Crude Oil Price, 2004$ & Nominal (Data Source: WTRG Economics)*



The major task of this master thesis is to systematically postulate the complex set of oil price impact parameters. This set of obtained impact parameters should be able to

[1] *Crude Oil is not perfectly homogeneous but is a mixture of complex hydrocarbons together with certain trace elements. Crude Oil is not used directly for any important purpose.*

support and facilitate the complex issue of oil price forecasting, which is not the subject of my study.

The following discussion explains shortly the problematic and used approaches of every particular section.

Recent price increases combined with – and partly due to – geopolitical pressures and high demand has re-ignited interest in structural explanations of oil price formation based on market equilibrium. Standard practice models the world oil market in terms of a supply-demand equilibrium schedule. This approach has proven difficult due to characteristics specific for the oil market. Although a demand curve that relates quantities to prices can accurately represent oil demand, modelling supply is more difficult because oil is supplied by both a set of independent producers (non-OPEC nations) that act as price takers and an organization (OPEC) that can influence price. Because of that it is important to distinguish between non-OPEC and OPEC production behaviors. Non-OPEC behavior is assumed to be competitive (but subject to geological and institutional constraints), while OPEC production is modeled using various behaviors that are identified by an extensive literature - for instance, Griffin (1985). Among the behaviors described, two can be identified as corner solutions: a cartel model, where OPEC is a price maker and a competitive model, where OPEC is a price taker. Efforts to choose among these behaviors focus in part on identifying the slope of OPEC´s supply curve.

All the problematic issued above was a motive for me to make an introducing analysis of the complex oil market structure. This is done in the Section 2 of my thesis. The major intention thereby is capturing of fundamental parameters impacting the crude oil price behavior. The Section 2 is divided into two subsections relating respectively to the explanation of general structure of markets for commodities and subsequent analysis of particular features of crude oil market.

The oil price trajectory over the past decades, with its volatility and apparent irregularity, has led commentators to suggest that attempts to find an accurate method of forecasting oil prices are equivalent to the search for the philosophers' stone. But a kind of contribution to our understanding of how things may change in the future is the modeling of past phenomena. The oil price modeling seems important since it allows an evaluation of the relative importance of various factors that are thought to have affected the price changes in the past.

Section 3 is used to introduce some existing methods of oil price modeling. Thereby I will try to concentrate on both short-term models and long-run considerations. The variables occurring there are of special interest for my analysis. Additionally, I will also present the method of oil price forecasting that is prevailing today since the statistical analysis of its performance and the comparison with the real oil price trajectory offer the possibility of capturing some hidden parameters impacting the crude oil price, which are not a part of supply-demand balance.

Section 4 is reserved for concluding remarks. I will try to sum up and systematically present the collected parameters impacting the crude oil price.

2 Crude Oil Market Structure

This section is used to explain the crude oil market structure.

Just as every market for extractive commodity, crude oil market has some general features that govern the process of decision making. In order to obtain these general characteristics, I will use the first part of this section to explain the general structure of commodity markets. The explanation is based on theoretical work of R. S. Pindyck, 2001 (*"The Dynamics of Commodity Spot and Futures Markets: A Primer"*).
The particularity of the crude oil market relates to the structure of the supply/demand market side - the supply side consists of two groups of producers (i.e. OPEC and non-OPEC producers), and the demand market side can be divided into OECD section and non-OECD section. These particular features of the crude oil market and their impacts on the decision making process will be discussed in the second part of this section.

2.1 "The Dynamics of Commodity Spot and Futures Markets: A Primer" by R. S. Pindyck

2.1.1 Introduction

In markets for storable commodities such as oil, inventories play a crucial role in price formation. They are used to reduce costs of changing production in response to fluctuations (predictable or otherwise) in demand, and to reduce marketing costs by helping to ensure timely deliveries and avoid stockouts.[2] Producers must determine their production levels jointly with their expected inventory drawdowns or buildups. These decisions are made in light of two prices – a *spot price* for sale of the commodity itself, and a *price of storage*. This price of storage is equal to the marginal value of storage. It is termed as the *marginal convenience yield.*

With respect to the relevance of two different prices when making decisions about the possible production level, the existence of two interrelated markets for a commodity seems to be proved. These can be denoted as *cash market* for immediate, or *spot,* purchase and sale, and the *storage market* for inventories held by both producers and

[2] *Industrial consumers also hold inventories mainly for the same reason (the commodity is used as a production input!).*

consumers of the commodity. The equilibrium in these two interrelated markets determines the prices, rates of production as well as the inventory levels.

Furthermore, because commodity markets are volatile, producers and consumers often seek ways of hedging and trading risks. In recent years the use and the importance of markets for risk trading arose. Instruments traded in these markets are *futures, forwards, options, swaps* and other *derivatives.* Futures contracts[3] are among the most important of these instruments, and provide also important information about cash and storage markets. Therefore, it would be useful to explain the relationship between spot prices, futures prices and inventory behavior.

2.1.2 Cash Markets and Storage Markets

In a competitive commodity market the market-clearing price is determined not only by current production and consumption, but also by changes in inventory holdings. When inventory holdings can change, production in any period need not equal consumption.

Thus, to understand commodity market behavior, we must account for equilibrium in both the cash and storage markets.

2.1.2.1 The Cash Market

In the cash market, purchases and sales of the commodity for immediate delivery occur at a spot price. The cash market can be characterized as a relationship between spot price and *net demand*[4], i.e., the difference between production and consumption. Total demand in the cash market is a function of the spot price, but may also be a function of other variables such as the weather, aggregate income, certain capital shocks and random shocks reflecting unpredictable changes in tastes and technologies.

Demand function in the cash market can be written as:

$$Q = Q(P; z_1; \varepsilon_1) \tag{1}$$

[3] *A futures contract is an agreement to deliver a specified quantity of a commodity at a specified future date, at a price to be paid at the time of delivery.*

[4] *Net demand represents demand for production in excess of consumption.*

- P : the spot price;
- z_1 : vector of demand-shifting variables;
- ε_1 : variable presenting random shocks;

One should notice that demand is also affected by random variables, and so it will fluctuate unpredictably.

The supply in the cash market is also a function of the spot price and some other partly unpredictable variables such as energy and other row material prices, wage rates and various capital stocks.

Random shocks reflecting unpredictable changes in operating efficiency, strikes, etc. also influence supply in general. These are the reasons for supply to fluctuate unpredictably.

The supply function in the cash market can be written as:

$$X = X(P; z_2; \varepsilon_2) \tag{2}$$

- P : the spot price;
- z_2 : vector of supply-shifting variables;
- ε_2 : variable presenting random shocks;

In order to follow the changes in inventories the variable N_t, which represents the inventory level at time t, has been used. The change in inventories at time t is then given by following identity:

$$\Delta N_t = X(P_t; z_{2t}; \varepsilon_{2t}) - Q(P_t; z_{1t}; \varepsilon_{1t}) \tag{3}$$

ΔN_t can also be characterized as net demand. Cash market is therefore in equilibrium when net demand equals net supply.

In order to express the spot price I will rewrite the identity (3) by presenting some inverse net demand function:

$$P_t = f\left(\Delta N_t; z_{1t}; z_{2t}; \varepsilon_t\right) \tag{4}$$

Equation (4) is presenting the spot price being determined by the state of net demand and supply/demand shifting variables, and being affected by random shocks taking place on the supply/demand market side.

The inverse net demand function is upward sloping in ΔN. It is a consequence of the fact that a higher price corresponds to a larger production and smaller demand. This further implies an increase in inventories.

The identity (4) presents relationship between the spot price and net demand. It is common to use this relationship as a *market clearing*, which postulates the equilibrium in the cash market as a function of net demand.

2.1.2.2 The Storage Market

Total quantity of inventories held by producers, consumers, or third parties is defined as the *supply of storage.* As usual, in equilibrium this quantity must equal the quantity demanded, which is further defined as a function of price. The price of storage is the payment by inventory holders for the privilege of holding a unit of inventories. It is common to denote the price of storage by ψ_t, so that the *demand for storage function* can be written as $N(\psi)$.

Moreover, price of storage lies on the demand curve, and so it is equal to the marginal value of the flow of services accruing from holding the marginal unit of inventory. One is used to refer to it as marginal convenience yield.

The price of storage is a complex term. The very first component of this price is a physical cost of storage. Second, there is always some forgone interest[5] presenting an opportunity cost of capital. Third, the prediction plays an important role. The spot price might be expected to fall over the period that the inventory is held and this expected depreciation is an additional component of the opportunity cost of capital.

[5] *Forgone interest occurs even if no change in the spot price is expected.*

Because one more unit of inventory would be of little extra benefit when the total stock of inventories is large, one can conclude that the marginal value of storage is likely to be small when the total stock is large. Otherwise, the marginal value of storage increases sharply when the stock becomes very small.
Thus, the demand for storage function seems to be downward sloping ($N'(\psi) \lhd 0$).

In order to finally express the price of storage in a similar manner that has been used by considering the spot price in the cash market, it is also necessary to introduce other parameters that impact the demand for storage function.
First one is the prediction with respect to the future rates of consumption (or production) of the commodity. For example, an expected seasonal increase in demand has as a result an increased demand for storage, which occurs because producers feel forced to build up the inventory stocks in order to avoid stockouts or possible later sharp increase in production. Second, the demand for storage depends logically on the spot price of the commodity. Finally, the demand for storage is also certain to depend on the volatility of price. This last variable is particularly important. The demand for storage should be greater, the greater is volatility because greater volatility makes scheduling and stockout avoidance more costly.

Considering all the parameters that have been mentioned above one can write the demand for storage function as follows:

$$N = N(\psi;\sigma;z_3;\varepsilon_3) \tag{5}$$

- ψ : price of storage;
- σ : volatility of price;
- z_3 : vector that includes the spot price, consumption, and any other variable (excluding volatility!) that affect demand;
- ε_3 : variable presenting random shocks;

By rewriting the identity (5) the equilibrium identity for the storage market can be presented:

$$\psi = g(N;\sigma;z_3;\varepsilon_3) \qquad (6)$$

(An *inverse demand function* has been postulated.)

If considering the equation (6), it seems obvious that the market clearing in the storage market implies a relationship between marginal convenience yield, i.e. price of storage, and demand for storage. Thus, equilibrium in the storage market is a function of the demand for storage.

2.1.2.3 Cash and Storage Markets: The Interrelationship

The identities (4) and (6) describe equilibrium in both the cash and storage markets.
This equilibrium is dynamic[6].

If there are no shocks (i.e., no changes in the exogenous variables) the system, which is presented above, will reach a steady-state equilibrium in which there is no change in inventory level. Thus, net demand would be equal to zero.
Much more interesting and detailed analysis of the equilibrium occurs by considering market variables changing in response to some temporary or permanent exogenous shock.

In order to say more about how the cash price, the price of storage and inventories will change following some exogenous shock, it would be useful to consider a specific situation in which some sustained increase in volatility appears. This analysis presumes a combined observation of cash market and market for storage. The interrelationship between these markets is interesting to follow.

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[6] *Given the values of* N_{t-1}, z_{1t}, z_{2t}, z_{3t} *and* σ_t, *these identities can be solved for the values of* ψ_t, N_t *and* P_t.

2.1.2.4 Sustained Increase in Volatility

We assume the volatility of spot price fluctuations is increasing. The change is expected to last for a significant period of time.

One of the main causes of spot price volatility is fluctuation in the net demand function, which in turn results from fluctuations in consumption demand and/or production.
Impacts of change in spot price volatility are in the following discussion object of detailed analysis.
Sustained price fluctuations will cause the consumption and production to fluctuate even more.[7] Therefore, an increase in price volatility will be accompanied by an increase in the volatility of production and consumption, and so market participants will tend to hold greater inventories at any given price in order to buffer these fluctuations in production and consumption. The demand for storage will increase and in turn the demand for storage curve will be upward shifted. *See Figure 2!*

When considering the impact of change in price volatility on the cash market state, one should focus on the production costs. Every producer has some *operating options*, i.e. options to produce now rather than waiting for possible increases or decreases in price.
These options add an opportunity cost to current production, i.e. the cost of exercising the options rather than preserving them. An increase in volatility increases the value of operating options. Therefore, an increase in volatility increases the opportunity cost of current production. In turn, the net demand curve will be upward shifted.[8] *See Figure 2!*

Let me now comment happenings presented in the Figure 2.

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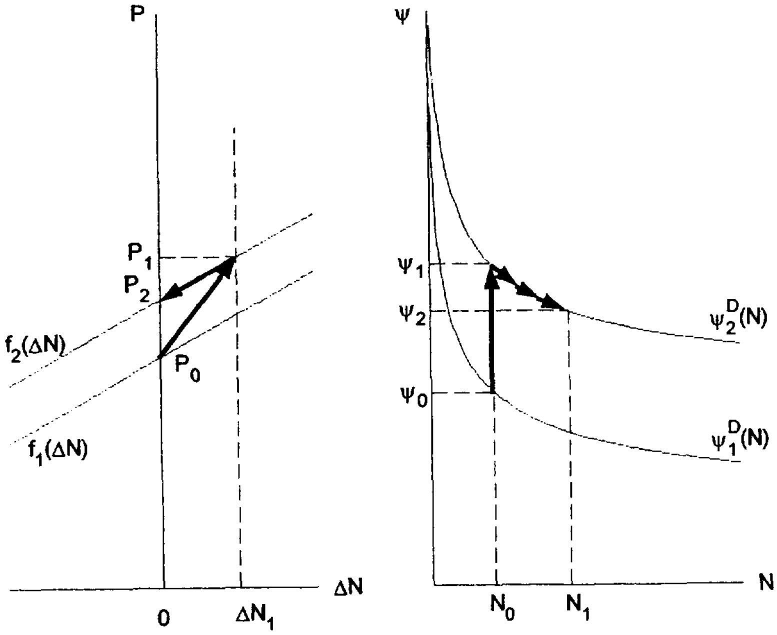
[7] *Causality in both directions!*
[8] *If considering the Figure 2, one should remember that inverse net demand function is upward sloping following the fact that some higher price leads to an increase in production and decrease in demand. On the other hand, the inverse demand for storage function is downward sloping and convex following the fact that the marginal value of storage seems to be small when the total stock of inventories is large but it can rise sharply when the stock level becomes very small.*

***Figure 2**: Response to Increase in Volatility*

- *Ψ: Price of Storage;*
- *N: Demand for Storage;*
- *P: Spot Price;*



Cash Market ***Storage Market***

As a result of some increased demand for storage the price of storage, i.e. marginal convenience yield, will increase (from ψ_0 to ψ_1). We assume that the supply of storage is initially fixed at N_0. In addition the spot price will rise (from P_0 to P_1) because of the shift in the inverse net demand curve and because of movement along the curve as inventories start to built up. With some increased net demand the inventory level increases (from N_0 to N_1) but the rate of change decreases with time. After some time it will drop back to zero. As a consequence, the spot price will stabilize at P_2. The price of storage will go down to ψ_2.

Assuming this increase in volatility persisting indefinitely, some new equilibrium would be established in which the spot price, the marginal convenience yield, and the level of inventories are higher than they were at the beginning.

2.1.3 Markets for Risk Trading

As it already has been said, the instruments that are mainly used in markets for risk trading are futures and forwards. In the following subsection the attention is primarily dedicated to the futures. Therefore, it seems useful to explain firstly the character of futures contracts. In addition to that, the context between futures prices, convenience yield and *expected future spot prices*, which is a major objective of this subsection, will be investigated.

A future contract is defined as an agreement to deliver a specified quantity of a commodity at a well known future date, at a price (the *futures price*) to be paid at the time of delivery. These contracts are usually traded on organized exchanges, such as the New York Mercantile Exchange[9].

The main difference between futures and forwards is the fact that futures contracts are "marked to market". It means that there is a settlement and corresponding transfer of funds at the end of each trading day. This daily "settling up" reduces the risk that one of the parties will default on the contract. Payments are based on each day's *settlement price*, which is the price denoted by the futures exchange as the market clearing price at the end of the trading day. Moreover, futures contracts tend to be more liquid than forwards.
If comparing the futures price with forward price the difference between them tend to be very small and might be ignored[10].

Furthermore, the majority of futures contracts are "closed out" or "rolled over" before the delivery date, so the commodity does not change hands. It means that although futures specify prices to be paid at the time of delivery, it is not necessary to actually take delivery. To explain the reason for that one should recall that these contracts are usually held for hedging or speculative purposes, so delivery of the commodity is not

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[9] *NYMEX*
[10] *Theoretically the futures price will be greater (less) than the forward price if the risk-free interest rate is stochastic and is positively (negatively) correlated with the spot price.*

needed. The oil consumer, for example, buys oil normally from his usual source over the year and never takes delivery on the futures contacts.

Futures trading of crude oil began with the introduction of the contract for *West Texas Intermediate*[11] crude petroleum in 1983.

2.1.3.1 The Expected Future Spot Price

A very interesting issue, if considering industrial commodities such as crude oil, is the relationship between the expected future spot price and the futures price. These two quantities must not be equal. Furthermore, it has been estimated that for the crude oil the difference between the futures price and the expected future spot price can be significant.

In the following discussion an econometric analysis of this relationship will take place.

Let me consider an investment in one unit of the commodity at time t. The total outlay for the investment at time t is P_t. This unit is going to be held until $(t+T)$ and then sold for the price P_{t+T}. Thus, the expected return on the investment is given as follows:

$$u = E_t\left(P_{t+T}\right) - P_t + \psi_{t+T} - k_T \qquad (7)$$

- E_t: The expectation at the time *t;* mathematically, it could be understood as some expectation operator at time *t;*
- ψ_{t+T}: convenience yield over the period T[12];
- k_T: per-unit cost of physical storage;

Because of $E_t\left(P_{t+T}\right)$ not being deterministic (the price P_{t+T} is not known at time t) this return is risky. By considering ρ_t as some *risk-adjusted discount rate* for the commodity, the identity (7) can be rewritten as follows:

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[11] *WTI*

[12] *Dividend obtained from holding a commodity!*

$$E_t(P_{t+T}) - P_t + \psi_{t,T} - k_t = \rho_t \times P_t \qquad (8)$$

On the other hand supposing the futures contract being agreed at time *t*, the expectation operator, which has been a part of identity (7) presenting the total return of the investment, has to be replaced by the futures price[13]. In that case, the total return on the investment is non-stochastic and it must equal the *risk-free rate* times the cash outlay for the commodity ($r_t \times P_t$). Thus, the convenience yield can be extracted as follows:

$$\psi_{t,T} = (1 + r_T) \times P_t - F_{t,T} + k_T \qquad (9)$$

By implying the identity (9) into identity (8), one can substitute the term $(\psi_{t,T} - k_T)$ as follows:

$$E_t(P_{t+T}) - P_t + (1 + r_t) \times P_t - F_{t,T} = \rho_T \times P_t \qquad (10)$$

Subsequent rewriting of the equation (10) makes it possible to obtain a simple relationship between the futures price and the expected future spot price:

$$F_{t,T} = E_t(P_{t+T}) + P_t \times (r_t - \rho_t) \qquad (11)$$

It seems obvious that the futures price will equal the expected future spot price only if the risk-adjusted discount rate for the commodity is equal to risk-free rate. In other words, the *risk premium* has to be zero; i.e. $\rho_T - r_T = 0$.

In the market for crude oil the spot price is expected to co-vary positively with the overall economy. Thus, one should expect to observe a positive risk-premium, i.e. the risk-adjusted discount rate is expected to exceed the risk-free rate. In turn, it means that the futures price should be less than the expected future spot price[14]. (*See the identity (11)!*)

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[13] *The price for delivery at time* $t + T$ *;*

[14] *The estimates made for crude oil show the annual risk premium being in the range between 4.5 and 9.0 percent. Thus, a six-month crude oil futures contract should "under-predict" the spot price six months out by around 3.0 to 4.5 percent.*

2.1.3.2 Backwardation

By concluding the observation of markets for risk trading, I would like to introduce the item of *backwardation*. Backwardation relates to risk trading by extractive resource commodities such as crude oil. In particular, weak or strong backwardation is prevailing on the futures market for crude oil most of the time.

But what is backwardation?

Backwardation occurs if the *net marginal convenience yield* $(\psi_{t,T} - k_t)$ takes positive values. It means that the dividend obtained by holding a unit of commodity exceeds the per-unit cost of storage. In particular, if net marginal convenience yield is large, the spot price will exceed the futures price. It is the case of strong backwardation. If net marginal convenience yield is positive but not large, the spot price will be less than the futures price, but greater than the *discounted future price* ($\frac{F_{t,T}}{(1+r_t)}$), and so a weak backwardation occurs.

The reason for the backwardation prevailing on the futures market for crude oil is the fact that owning in-ground reserves is equivalent to owning a *call option* with an *exercise price* equal to the *extraction cost* of the commodity, and with a payoff equal to the spot price of the commodity. If there were no backwardation, producers would have no incentive to exercise this option and there would be no production.[15]

In the case of high spot price volatility (as it is the case when considering the oil price today!), the option to extract and sell the commodity becomes even more valuable, so that production is likely to require strong backwardation in the futures market. It means that some high volatility raises the spot price relative to the futures price because of the fact that the option value of keeping the resource in the ground increases.

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[15] *Litzenberger and Rabinowitz (1995) developed an option model for crude oil production, viewing ownership of an oil field as a call option with an exercise price equivalent to extraction costs. Producers have two choices: to exercise the option to pump oil at marginal extraction costs or to preserve the option to produce in the future by leaving oil underground. Litzenberger and Rabinowitz determined that weak backwardation, when discounted futures prices are below spot prices, is necessary for current production because all producers would choose to defer production if discounted future prices were higher than spot prices.*

All facts mentioned above confirm that the "call option" characteristic of an extractive resource such as crude oil plays an immense role by influencing the actual market state.

2.1.4 "The Dynamics of Commodity Spot and Futures Markets: A Primer" – Personal Remarks

Previous analysis propounds the complexity of markets for extractive commodities such as crude oil, which in turn reveals difficulties relating to decision making in these markets. The market for storage has been used to capture the effects of stocking and de-stocking. The market for risk trading, which became particularly important in recent years, covers the field of speculation and the cash market has been denoted as a market for immediate delivery of purchased/sold commodity. These markets are interrelated; in particular the commodity spot price seems to be determined by equilibration in both two interrelated markets – a cash market and a market for storage - and its magnitude relative to the futures price exhibits the current wish to extract a unit of commodity.

Although this kind of structuring offers the possibility for detailed theoretical analysis, it does not contain particular features of the crude oil market and is therefore unfit to be applied for the task of oil price modelling.

2.2 Characteristics of International Crude Oil Market

One should understand the econometric analysis that has been conducted by Pindyck (2001) as a kind of skilled presentation of basics determining markets for extractive commodities in general. As expected, these basics have to be supplemented by some particular features of the crude oil market if intending to sum up the oil market fundamentals.

Therefore, the following discussion is primarily used to explain the crude oil market fundamentals by taking into account particular features of the international crude oil market.

2.2.1 Basic Structure – Supply Side

Crude oil is a naturally occurring substance which is found in widely differing amounts in various countries throughout the world. Therefore, if considering characteristics of the crude oil market, the structure of the supply-side seems to be a very interesting issue.

Two groups of producers currently determine the oil supply. These are so-called OPEC and non-OPEC nations. Every single group implements different supply behaviour, and it is common to distinguish between OPEC and non-OPEC supply.

OPEC (*Organization of Petroleum Exporting Countries*) is a group of thirteen member nations. These are: Algeria, Ecuador, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates and Venezuela.
All other oil producing countries are denoted as non-OPEC producers. Among them most important are: Russia, Mexico, China, USA, Norway, Canada, Brazil, UK and Kazakhstan.

OPEC performs as residual supplier while non-OPEC produces almost with full capacity. However the role of OPEC is balancing demand and supply regarding a target price band and that is the reason for OPEC to be considered as a price maker. But the ability of OPEC to influence the prices is effected by the non-OPEC production. In particular, non-OPEC production capacity determines the OPEC's share of the world oil supply.

Let me now introduce some difficulties, which in general strongly complicate the accurate specification of the supply side of oil market.

First, crude oil is a primary commodity so the identification of potential supply (the number of oil wells) requires good data. Second, the productivity of the wells can vary so enormously that it is essential to take this into account. Crude oil is exhaustible resource and the production from a field will vary over its lifetime[16]. "Accurate data on the reserves of oil in each field still remaining at each point of time are not available so that it is far from simple to estimate the maximum potential production." (*Robert Bacon, "Modelling the Price of Oil", 1991)*

Third, it is to notice that many countries have national oil companies. Their goal is not just to maximize the profit. In fact, the companies are often used as objects of government policy and their production is therefore strongly influenced by all kinds of random shocks.

In the following discussion I will consider the supply of OPEC and the relevance of cartel existence to the oil market structure.

2.2.1.1 OPEC Supply

As it has been mentioned in the Chapter 1, the OPEC production can be modelled using various behaviours. The reason is the fact that OPEC production behaviour relates to market conditions.

There are two corner solutions if considering the wide range of possible OPEC production behaviours. These are *cooperative* production behaviour and *competitive* production behaviour. As a consequence of the former one, OPEC's market power

[16] *An important barometer for the state of the field is the so-called production to reserves ratio with the value 10 as a threshold!*

(caused by cartel discipline) dominates, and so OPEC takes a *price-maker* role.[17] Otherwise, if competitive behaviour prevails, OPEC is a *price-taker*.
(The model of cooperative production behaviour is actually presenting OPEC as some *monolithic cartel*. Oppose to that, model of competitive behaviour should be understood as some *oligopolistic* solution, which is based on *Nash–Cournot intertemporal equilibrium*.)

In order to explain the OPEC production behaviour relating to market conditions I will mainly concentrate on observation made by F. Wirl (1990).
I will begin the following discussion by considering some extreme economic point of view.
With respect to dynamic but sluggish nature of demand behaviour in the oil market, one should easily conclude that some volatile oil price strategy is optimum for the supply-side intending to maximize its revenues. It means that optimal cartel policy indicates price swinging. It is common to say that optimal cartel policy alternates between a *penetration* and a *skimming* policy, responding respectively to low and high demand pressures.

But in the real world OPEC is not a cartel in the narrow economic sense and that's why the pure economic and monopoly description of OPEC behaviour, which has been assumed above, has to be extended.

It is common to characterize OPEC as a "loose arrangement of politically motivated members" (*F. Wirl, OPEC: a temporary and politico-economic cartel, 1990)*. Member states have different long-term and short-term objectives. Variations in their *discount rates* reflect different attitudes.
(The choice of *discount rate* is determined through amount of population and the *per capita reserves* of the corresponding state. Table 1 summarizes the assumptions on *discount rates* of OPEC member states.)

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[17] *Since the beginning of 1970s OPEC has the ability to enforce monopolistic price policy – OPEC obtained a dominant market share and all OPEC member states met the necessary institutional conditions (nationalizing of oil companies).*

The diversity among member states indicates the complexity of organization. The unique policy of OPEC (and thus cooperative behaviour) is only achievable if demand is extremely high and sluggish. Thus, competitive behaviour prevails if current demand is in equilibrium.

"The monopoly strategy requires a high price. Hence, the arrangement of cooperation will lead to a (presumably large) price increase over the price level prevailing during the previous regime of oligopolistic behaviour. However, as aggregate OPEC demand and individual quotas decrease, the gains from opportunism and deceit increase, and sooner or later the contract will be breached by some members due to these *ex post* gains." (*F. Wirl, OPEC: a temporary and politico-economic cartel, 1990)*

It seems important to mention at this point that cartel arrangements (production quotas among OPEC member states to support a crude oil price increase[18]) seem to be sustainable only if the demand for OPEC oil remains so high that the swing producers – particularly Saudi Arabia – accept a reduction of their residual demand. Otherwise, if for instance Saudi Arabia falls below a certain threshold, cooperation will cease.[19] (Responding to their possible need for foreign exchange some flexible OPEC producers might be unwilling to swing with total OPEC output!)

All these difficulties relating to the cooperative OPEC behaviour (sustained cartel arrangements!) are very often the reason for OPEC to react sluggish and insufficient on temporary market crisis.

[18] *The current high oil demand resulting in high oil price illustrates the need for OPEC cooperation policy (increase of production quotas!) intending to decrease the actual price of oil. So, the monopoly strategy of OPEC seems to prevail also if the oil price is in the long run large relative to the OPEC target range.*

[19] *OPEC is differentiated into flexible and inflexible producers. Swing producers are: Saudi Arabia, United Arab Emirates, Kuwait and Lybia.*

Table 1 *(Data sources: BP Statistical Review of World Energy, BP (1994))*

Member Country	***Discount rate***	***Population, millions***	***Reserves per capita, b/cap***
Algeria	*0.15*	*24.6*	*342*
Ecuador	*0.15*	*10.5*	*133*
Gabon	*0.15*	*1.1*	*446*
Indonesia	*0.15*	*178.2*	*47*
Iran	*0.10*	*54.0*	*1722*
Iraq	*0.10*	*17.8*	*5632*
Kuwait	*0.05*	*2.1*	*44829*
Libya	*0.05*	*4.4*	*5023*
Nigeria	*0.15*	*128.3*	*125*
Qatar	*0.05*	*0.3*	*9697*
Saudi Arabia	*0.05*	*14.4*	*11781*
United Arab Emirates	*0.05*	*1.6*	*62065*
Venezuela	*0.10*	*19.3*	*3018*
OPEC total	***0.10***	***456.4***	***1481***

I will concentrate now on identities simulating two corner solutions of OPEC production behaviour, which appear in the empirical work of Dées *et al* (2004).

The identity, which simulates the cooperative behaviour, assumes OPEC setting production to match the difference between world oil demand and non-OPEC production:

$$PROD^{OPEC} = \sum_i DEM_i + \Delta\overline{Stocks^{OECD}} - \overline{NGLS} - \sum_j PROD_j^{non-OPEC} - \overline{PG} \qquad (12)$$

- $\overline{Stocks^{OECD}}$: Level of stocks reported by *OECD*[20];
- $\overline{NGLS}$: Natural Gas Liquids[21] in mbd[22];
- $\overline{PG}$: Processing Gains in mbd (*net*);

[20] *Organization for Economic Development and Co-operation*
[21] *Most natural gas is processed to separate the heavier hydrocarbon liquids from the natural gas stream. These heavier hydrocarbon liquids are commonly referred to as natural gas liquids (NGLs).*
[22] *million barrels per day*

- DEM_i : Oil Demand in mbd (*for i = US, Euro Area, UK, Switzerland, Other Dev. Eco., NJA, Transition Economies, Latin America, Rest of the World*);
- $PROD_j^{non-OPEC}$: Oil Supply in mbd (*for j = US(48+Alaska), Canada, Asia, Africa, Latin America(Brazil, Mexico and others), Europe*);

The identity (12) is stating the OPEC production as a residual supply, generally matched to cover the need for OPEC oil. It is an extended form of supply-demand equilibrium equation, which incorporates stock movements absorbing supply-demand imbalances. The key attribute for modelling OPEC cooperative behaviour is that oil price need not be taken as exogenous variable.

Cooperative behaviour can be used to describe OPEC production since the third quarter of 1986. *See Kaufmann (1995)!*

Alternatively, second corner solution regarding the possible OPEC production behaviour assumes OPEC nations competing among themselves and with non-OPEC producers for market share. To compete for market share, OPEC increases production to rates that are consistent with operable capacity.

To account for competitive production behaviours, OPEC production is simulated using following equation:

$$PROD^{OPEC} = 0.95 \times \overline{Capacity^{OPEC}} \qquad (13)$$ [23]

- $\overline{Capacity^{OPEC}}$: OPEC Operable Capacity in mbd;

Competitive behaviour described by identity (13) implies that production does not match demand. Oil produced in excess of demand is put into stocks, which in turn depresses oil prices.

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[23] *95 percent rate of capacity utilization is an arbitrary value. Price modelling argues the rate of capacity utilization to be calculated basing on the call for OPEC oil that is given by the identity (12)!*

2.2.1.2 An Microeconomic Analysis of Crude Oil Market Structure

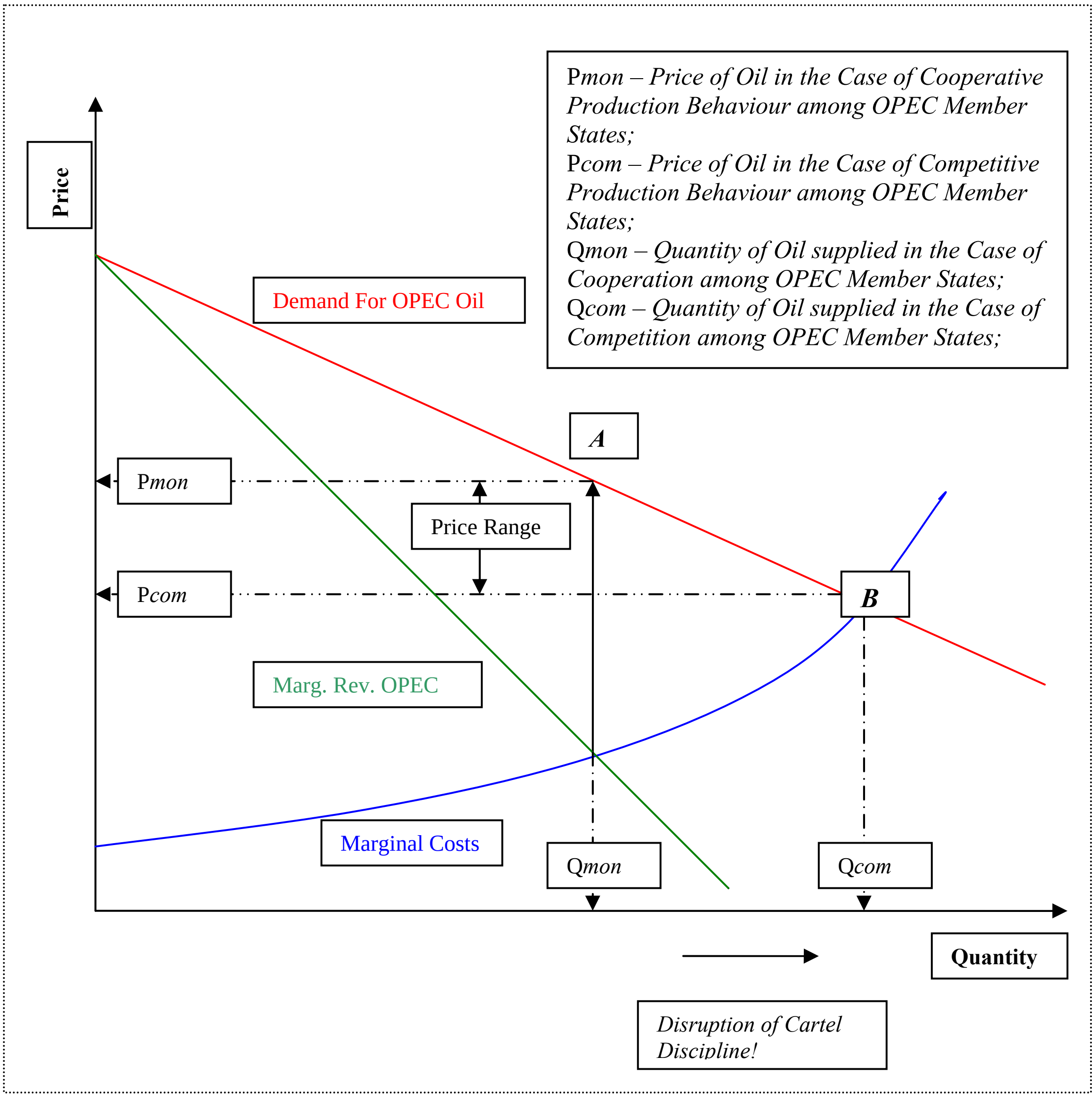
By concluding discussion about basic structure of the oil market, I would like to consider its impact on the oil price behaviour. In order to do so, I used to take into account some basic principles of microeconomics.
The following analysis proves the significance of cartel existence if considering the oil price formation. Moreover, it represents an economic overview of market relations and makes it possible to obtain the oil market fundamentals.

I would like you to take a look at the figure 3.

As a result of absolute cartel discipline, OPEC is a price maker and has a role of monopolist on the oil market. It means that cartel has the ability not only to vary its production quantity but also the actual oil price in order to maximize its revenues. The optimal quantity produced by OPEC is in this case determined by equating marginal cost of producing to marginal revenue. Finally, obtained optimal quantity and the state of demand for OPEC oil determine the price of crude oil if considering such an cooperative solution.
Disruption of cartel discipline happens due to wish of some OPEC member states for surplus in their revenues. Therefore, they increase their production rates and the total quantity produced by OPEC increases as well. As a consequence, the oil price falls down. The second corner solution of OPEC production behaviour, which is denoted by means of full competition among oil producers, imposes the oligopolistic market state, and so the “low” state of the oil price.

The whole story presented above implies the existence of some price range. In particular, oil prices are moving between “high” and “low” values following the actual degree of OPEC’s cartel discipline. The margin values of this price range are determined through the marginal costs of producing and the demand for OPEC oil – demand for OPEC oil is the difference between global oil demand and non-OPEC production rate.

Figure 3: *Crude Oil Market, an Illustration of Market Fundamentals;*



Assuming the degree of OPEC's cartel discipline as a proxy for cartel's ability to pursue monopoly pricing policy, it seems reasonable to postulate three oil market fundamental parameters. These are the marginal costs of producing, global oil demand, and cartel market power.

The following discussion is used to analyse the fundamental parameters of the oil market. Since OPEC production behaviour - cartel's perseverance in practicing the market power - has been already extensively discussed, I will concentrate on the marginal costs of producing and demand for OPEC oil.

2.2.2 Some Fundamental Parameters Impacting the State of the Oil Market

2.2.2.1 Marginal Costs of Producing

As it has been tacitly assumed in the previous discussion, the marginal costs of producing are increasing following the rise in the rate of production. That is quite understandable and consistent with economic theory since it is always more expensive to produce at maximum of production capacities.

But marginal costs of producing for exhaustible resources, such as crude oil, are always depending on the amount of ultimate recoverable reserves as well. In particular, marginal costs increase as recoverable reserves deplete because of increase in opportunity cost of production as well as because of necessity for use of some additional methods of extracting.

By taking into account major impact parameters on marginal costs of oil producing, D. J. Celta & Carol A. Dahl (2000) developed a log-linear equation that specifies the function of marginal costs of producing for OPEC as follows:

$$\log(MC) = \beta_0 + \beta_1 \log(Q_{OPEC}) + \beta_2 \log(R_{OPEC}) \qquad (14)$$

- MC : Marginal Costs of Production;
- Q_{OPEC} : Rate of OPEC Production;
- R_{OPEC} : OPEC Recoverable Reserves;

The regression results of equation (14) prove the positive sign on OPEC's production coefficient and negative sign on OPEC's reserves coefficient suggesting that as OPEC depletes the resource, marginal cost of producing should increase. [24]

Finally, Figure 4 is illustrating the costs of oil extraction for most important oil producers. These costs differ strongly across regions due to different states of depletion of corresponding reserves. *See Figure 4!*

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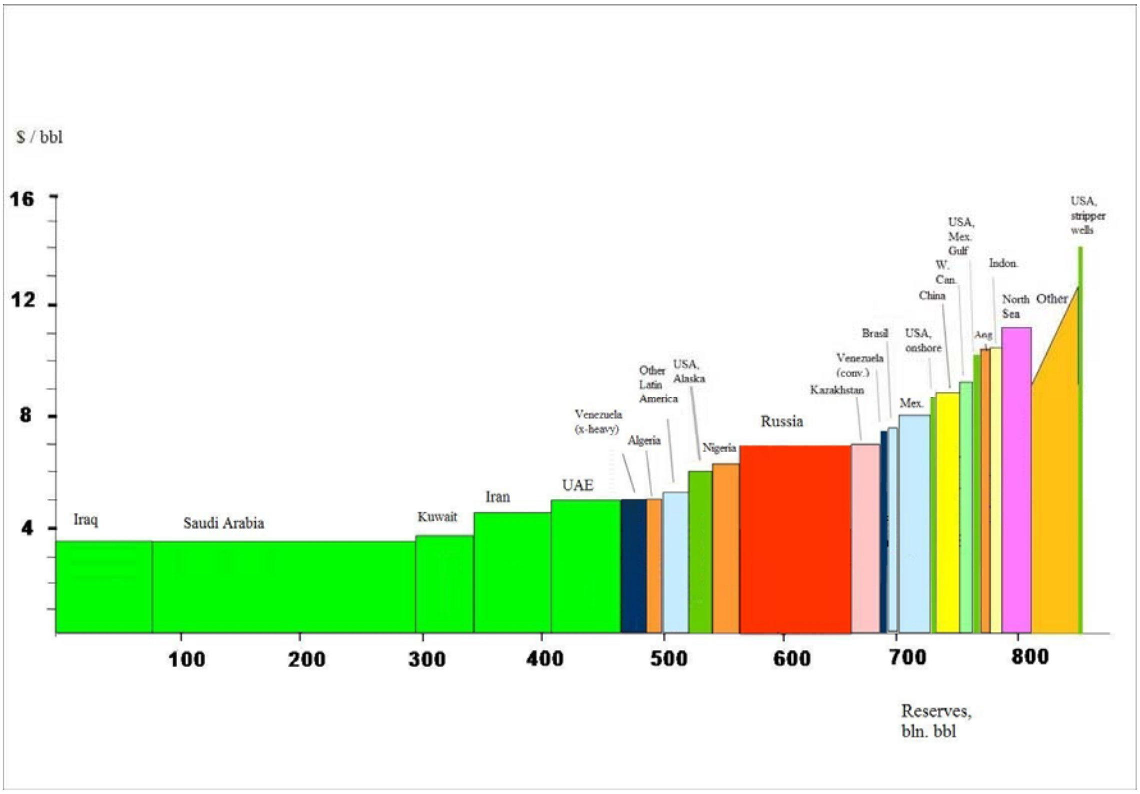
[24] *Function of marginal costs of producing has been evaluated at estimated reserves of 778,000,000 mbpd (Oil and Gas Journal, 1994). Results: Production Coefficient ~ 0.3026, Reserves Coefficient ~ -2.3356.*

***Figure 4**: Worldwide Cost of Oil in 2001: Finding, Development & Production*
(Data Source: OMV, 2001)



2.2.2.2 <u>Demand For OPEC Oil</u>

2.2.2.2.1 Global Oil Demand

Global oil demand is in general a function of real GDP[25], real oil prices and a time trend that represents technical changes that affect energy efficiency.
It is common to disaggregate the global oil demand by regions. So, the general specification for the econometric equations of oil demand is given by:

$$DEM_i = \Phi\left(Y_i ; \frac{P_{Oil}}{P_i^D} \times \overline{E_i} ; time \right)^{26} \qquad (15)$$

- Y_i : Real GDP (*for i : US, Euro Area, UK, Other. Dev. Eco., NJA, Transition Economies, Latin America, Rest of the World*);

[25] *Gross Domestic Product*
[26] *Dées et al, "Modelling the World Oil Market, 2004"*

- $\overline{E}$: Exchange rate vis-à-vis USD;
- $time$: time trend;
- P_{Oil} : Oil Price in USD;
- $\overline{P^D}$: Domestic Price Index;

Some analysts showed the interest to include also the relative prices of competing forms of energy into equations specifying the oil demand. But since these competing forms of energy, such as gas, are much less widely internationally traded than oil, there are no obvious international prices for them and this has limited the testing of such hypothesis.
Furthermore, there is strong seasonality in oil demand, and so it could be useful to extend the specification (15) by using an index of "degree days" (*R. Bacon, 1991*), which relates to the extremes of temperatures in the northern hemisphere, in order to model the variations in the severity of the winter months.

The following discussion is used to take a short look at the impacts of *GDP* and *time* - I try to concentrate on parameters that seem to be exogenous most of the time, and so I will not consider the oil price impact on demand since demand function permanently co-determines the oil price. *See Figure 3!*[27]

Activity in an economy - *GDP* variable in the specification (15) - is a crucial impact parameter, which is mostly exogenous,[28] if searching for grounds of oil demand shifting. GDP is the principal long-term driving force. Consequently, it is likely that the response of demand for oil to changes in growth occurs gradually.
However, estimations of demand specification (15), made by *Dées et al* (2004), suggested the short-run GDP elasticity being in some regions even larger than the long-run elasticity (Japan - 0.89 comparing to 0.61, the UK - 0.65 comparing to 0.17, and non-Japan Asia - 1.73 comparing to 0.77), which may cause oil demand to over-react to changes in real GDP in the short run. *See Table 2!*

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[27] *The impacts of exchange rates, relating to the US monetary policy, are going to be extensively discussed later on. See Section 3.2. – Oil Price Characteristics!*
[28] *GDP cannot be considered as an exogenous variable for demand if we are looking at periods in which the oil price changed substantially. It is a commonplace that the first two oil shocks contributed substantially to the slow-down in world growth that followed.*

The reaction of corresponding regional oil demand to the Asian financial crisis is an example for oil demand responding strongly to changes in real GDP in a short run. (Asian financial crisis occurred in July 1997. Rather than growing by the pre-crisis expectation of 1 mbd/year, oil demand in 1998 actually declined by 0.5 mbd/year – it was the first decline since 1985. *See Figure 5!*)

Table 2*: Econometric Results for GDP Elasticities of Oil Demand*

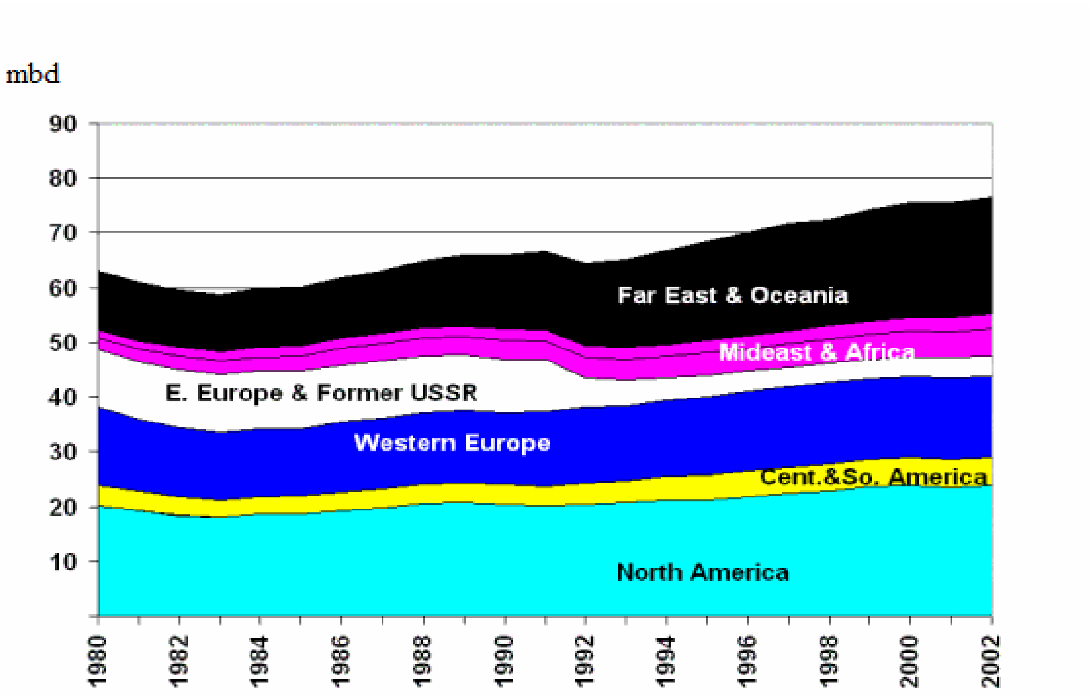
(Data Source: Dées et al, 2004)[29]

	United States	*United Kingdom*	*Japan*	*Euro Area*	*Non - Japan Asia*	*Transition Economies*	*Other Developing Economies*	*Latin America*	*Rest of the World*
GDP- L. T.	0.98	0.17	0.61	0.57	0.77	0.51	0.39	0.85	0.55
GDP- S. T.	0.77	0.65	0.89	0.45	1.73	0.002	0.001	0.82	0.58

Remark*: All estimated elasticities are positive suggesting that an increase in GDP increases the demand for oil.*

Figure 5: *Global Oil Demand by Regions 1980 -2002*

(Data Source: Intern. Energy Annual)



[29] *DOLS Regression and quarterly data from 1984Q1 to 2002Q1;*

As it has been already mentioned, time is second important exogenous parameter if considering the shifts of demand for oil function. Technical progress in energy-saving design and techniques, represented by the *time trend* variable in the specification (15), is well significant if analyzing the shifts of demand in the long run.

Let me now comment the changes in oil demand structure over last decades, caused by technical progress. I will compare the Charts 1 & 2, which are illustrating demand structures in years 1973 and 1998.[30] *See Charts 1 & 2!*

Growth in transport put pressure on oil demand. An important driver of the increased demand was car travel where annual car use increased much more rapidly than car fuel intensities fell across the IEA-11 countries. Similarly for freight transportation, haulage by trucks increased rapidly while there were only small reductions in truck fuel intensities in most IEA-11 countries. Conversely, oil use fell significantly in all three stationary (non transport) sectors. In manufacturing this came as a result of three factors: reduction in energy intensities, structural changes towards less oil-intensive sub sectors, and direct substitution of oil by other fuels.
The total effect for the IEA-11 was that manufacturing oil use fell much more than total manufacturing energy did (60% versus 8% between 1973 and 1998!). Oil use in residential and service sector buildings also fell considerably, 40% and 50% respectively, between 1973 and 1998. This decline is primarily a result of shifts from oil to other heating alternatives and a general reduction in space heating intensities. The share of oil use for all three stationary sectors fell from almost half of total final oil demand in 1973 to only a fifth in 1998.
Oil use has become concentrated primarily in transportation.

[30] *Data presented is restricted on the IEA 11 countries.*

Chart 1: *Oil Demand by Sectors, IEA-11, 1973*

(Data Source: International Energy Agency)

Global Oil Demand in Year 1973 was about 57 million barrels a day.

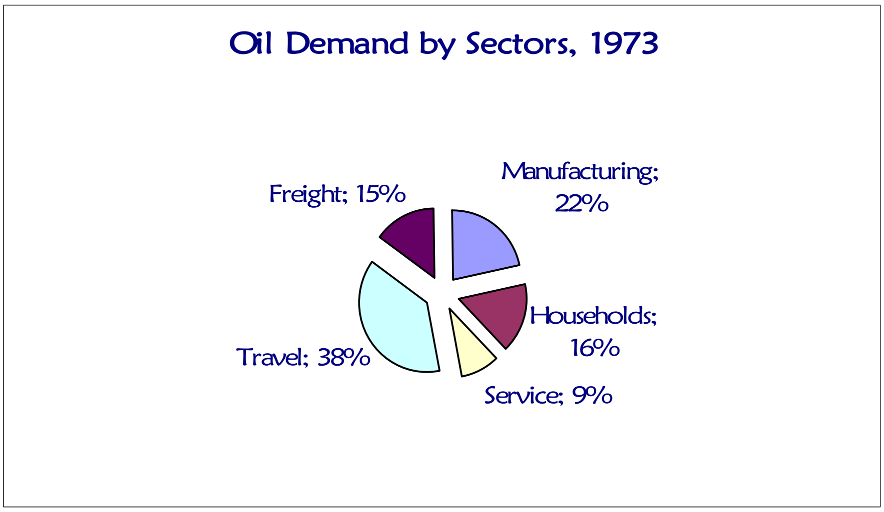
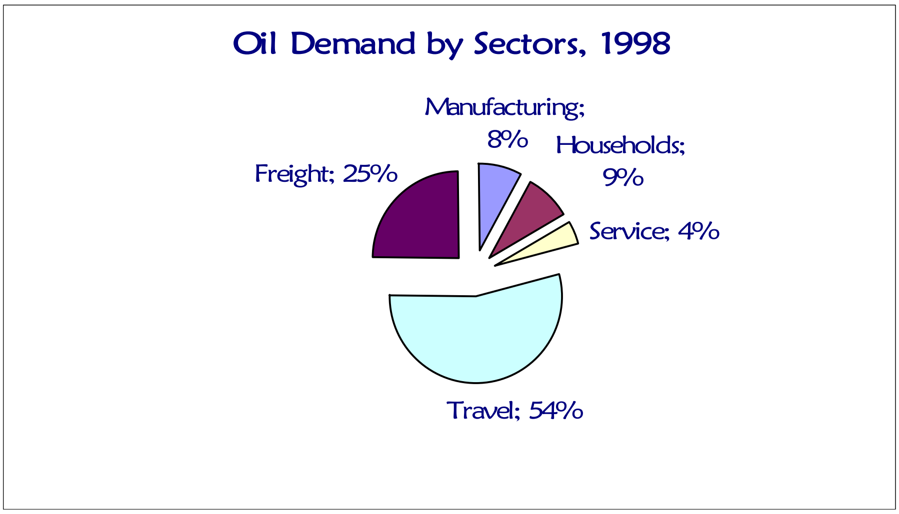


Chart 2: *Oil Demand by Sectors, IEA 11, 1998*

(Data Source: International Energy Agency)

Global Oil Demand in Year 1998 was about 75 million barrels a day.

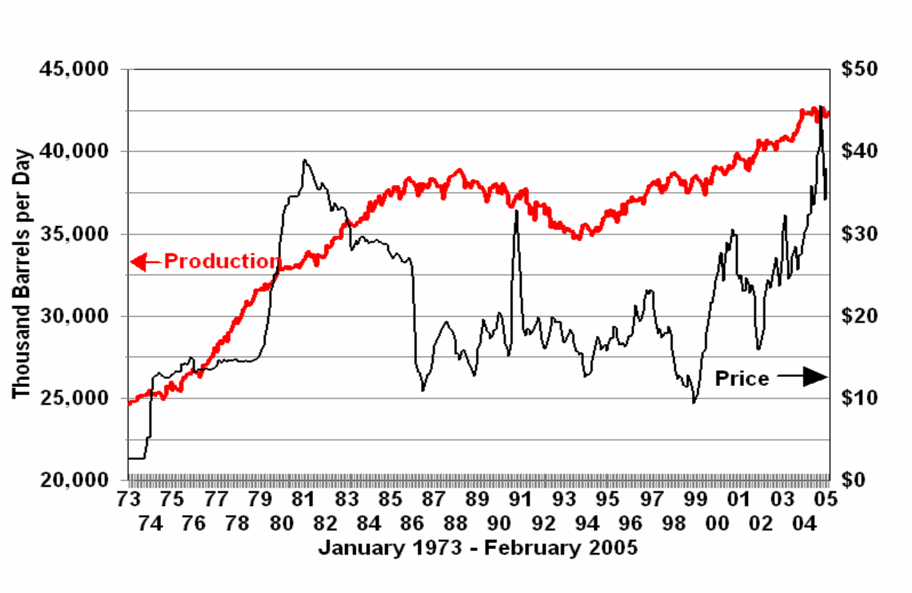


2.2.2.2.2 Non-OPEC Production

Since OPEC possesses a role of residual supplier on the oil market, cartel's market share is directly relating to the state of non-OPEC production. Therefore, it seems useful to analyze the non-OPEC supply.

Most producers outside OPEC can be considered as price takers and profit maxi-misers. Thus, non-OPEC production behaviour is assumed to be competitive.
But pure economic models of non-OPEC production have generally proved unreliable because there is no simple relation between real oil prices and production. *See Figure 6!* For example, US oil production increased significantly between the end of World War II and 1970, despite a general decline in price. Conversely, prices increased greatly between 1970 and 1985, but production declined. Similar contradictions between price and production are observed in the North Sea.
These contradictions can be explained if taking into account not only economic incentives but also resource depletion, technical change, and political considerations. So, all these factors must be included if specifying the non-OPEC oil supply.

Figure 6: *Crude Oil Production (mbd), Non-OPEC Countries Averages/Totals (Data Source: WTRG Economics)*



In order to present you equation specifying non-OPEC supply and thereby addressing the complex mix of economic, institutional and geological factors, I will concentrate on the study of R. K. Kaufmann (1991). In his study author used to combine the curve fitting technique developed by Hubbert with econometric methods.

The hybrid methodology made by Kaufmann has been developed in two steps.

Firstly, R. K. Kaufmann concentrated on physical characteristics of oil fields.
He estimated the logistic curve for cumulative oil production by using the following equation:

$$\ln\left(\frac{Q^{\infty}}{Q_t - 1}\right) = \ln(a) + b(t - t_0) \qquad (16)$$

- Q^{∞} : ultimate recoverable supply of oil;
- Q_t : cumulative oil production at time t;
- t_0 : starting date of depletion;
- a , b : amplitude parameters;

The first difference of the logistic curve defines the production curve (ΔQ_t)[31]. This production curve generates the annual rate of production.

The second step of Kaufmann's study was to define the co-integrating relationship for the economic, geological, and institutional determinants. He used to specify the following equation doing so:

$$PROD_t = \alpha + \beta_1 ROIL + \beta_2 Dummy + \beta_3 \Delta Q_t + \beta_4 Asym + \mu_t \qquad (17)$$

- $PROD_t$: oil production (non-OPEC production);
- $ROIL_t$: real price of oil;

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[31] *Hubbert's bell shaped curve for the production cycle of a non-renewable resource;*
Using this curve, Hubbert was able to generate a remarkably accurate forecast for the peak in US oil production.

- ΔQ_t : annual rate of production generated by the production curve;
- $Dummy$: dummy variable that may affect local production;
- $Asym$: variable designed to test the assumption of symmetry that is implicit in the production curve; it can be used only for regions where production has continued beyond the peak of the production curve;
- μ_t : residual factor;

While $Dummy$ variable presents a set of possible institutional (political) factors impacting the non-OPEC production (for instance, prorationing by the Texas Railroad Commission or the "Peso" crisis in Mexico), real oil price and annual production rate incorporate economic and geological aspects respectively.

Dées *et al* (2004) used to update the model developed by Kaufmann in order to test the relevance of geological, economic and institutional factors for nine non-OPEC supply regions: Lower 48 (US), Alaska (US), Canada, W. Europe, non-OPEC Asia, non-OPEC Africa, non-OPEC S. America, Brazil, and Mexico.[32]
The regression results confirmed the influence of $Dummy$ variable in Alaska (US) and Mexico. $Asym$ variable was proved to be significant for the production of Lower 48 (US), Alaska (US) and non-OPEC Latin America while, as expected, annual rate of production and real oil price were proved to impact the oil production in all observed regions.

2.2.3 Some Final Remarks With Respect to the Crude Oil Market

International crude oil market can generally be organized in two related structures, OECD section and non-OECD section.

In OECD section one can formulate the short-term balance between supply and demand by considering the inventory changes. *See Cash Market Fundamentals, Subsection 2.1.2.1.!*

[32] *The estimation sample includes quarterly data from 1984Q1 to 2002Q1.*

In non-OECD countries we confront with some difficulties. The market is characterized with shortage and unreliable data and is also, unlike OECD section, deprived of stocks. Although some countries, like China, meanwhile moved towards creating stocks in order to secure from disruption in supply, data summarizing stocks are in these countries very often not available or a matter of secret. Therefore, it is not possible to follow the trajectory of inventory stocks for this market section, and so the use of inventory changes for the purpose of price modelling is not applicable.

3 Oil Price Modelling

The main goal of this master thesis is the investigation of oil price impact parameters. An extensive introduction into the field of price impact parameters took place in previous Section by discussing fundamentals of the crude oil market. In this Section I will turn my attention to the existing methods of oil price modelling following the intention to sum up the impact parameters common used in previous studies of price analysis. Additionally, I will present the actual model of oil price forecasting that incorporates the market fundamentals. Statistical analysis of its performance and the comparison with the recent oil price trajectory reveal the existence of impact parameters, such as speculation, that are well significant as a supplement to the supply-demand balance.

3.1 Introduction

If speaking about price modelling, it seems essential at begin to shortly remind on how an economic model is generally built.

First, it is necessary to postulate the form of the model by means of determining parameters – some variables are suggested as being the determinants.

Second, it is important to quantify the relevance of this relationship from historical evidence - this can be done by using one of the statistical techniques described in econometric textbooks such as Pindyck & Rubinfeld (1981).

Modelling is in practice used for the purpose of forecasting, and so there are three sources of potential error if forecasting the oil prices:

"(i) the incorrect determining factors may have been identified (…); (ii) the quantitative relation between the factors and oil prices may not in fact be the same as estimated (…); (iii) the choice of the values used for the forecasting period of the variables determining the series are incorrect!" (*Robert Bacon, "Modelling the Price of Oil", 1991)*

3.2 Oil Price Characteristics

I will use this subsection to present some general features of the crude oil price.

A given crude oil price determined on a particular day can have two dimensions of variation. In particular, prices are quoted by location and by date of delivery. The transport of crude oil may be very expensive, and therefore the price at the point of production (fob) does not equal to the price at the point of import (cif) [33]- the margin for transport costs, insurance and handling costs is substantial and on occasion can vary substantially, for instance in the case of sudden shortage of tankers. But physical transport of crude oil also takes some time as well. This time period might be quite long (a couple of weeks), and so it is one of the reasons for the market of risk trading to be established since firms often wish to purchase "forward".

Oil prices are conventionally quoted in US dollars per barrel [34] whatever the point of delivery, and hence to obtain a domestic price an exchange-rate conversion will be needed. This characteristic of crude oil price makes it being especially sensitive to the US monetary policy.

Let me now take a closer look at the way fiscal policy affecting oil prices. Data summary that is subsequently used relates mainly to the work of A. Al-Faris (1991).
An appreciation of the dollar vis-à-vis other major currencies is expected to lead to a decrease in demand outside US. At the same time, this appreciation in the value of the dollar would lead to an increase in supply outside the US. This increase in supply, combined with decreasing demand, would drive the nominal price of oil down. The opposite is expected to happen if a depreciation of dollar occurs. But the situation is much more complicated if considering the real oil prices. An appreciation in the US dollar against the currencies of the major industrialized countries could offset the adverse impact on inflation. Nevertheless, this factor could play either way. In some instances, the depreciation of the US dollar tended to amplify the decline in the oil prices in real terms. In 1978-79, for example, the depreciation of the US dollar added to the decline in oil prices in real terms, which was compensated by a sharp rise in nominal prices in 1979-80.
The effect of inflation on both the magnitude and frequency of price changes was evident in the 1970s (*See Figure 7!*). Following the first oil price shock in 1973, the industrialized countries witnessed a high inflation rate. The deterioration in the oil-exporting countries' purchasing power induced them to revise oil prices upwards. In the

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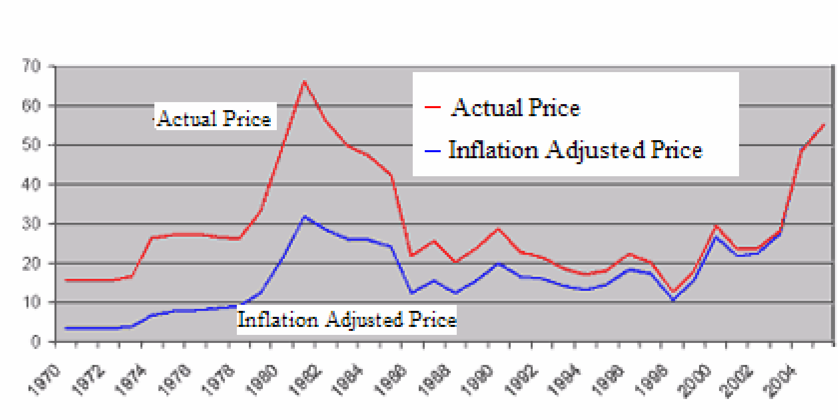
[33] *Assuming that transport is needed!*
[34] *One barrel of crude oil is 0.136 metric tonnes or 261 imperial gallons*

first half of 1980s, however, there was a deceleration of the rate of inflation. The wholesale price index in the seven industrialized countries dropped from 13.4 per cent in 1981 to 4.4 per cent in 1985. On the other hand, crude oil prices rose over the period 1980-1981, and witnessed relative stability during 1982, before falling constantly over the period 1983-85. A large part of the decline in nominal prices was offset by the rising value of the US dollar.

***Figure** 7: The Average Price of Barrel of Oil over the Period 1970-2004*
(Data Source: Energy Information Administration)



Finally, I would like you to notice that three particular oil crudes have tended to be the reference points for comment and for modelling:

- Dubai Light (API 32) – a representative crude price for Middle East producers; successor of Arab Light (API 34);
- Brent Blend (API[35] 38) – a blend of similar crudes from the North Sea; the nearness of the North Sea to the major refining industry and large North European market increased the importance of this crude;
- West Texas Intermediate (API 40) – crude that serves as a reference point for the US market;

[35] *API is a scale devised by the American Petroleum Institute to measure the specific gravity of crude oil;*

Prices of different crudes move strongly together, and so it seems reasonable to focus on single crude that is consistently defined. This kind of approach is in common for all of the studies relating to the oil price modelling.

3.3 Selected Methods of Oil Price Modelling

Before 1973 oil prices were largely administrated and were roughly constant in nominal terms so that there has been little interest in modelling the behaviour of world oil prices before this date. Consequently, all existing pricing models relate to the course of oil price trajectory initiating at 1973.

Following subsections are used to discuss some selected concepts of oil price modelling. I will thereby restrict on considering the ideas of R. Bacon (1991), A. Al Faris (1991), F. Wirl (1990, 1991, and 1994), Kaufmann *et al* (2004), and Zamani (2004) on this issue. These are offering the possibility to capture not only short-run impact parameters but also those being relevant in the long run.

3.3.1 "Modelling the Price of Oil" by *R. Bacon* & "The Determinants of Crude Oil Price Adjustment in the World Petroleum Market" by *A. Al-Faris*

In order to present the standard practice of oil price modelling I will combine the analysis made by A. Al-Faris (1991) with theoretical explanations issued by R. Bacon (1991).

Al-Faris (1991) analyzed two distinct but closely related objectives - he tried to explain the process of oil price formation as well as the impact of market structure on the oil price behaviour. This second objective was of special interest for him. He wanted to prove the correlation between the degree of concentration (taken as a proxy measure of market power) and the relative degree of price rigidity. Al-Faris assumed, beginning his analysis, that an increase in control over the market by some firms automatically provoke some correspondent decrease in price variability and vice versa.[36]

[36] *The relationship between concentration and price rigidity has been tested also earlier in the past. For example, study that has covered 34 Canadian industries over the period 1948-75 found persuasive evidence that there is a strong relationship between industrial concentration and price rigidity.*

In order to develop the final price identity Al-Faris worked gradually. He began with the simple static equilibrium model of price determination.[37] This simple static equilibrium model presents a set of functions which relate oil prices to various market factors. The basic idea defines the interaction between supply and demand as price determining matter.

Al- Faris assumed the demand to be a function of the crude oil price P, the level of real economic activity in industrialized countries (GDP) that will be denoted as Y, and the exchange rates between the currencies of those industrialized countries and the US dollar ($R^{'}$).

He used to express the demand function as follows:

$$Q^d = \alpha_0 + \alpha_1 P_t + \alpha_2 Y_t + \alpha_3 R^{'} + \mu_1 \qquad (18)$$

- μ_1: stochastic disturbance;

In addition, the supply was assumed to be a function of the commodity price[38] and the exchange rate between the currencies of oil-producing countries and the US dollar ($R^{''}$).

Thus, the supply function has been expressed as follows:

$$Q^s = \beta_0 + \beta_1 P_t + \beta_2 R^{''} + \beta_3 Du + \mu_2 \qquad (19)$$

- μ_2: stochastic disturbance;
- Du: dummy variable presenting supply shocks;

---

[37] *The same kind of approach has been pursued by R. Bacon. Bacon concentrated on global supply - demand balance in year 1990.*

[38] *Producers are competing among themselves for the market share.*

Point where supply and demand intersect denotes the market equilibrium. Therefore, by using identities (18) & (19) the equilibrium price can be presented as:

$$P_t = \Psi_0 + \Psi_1 Y_t + \Psi_2 R_t^{'} + \Psi_3 R_t^{''} + \Psi_4 Du + \zeta_t \qquad (20)$$

where:

$$\Psi_0 = \frac{\beta_0 - \alpha_0}{\alpha_1 - \beta_1}; \quad \Psi_1 = \frac{\alpha_2}{\alpha_1 - \beta_1}; \quad \Psi_2 = \frac{\alpha_3}{\alpha_1 - \beta_1}$$

$$\Psi_3 = \frac{\beta_2}{\alpha_1 - \beta_1}; \quad \Psi_4 = \frac{\beta_3}{\alpha_1 - \beta_1}; \quad \zeta_t = \frac{\mu_2 - \mu_1}{\alpha_1 - \beta_1}$$

The static equation (20), postulated by Al-Faris, states that the crude oil price is determined by the level of economic activity in consuming countries, as well as by the exchange rates between the national currencies of oil-consuming and producing countries vis à vis US dollar. In addition, a supply shock was included to account for external influences.

Empirical estimations of the identity (20) (quarterly data: 1973 to 1985) proved that more than 86 per cent of price variations are explained by the specified variables.[39]
The relevance of all used variables has been confirmed. In particular, the level of economic activity in industrialized countries and the exchange rate of the oil producing countries' currencies vis-à-vis the US dollar were proved to be correctly signed and well significant at the 99 per cent level while the exchange rate of the industrialized countries was proved to be correctly signed and significant at the 80 per cent level.[40]
But estimations also included a Durbin-Watson ("DW") test of serial correlation. DW was about 0.76, which is relatively low, suggesting a misspecification of equation (20). Al-Faris subsequently assumed that suggested misspecification results from excluding some relevant variables from the model, and so he decided to go ahead with his study of price formation.

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[39] *Ordinary Least Squares Regression (OLS): squared coefficient of multiple correlation ~ 0.8655;*
[40] *The exchange rate of oil-producing countries vis-à-vis US dollar is negative signed suggesting an inverse relationship with oil price.*

At this point I would like to state one obvious difference when comparing the static equilibriums of Al-Faris (1991) and Bacon (1991). Since Bacon succeeded in recognizing the importance of stocks in the short run, he decided to introduce the stock movements into model equation. "Putting the three elements of supply, demand and stock changes together will in principle allow a market clearing price to be calculated. (…) However, by their nature, substantial stock accumulations or drawdowns are unlikely to persist over lengthy periods of time. (…) Stocking and de-stocking can be extremely important in the short run, but is unlikely to be important in the long run." (*R. Bacon*)

In his further study of the static equilibrium model Al-Faris recognized three major drawbacks. "The first is the neglect of the influence of market power on price behaviour. The second is the problem of modelling a market with a dual price system. And the third is the dynamic nature of price formation in the oil industry." (*A. Al-Faris*)

As a consequence, Al-Faris introduced two new variables (concentration ratio (C) & the wealth of the oil producing countries (W)) in order to capture the effect of the market power, and the possible influence of producers collaboration.[41]
By considering the dual price system in the oil market he assumed the spot market as the marginal supply[42], and in addition, he introduced the spot price as an independent variable - dual price system usually exists whenever there is output rationing.
Moreover, by arguing that in an inflationary environment the frequency of price adjustment positively correlates with the inflation rates, Al-Faris also decided to use an index of inflation (OECD countries) as an independent variable.

Thus, the equation (20) has been extended as follows:

$$P_t = \Psi_0 + \Psi_1 Y_t + \Psi_2 R_t^{'} + \Psi_3 R_t^{''} + \Psi_4 C_t + \Psi_5 W_t + \Psi_6 P_{t-1}^{s} + \Psi_7 N_t + \zeta_t \qquad (21)$$

- P^s : the spot price;

[41] *The wealth of the oil-producing countries is the aggregate total international liquidity of all OPEC members. It reflects their ability to practice a collaboration policy.*
[42] *Following R. Bacon, "A Study of the Relationship between Spot Product and Spot Crude Prices", 1984;*

- N : index of inflation in OECD countries;

Empirical estimations of the equation (21) suggested that more than 99 per cent[43] of price variations are obtained by the specified variables.[44] All new variables were confirmed to be relevant (the lagged spot price and the variable presenting the wealth in oil producing countries were correctly signed and significantly different from zero at the 99 per cent level, the current inflation was significant at the 90 per cent level while the concentration ratio's coefficient was correctly signed and significantly different from zero at the 80 per cent level)[45], but in this case the degree of significance of exchange rates of neither the industrialized countries nor the oil-producing countries proved to be different from zero at the five per cent level.

Finally, in order to capture the dynamic nature of price formation Al-Faris developed the error correction mechanism for price adjustment.[46] The reason for implementing this kind of price adjustment is the fact that all oil producers possess some theory about the way the oil market works. This theory, used in their daily market activity, is a mixture of their experience, present observations and future expectations. "If past observations are used to form future expectations or lead to systematic price revisions in a way that maintains the future realizations of the official prices, then dynamic price adjustments suggest an error correction formulation." (*A. Al-Faris*)

At the end of this subsection I will summarize some final remarks made by authors.

R. Bacon (1991) stated four major components of the supply/demand market clearing model as follows:

- The size of the short- and long-run price elasticities of supply and demand;
- The elasticities of the other 'regular' factors, such as world GNP[47];

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[43] *OLS Regression: squared coefficient of multiple correlation ~ 0.9907, DW ~ 1.92;*
[44] *The lagged price variable has been added to the right side of the identity (21) for the purpose of estimation!*
[45] *The wealth variable is negative signed suggesting an inverse relationship between market power and price variation.*
[46] *The presentation of error-correcting mechanism is a matter of pure econometrics, and so I won't make any further comments on that.*

- The likely movements of the ‘regular’ factors;
- The possible magnitude of any major shocks;

Making additionally some long-run considerations on oil price behaviour, Bacon indicated the importance of investment and relative prices of competing forms of energy.
Finally, he specified the modelling and forecasting of large shocks, which appear to hit oil market from time to time, as the crucial task for the future studies of price formation.

The results obtained by Al-Faris made him feel confirmed in his assumption of correlation between the market power and the direction of price adjustments. “A fall in the largest producers’ share, because of either new entry or the fringe producers’ aggressive price policy, would tend to create downward pressure on prices.” (*Al- Faris*)
Moreover, he stated that the existence of a unified goal among largest agents may allow them to exercise a degree of power even greater than that suggested by the concentration ratio.

3.3.2 “The Future of World Oil Prices: Smooth Growth or Volatility?” & “The World Oil Market after the Iraq - Kuwait Crisis: Economic and Politicoeconomic Considerations” by *F. Wirl*

Wirl used to characterize and compute rational oil price trajectories by applying the differential game theory[48] to the theory of exhaustible resources that dates back to H. Hotelling (1931).
He adopted the reasoning in which OPEC reasonably well knows the size of recoverable reserves, the costs of production and the demand for their crude oil. Moreover, he assumed OPEC members trying to maximize the present value of profits from oil sales.

Wirl defined the following demand relation for OPEC oil:

$$x_t = \alpha + \beta \times p_t + \gamma \times t + \delta \times x_{t-1} \qquad (22)$$

[47] *Gross National Product;*
[48] *A. Mehlmann, Applied Differential Games, Plenum Press, New York (1988);*

- t: time variable referring to annual figures;
- x_t: demand for OPEC oil in period *t ;*
- p_t: price of crude oil;
- $\alpha, \beta, \gamma, \delta$: numerical coefficients obtained from data sources covering the observed period;

Steady state of the above dynamic empiric relation (i.e., there is no lagged variable x_{t-1}!) can be presented as follows:

$$x_t = \alpha_1 + \beta_1 \times p_t + \gamma_1 \times t \tag{23}$$

So, the inverse demand function for OPEC oil, which determines the market-clearing price p for given aggregate OPEC extraction x [49], can be written as:

$$p_t = P(x_t, t) = \alpha_2 + \beta_2 \times x_t + \gamma_2 \times t \tag{24}$$

- The intercept α_2 determines the backstop price (which chokes off demand) at the time $t = 0$, whereas $\alpha_2 + \gamma_2 \times t$ determines the backstop price at time t;

The function P increases with time as the result of growing incomes and resulting higher oil demand without rising oil prices.

The OPEC extraction x_t presents the sum over the producer outputs:

$$x_t = x(t) = \sum_{i=1}^{N} x_i(t) \; ^{50} \tag{25}$$

Output of every particular producer is a matter of the correspondent production policy. Each producer tries to maximize the present value of profits by choosing optimal

[49] *OPEC extraction meets the demand for OPEC oil.*
[50] *For N=1, there is cooperation or a monopolistic solution.*

depletion strategy and a depletion date – every single depletion strategy imposes different costs of producing. Quest for optimal depletion strategy is subject to producer's initial resource stock and to amount of his cumulative production up to the period t. But nevertheless, if searching for maximized value of profits, every producer has to include into calculations also the actual crude oil price, and so the optimization problem for each producer depends on the strategies of the competitors.[51]

Because all these opponents solve a similar optimization problem, the Nash-Cournot equilibrium is a natural candidate for these independent decisions.[52]

Following the analysis presented above, F. Wirl tried to forecast the rational trajectory of the crude oil price. He supplemented his model of price formation by assuming OPEC as a loose arrangement of politically motivated members, some of which are able to swing the production appreciably in the short run - Saudi Arabia is the main swing producer of OPEC. (OPEC behaviour is somewhere between two corner solutions!)

As a result of this study, Wirl suggested the volatile price behaviour, in which the oil price alternates between "high" and "low", being the rational one since it presents the optimal cartel policy (*See Figure 8!*). He argued that a small short-run price elasticity of demand, which offers the possibility for enormous short-run profits, provides the economic basis for successful cooperation among OPEC members if intending to force some price hike. After some time, these high prices would reduce demand for OPEC oil (*Compare Figures 9 and 10!*), and would subsequently require a reduction of the production quotas. "These circumstances of high oil prices but low production quotas increase the potential profits from *ex post* opportunism, and as a consequence, prices would tumble – sooner or later - due to the continuous erosion of cartel discipline."

Finally, Wirl specified the boundary prices (the corner solutions of a target price range) as reflection of constraints exogenous to the cartel. "The loss of political good will and the threat of counterstrategies of the oil importing countries are examples for the upper price limit. Internal and domestic constraints like a minimum of a financial cash flow at any period are examples for the lower price boundary." (*F. Wirl*)

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[51] *The extraction rate of complementary players impact the global OPEC extraction rate and so the market clearing price.*

[52] *A Nash-Cournot equilibrium is given if all producers maximize their profits, and so no one has an incentive to change his strategy.*

Figure 8: *Optimal OPEC Price Strategy (Data Source: The Future of World Oil Prices - Smooth Growth or Volatility?, F. Wirl, 1990)*

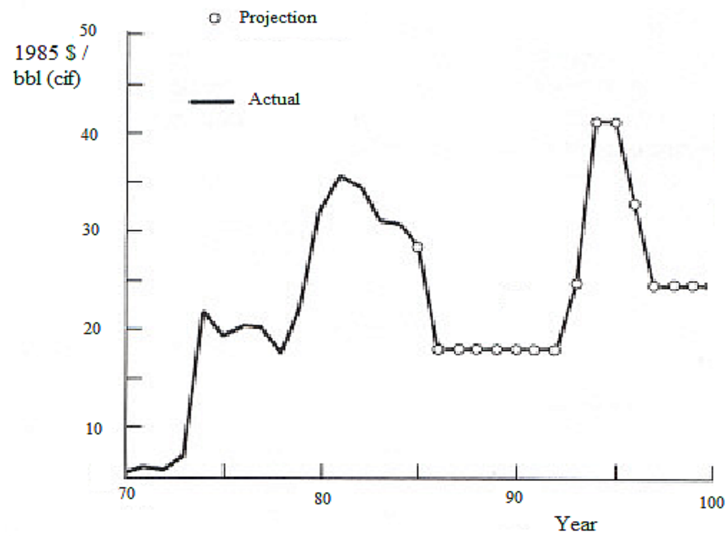
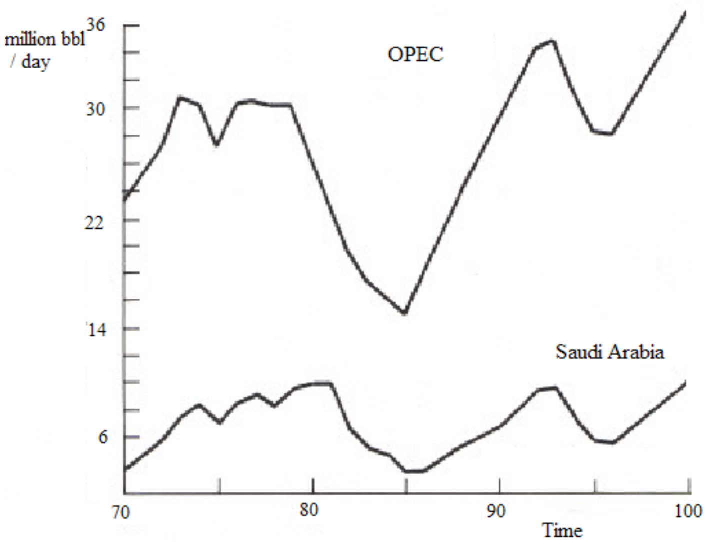


Figure 9: *Demand for OPEC Oil – Optimal OPEC Price Strategy (Data Source: The Future of World Oil Prices - Smooth Growth or Volatility?, F. Wirl, 1990)*



3.3.3 "Does OPEC matter? – An Econometric Analysis of Oil Prices" by *R. K. Kaufmann, S. Dées, P. Karadeloglou, and M. Sánchez*

In their study Kaufmann *et al* (2004) suggested the crude oil price relating to measures of OPEC production behaviour and market indicators of the supply/demand balance. They assumed that, at any given price, demand determines the optimal quantity of oil supplied. In addition, non-OPEC countries adapt their production to this new price and OPEC acts as the swing producer to equilibrate supply and demand consistent with the optimal price/quantity situation.

Kaufmann *et al* postulated the following specification of the price rule for crude oil:

$$\begin{aligned} P_t^{Oil} &= \alpha + \beta_1 \times Days_t + \beta_2 \times \overline{Quota_t^{OPEC}} + \beta_3 \times Cheat_t + \beta_4 \times Caputil_t \\ &+ \beta_5 \times Q_1 + \beta_6 \times Q_2 + \beta_7 \times Q_3 + \beta_8 \times War + \mu_t \end{aligned} \tag{26}$$

- $Days$: the variable presenting days of forward consumption of OECD crude oil stocks, i.e. $\dfrac{\overline{Stocks^{OECD}}}{\sum_{i \in OECD} DEM_i}$;
- $\overline{Quota}$: the variable presenting OPEC production quota in mbd;
- $Cheat$: the variable presenting the difference between OPEC production and OPEC quota, i.e. ($PROD^{OPEC} - \overline{Quota}$);
- $Caputil$: the variable presenting capacity utilization by OPEC, i.e. $\dfrac{PROD^{OPEC}}{\overline{\overline{Capacity^{OPEC}}}}$;
- Q_1, Q_2, *and* Q_3: dummy variables for quarters I, II, and III, respectively;
- War: dummy variable for the Persian Gulf War (third and fourth quarters of 1990);

By testing the relevance of the equation (26), Kaufmann *et al* estimated the significance of used impact parameters.[53] Table 3 presents regression results.

Table 3: *Estimates for Price Equation*

(Data Source: "Modelling the World Oil Market", Dées et al, 2004)

Variables	***Coefficients***
Days	*-1.45*
Caputil	*32.47*
Cheat	*-2.00*
Quota	*-2.05*
Adjustment rate[54]	*-0.56*

The regression coefficient associated with the variable *Days* is negative suggesting that an increase in stock reduces real oil price by reducing reliance on current production and thereby lowering the risk premium that is associated with a supply disruption. Similarly, an increase in the *Cheat* variable also tends to reduce the oil price – an increase in OPEC production relative to their quota increases supply relative to the demand perceived by OPEC when setting the quota[55].

The positive sign on the regression coefficient associated with *Caputil* indicates that increases in capacity utilisation tend to increase prices. In particular, as demand for OPEC oil increases production relative to capacity, utilisation rates rise, which signalizes a "tightness" in the oil market.

As a final remark, estimates of Kaufmann *et al* also suggested the *War* variable, which has a positive effect on prices – prices rose after the Iraqi invasion on Kuwait, being of temporary nature since it was proved to disappear during the first quarter of 1991.

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[53] *Dynamic Ordinary Least Squares (DOLS), Ordinary Least Squares (OLS): Quarterly Data from 1984Q1 to 2002Q1;*

[54] *The Error Correction Term indicates that prices do not adjust immediately to the long-term relationship. In particular, the negative corresponding coefficient implies that 56 per cent of the disequilibrium among prices and the right-hand side variables in equation (26) is eliminated after one quarter.*

[55] *Perceived demand may not be the most important variable used to set the quota.*

3.3.4 "An Econometrics Forecasting Model of Short Term Oil Spot Price" by M. Zamani

The first part of Zamani's forecasting study (2004) presents developing of a quarterly model of WTI using OPEC supply, OECD stocks, and non-OECD demand. This WTI model will be the subject of my further discussion since its way of treating inventory situation impact on prices seems to be representative for a big part of recent studies analyzing the oil price behaviour.

After considering OECD stocks, Zamani was convinced to have noticed their two major characteristics. First, stocks exhibit seasonal trends due to the different seasonal patterns of OECD supply and demand. Second, there is always some normal level of stocks that is required to balance the market, and so any deviation from this normal level would influence market prices. (Theoretical and empirical evidences for this will be provided later on. *Subsection 3.4.1.!*) The Degree of such an deviation in stocks was of special interest for Zamani, as the subsequent explanation of his modelling approach reveals.

Zamani used a simple econometric model, applying seasonal dummy variables, to express the normal commercial inventory level - in contrast to majority of other studies dealing with OECD stocks, he analyzed separately the commercial stocks and government stocks (i.e., SPR[56]) arguing that these two in general follow different objectives. In addition, he defined the corresponding deviation variable that indicates deviation of actual commercial stocks from normal commercial stock level as follows:

$$SIS = SI - SIF \tag{27}$$

where:

$$SIF = \alpha_1 + \sum_{i=2}^{4} \beta_i D_i + \varepsilon_t$$

- D_i : dummy variables used to capture seasonal pattern;
- SIF : forecasting model of the normal commercial stock level;
- SI : actual commercial stock level;

[56] *Strategic Petroleum Reserves;*

Government stocks were recognized to follow a time trend, and so Zamani used to model the government stocks as a linear function of time trend variable. In addition, the deviation from normal government stock level was denoted as follows:

$$SGS = SG - SGF \qquad (28)$$

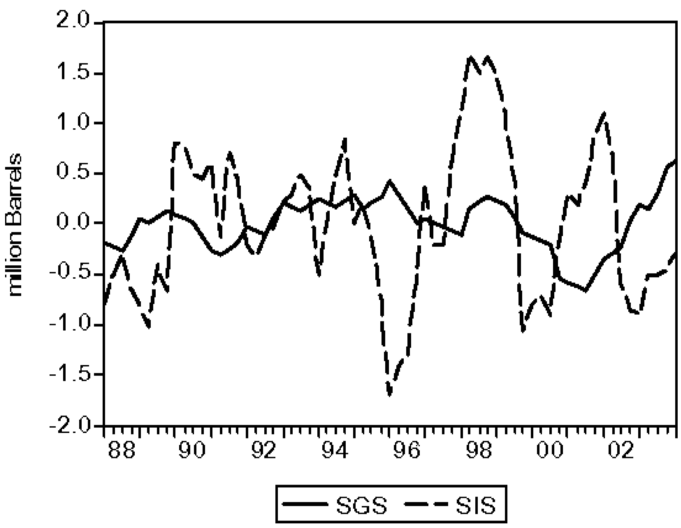
where:

$$SGF = \alpha_1 + \beta \times t_i + \varepsilon_t$$

- SGF : forecasting model of the normal government stock level;
- SG : actual government stocks;

Trends of two deviation variables over the period 1988-2003 justify the assumption of different objectives driving the commercial and government stock behaviours. Although the correlation between these two deviation variables does not vanish[57], it is not to oversee that in some duration they definitely follow fully different directions (*See Figure 10!*). Therefore, Zamani felt confirmed in his intention to separately introduce commercial and government stocks in his modelling method.

Figure 10: *Deviation from Normal Industrial (SIS) and Government (SGS) Stocks (Data Source: M. Zamani, 2004)*



[57] *Zamani calculated the correlation as -0.1.*

After performing an extensive series of statistical approaches in order to examine the persistence and direction of possible causal relationships among variables, Zamani postulated his modelling equation for WTI as follows:

$$WR_t = \alpha_1 + \alpha_2 QU_t + \alpha_3 OV_t + \alpha_4 SIS_t + \alpha_5 SGS_t + \alpha_6 DN_t + \alpha_7 D90 + \mu_t \qquad (29)$$

- WR : real price of WTI;
- QU : OPEC quota;
- OV : OPEC overproduction;
- SIS : deviation from normal level – commercial stocks (OECD);
- SGS : deviation from normal level - SPR (OECD);
- $D90$: dummy variable for Iraq war in third and fourth quarter of 1990;
- DN : non-OECD demand;

As a remark, the OPEC production behaviour is modelled by Zamani on the same way as it was by Kaufmann *et al* (2004) - actual OPEC production is assumed to be a sum of OPEC production quota and some overproduction.
"Quota allocation changes when oil price moving and remaining out of the OPEC target range and when quota changes in reveres direction influences price, however their relationship should be investigated using statistical approaches. The need for higher oil export revenues and market share is the pre assumption for overproduction behaviour so a negative causal relation from overproduction to oil price is reasonable" (*M. Zamani*)

Finally, OLS regression has been used to estimate the relevance of impact parameters used in the specification (29). Table 4 presents OLS regression result[58].

[58] *Quarterly data for period 1988 – 2004 has been used (IEA);*

***Table 4**: OLS Regression Result*
(Data Source: M. Zamani, 6th IAEE European Conference 2004)

Variable	***Coefficient***[59]
QU	*-0.17*
OV	*-0.77*
SIS	*-2.7*
SGS	*-3.0*
DN	*1.2*
D90	*12.9*

The regression results that are presented in Table 4 generally agree with those obtained by Kaufmann *et al* (2004). *See Subsection 3.3.3.!*

3.4 Actual Oil Price Forecasting Model – An Econometric Analysis of Model Performance Providing the Evidence for the Impact of Speculation on Crude Oil Prices

At this point I would like to begin dealing with actual forecasting model of oil spot price. My major intention thereby is not to extensively analyze the forecasting method but to propound the statistical evidence of impact of speculation on crude oil price – none of previous studies considered the impact of risk trading. In order to do so, in addition to explanation of basic principles of present forecasting method incorporating market fundamentals, I will mainly concentrate on recent analysis of model performance and subsequent model revision made by A. Merino & Á. Ortiz (2005).

3.4.1 Standard Forecasting Method Consistent With the OECD Petroleum Inventory Situation

Accruement of actual oil price forecasting method dates back to Ye *et al* (2002).

3.4.1.1 "Crude Oil Market in the Recent Decade" by Ye *et al*

The petroleum market in the 1990s exhibited some features that allowed for the establishment of quantitative insights between crude oil prices and market fundamentals. Over much of the time in the 1990s, OPEC did relatively little to adjust

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[59] *The negative signs of estimated coefficients indicate variables being in inverse proportion to price.*

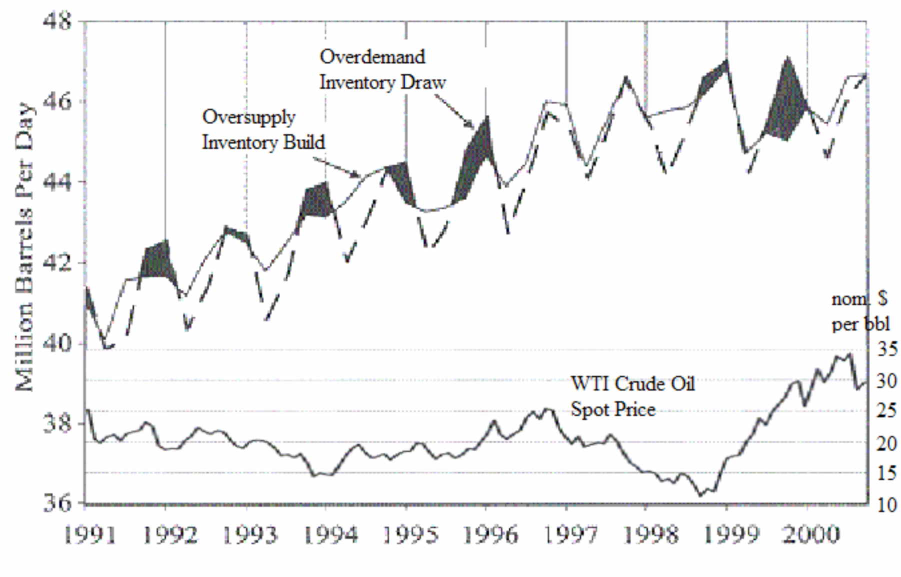
production to balance demand changes. Sometimes, when action took place, it was either insufficient or excessive, and so there has been a fairly long period in which prices exhibited some rather large cyclical swings. *See Figure 11!*

Figure 11: *Monthly Average WTI Crude Oil Spot Price (Data Source: IAER, 2002)*

Global demand for petroleum products is highly seasonal and is greatest during the winter months, when countries in the Northern Hemisphere increase their use of distillate heating oils and residual fuels. Supply of crude oil, including both production and net imports, also shows a similar seasonal variation but with smaller magnitude. During the summer months, supply exceeds demand and OECD petroleum inventories normally build. During the winter demand exceeds supply and inventories are drawn down. That is the reason for the inventories to demonstrate seasonality.
Thus, if market supply and demand are balanced over the period of a year, the increase in inventories over the summer will equal the decline over the winter.

Figure 12 indicates that oil market was well out of balance in 1998. In that year we had slowing demand growth and increasing supply. Reasons for the slowing demand growth were Asian financial crisis and two successive warm winters. On the other hand, because of Iraqi crude oil exports who came back into the market in 1997 (Oil for Food Program), the crude oil supply in the 1998 strongly increased. As a result, the inventories grew to unusually high levels in that period, and so WTI crude oil prices fell to near $10 per barrel by the end of 1998.

Figure 12: *OECD Crude Oil Supply and Petroleum Demand*
(Data Source: IAER, 2002)

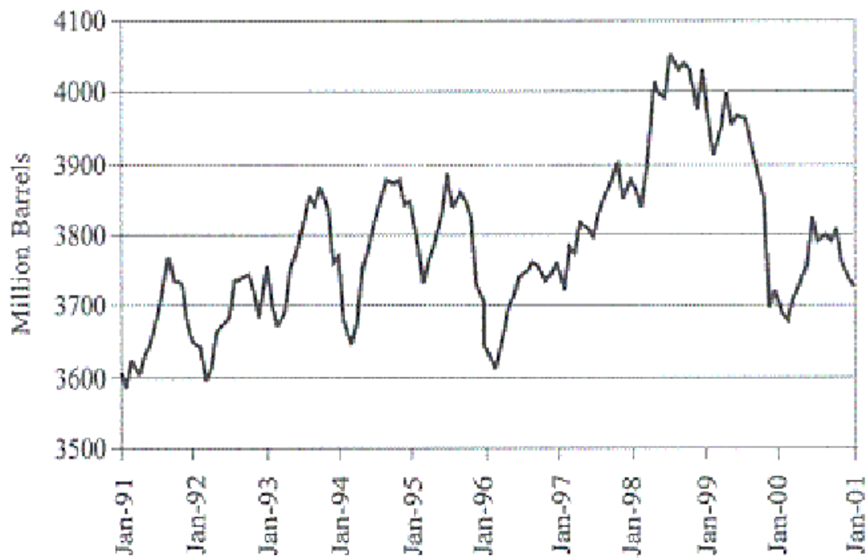


Following the concern of oversupply and extremely low prices, OPEC agreed in March 1999 to cut back the production to a level well below demand. But, as opposed to expectations, during this time Asian economies had an quick recovery, so that demand for crude oil increased. Thus, over the 1999, the supply-demand imbalance reversed. Demand well exceeded supply, and so the inventories decreased. The excess inventories that had been built up fell rapidly to bellow normal, and WTI crude oil spot price rose to over $30 per barrel by early March 2000. *See Figure 12!*

Figure 13 illustrates how the total OECD oil inventories, defined as the sum of government stocks and commercial stocks of both crude oil and petroleum products, have changed over the 1990s. It is easy to notice the large excess and then underage of inventories over the last several years of 1990s relative to variations away from some kind of normal level seen in the first half of the decade.

The above discussion has revealed empirically the importance of such an normal level in OECD inventories when exploring inventory relationships to price, and the following subsection supplements that issue providing an short theoretical analysis.

Figure 13: *Total OECD Petroleum Inventory (Data Source: IAER, Nov. 2002)*



3.4.1.2 <u>"Crude Oil Market Fundamentals" by Ye *et al*</u>

Assuming no losses or volume changes during processing, the following balance equation for the oil market can be written:

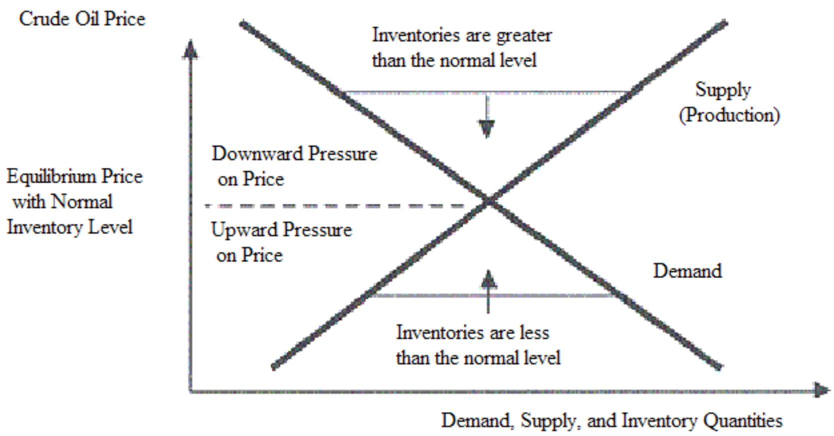
$$Demand_t = Supply_t - InventoryChange_t \qquad (30)$$

Because of the fact that $InventoryChange_t$ variable presents the difference in inventory levels when comparing the periods t & $(t-1)$, the equation (30) can be presented on the other way as well:

$$Inventory_t = Inventory_{t-1} - (Demand_t - Supply_t) \qquad (31)$$

Figure 14 illustrates how changes in inventories affect the price behaviour. Equilibrium price is achieved for initial equilibrium inventories (normal inventory level). If, for instance, demand exceeds production in a given period, inventories will be drawn down below desired normal levels and there will be positive (upward) price pressure.

Figure 14: *An Illustration of Impact of Inventory Behaviour on Price*



The case of equilibrium inventories means that the *relative inventory level*, defined as the deviation of actual inventory level from its corresponding desired normal level, is zero. Otherwise, if there is some positive (negative) relative inventory level, a downward (upward) pressure on the price occurs as a consequence.

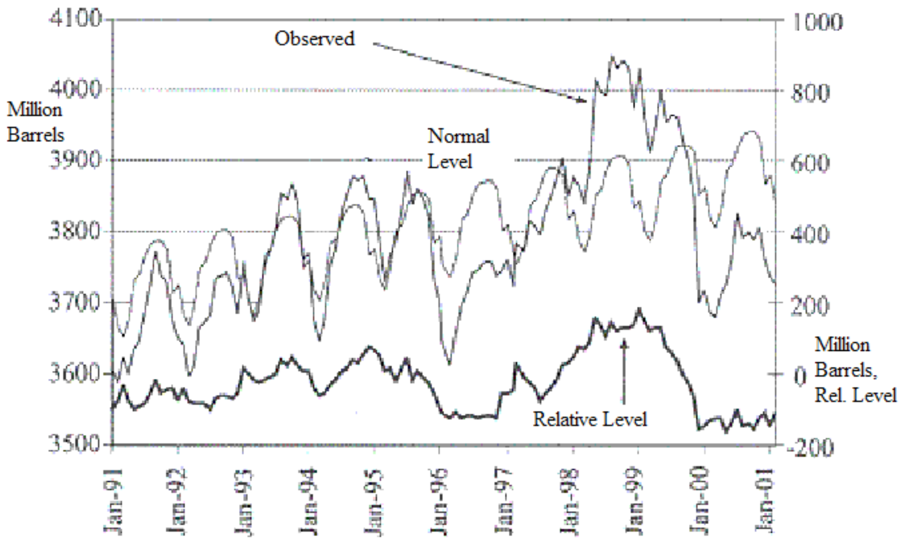
Thus, the relative inventory level seems to be crucial market parameter. It indicates if the market is tight or loose, and so reflects increase or decrease in price pressure.

Figure 15[60] is presenting the comparison between the desired (normal) level and observed level of total OECD petroleum inventories over 1990s. The normal level demonstrates a positive trend and expected seasonal movements.[61] The difference between the observed inventory level and the corresponding desired level is the so-called relative inventory level or the de-seasonalized and de-trended inventory level.

[60] *Data of OECD total inventories (crude oil & petroleum) are available since March 1984, but IEA changed its data collection methodology in December 1990.*

[61] *It is common to model the desired inventory level by applying seasonal dummy variables. See modelling of M. Zamani, Subsection 3.3.4.!*

Figure 15: *The normal Level of OECD Petroleum Invent. vs. observed Invent. Level (Data Source: IAER, Nov. 2002)*



3.4.1.3 Standard Forecasting Model – Model Equation and Model Performance

The forecast model of nominal crude oil spot price, which is consistent with the inventory situation, considers current and lagged values of deviations from desired normal level of total OECD petroleum inventories. The forecast equation can be presented as follows:

$$P_t = c + \sum_{k=0}^{n} d_k \times RIN_{t-k} + \varepsilon_t \quad [62] \qquad (32)$$

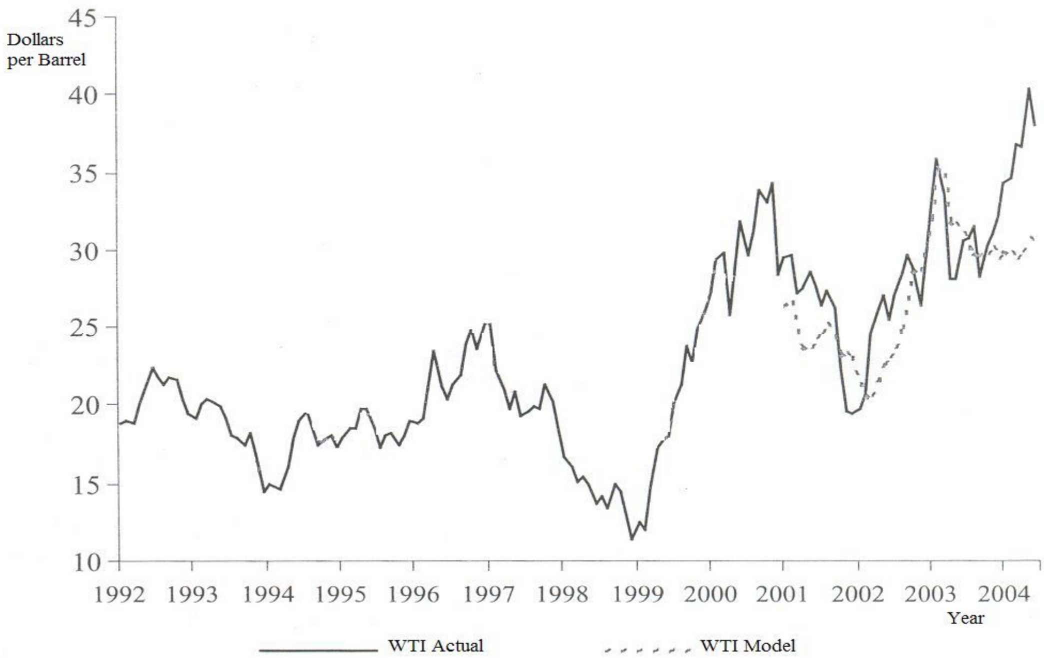
- P : crude oil spot price;
- RIN : relative OECD inventory level;
- ε : random term;
- c , d_k : coefficients to be estimated;

Although statistics of model performance indicates model prices being very much consistent with the real oil price trajectory over 1990s, the basic forecasting model

[62] *A. Merino & Á. Ortiz (2005)*

failed to explain high oil prices of recent years. In the second half of 2003 and during 2004 oil prices dramatically increased, reaching maximum levels in historical, nominal terms. The model underestimates actual prices, generating a considerable premium between actual oil price and the estimated price.[63] *See Figure 16!*

Figure 16: *Oil Price (WTI) vs. Oil Model Price (WTI) since 2001*
(Data Source: A. Merino & Á. Ortiz, OPEC Review, June 2005)



In order to explain the recent differences between the market price and price in line with model calculations, A. Merino & Á. Ortiz (2005) decided to revise the basic forecasting model. They assumed that basic model does not good enough describe the fundamentals of the oil market, and so they concluded to test the significance of some new variables trying to extend the basic model consistent with inventory situation. “We think that this model does not include enough information about “fundamentals” and, therefore, we do not share the view that the differences between the market price and the price estimated

[63] *The 2004 situation is particularly relevant. The price consistent with the inventory situation is close to $30.50/barrel and taking into account the upper bounds of the 95 per cent confidence level the estimated oil price could even reach $34–35/barrel. However, oil market prices jumped to $40/barrel, or even higher, maintaining a premium of at least $5/barrel.*

by the model should be called a "price premium", which is not explained by fundamentals." (*A. Merino & Á. Ortiz*)

3.4.2 "Explaining the so-called "Price Premium" in Oil Markets" by A. Merino & Á. Ortiz

In their study Merino & Ortiz firstly estimated "price premium" above the price level implied by the model, and thereafter they used to probe if there exist some new variables that could systematically explain this premium.

Merino & Ortiz began their analysis by defining the relative inventory variable (*RIN*) on the way Ye *et al* (2002) did. They departed from Ye *et al* only by expressing relative inventories in a percentage of total current levels (*RIN%*).
Once the measure of *RIN* was defined, Merino & Ortiz used to regress the crude oil price on present and past values of that *RIN* measure:

$$P_t = c + \sum_{k=0}^{n} d_k \times RIN\%_{t-k} + v_t \qquad (33)$$

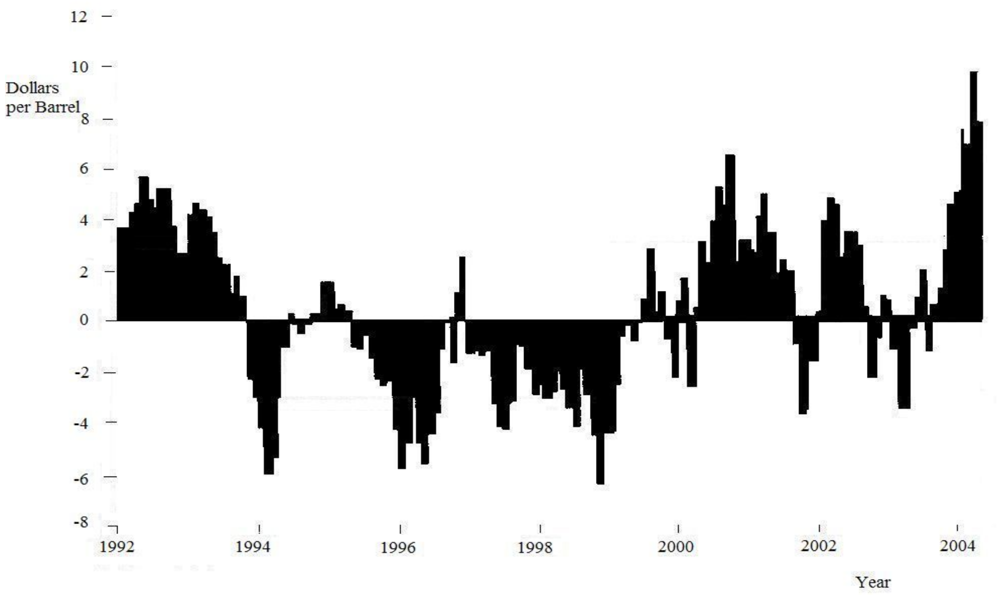
Comparing to that, the oil price level suggested by the supply-demand balance in the oil market is defined as follows:

$$P_t^* = c + \sum_{k=0}^{n} d_k \times RIN\%_{t-k} \qquad (34)$$

Merino & Ortiz defined the residual series v_t as the deviation of the oil price over the "inventory fundamental level".[64] That is the premium, which was the object of their further analysis. *See Figure 17!*

[64] $v_t = P_t - P_t^*$

Figure 17: *Difference between Actual Oil Price (WTI) & Model Price (WTI) - Premium (Data Source: A. Merino & Á. Ortiz, OPEC Review, June 2005)*



After they estimated the premium over the price level suggested by basic forecasting method consistent with inventory situation, in the second phase of their study Merino & Ortiz analyzed the information content of several variables on this premium. In particular, they used to test the ability of selected variables to explain the price premium trying to experience whether some variables contain systematic information not included in the supply-demand balance.

In order to do so, they firstly used to split all tested variables into two groups:

- Oil market directly related real and financial variables (*X* oil);
- Other financial and commodity variables (*X* fc);

Once the causality relationship has been tested[65] (Granger causality test has been executed[66] - the test checks whether the past values of our testing variable help to

[65] *They used to run the tests for the period 1992-2004 and for two other subperiods as well: 1996-2004 & 1999-2004.*

[66] *The Granger approach to the question of whether a variable X causes Y is to see how much of the current Y can be explained by past values of Y and then to see whether adding lagged values of X can*

explain the current values of the premium), they reintroduced the testing variable in equation (33) resulting in an extended model (the basic one plus the candidate variable), which can be presented as follows:

$$P_t = c + \sum_{k=0}^{n} d_k \times RIN\%_{t-k} + v_t \sum_{k=0}^{n} d_k \times X_{t-k} \qquad (35)$$

Additionally, Merino & Ortiz analyzed the hypothetical gain of every variable X in explaining movements in oil price by comparing the two error terms (i.e., deviations of oil price from its "inventory fundamental level" in both models, given by identities (34) & (35)).

The results for oil market related variables suggested that only backwardation (the difference between actual prices and future prices) and speculation[67] (measured by the long positions held by non-commercials of oil, gasoline and heating oil in the futures market, NYMEX) have information content for the premium over the entire estimation period (1992-2004). Moreover, Merino & Ortiz recognized the backwardation as an endogenous variable (Granger causality proved to run in both directions (backwardation Granger causes premium and vice versa).), and they therefore accepted only the speculation as a pure exogenous variable.
"However, we find that speculation (…) can improve the traditional model and explain a big part of the premium during the last period (…)." (*A. Merino & Á. Ortiz*)

The tests also suggested that two other variables have explanatory power on the premium if considering the period 1999-2004.
"The first one is the reduction in OPEC spare capacity[68] and the second one is the deterioration in the United States' gasoline situation[69]. (…) These variables improve

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improve the explanation. Y is said to be Granger-caused by X if X helps in the prediction of Y, or equivalently, if the coefficients on the lagged's are statistically significant.

[67] *"The term non-commercials refers to agents not involved in the production, processing or merchandising of a commodity. However, this does not represent the total amount of speculation in the market given that part of commercials and participants outside of these two categories (mainly investors in commodity index) can take speculation positions." (A. Merino & Á. Ortiz)*

[68] *One is used to calculate OPEC spare capacity as the difference between sustainable capacity and current OPEC crude oil production.*

only marginally the "inventory model" and fail to explain a big part of the premium." (*A. Merino & Á. Ortiz*)
Merino & Ortiz therefore concluded that these two variables do not contain more systematic information beyond that included in the supply-demand balance, as reflected in the inventory situation.

Regarding the non-oil variables (other financial and commodity variables), the Granger tests failed to prove any kind of causality for all used variables. (Merino & Ortiz tested subgroup of interest rates - long-term interest rate, short-term interest rate and the Baa Spread[70] - as well as US dollar exchange rate vis-à-vis Euro and US dollar trade weighted index.)

By concluding their study, Merino & Ortiz defined the speculation as a prior objective of future research efforts dealing with oil price modelling and forecasting.
It would be important to explain the sources driving the speculative behaviour. "One possibility is that speculation is driven not by the current situation of the oil market, but by rational expectations about future disequilibrium in the supply and demand balance. Another possibility is that speculation reflects the increasing degree of geopolitical concerns." (*A. Merino & Á. Ortiz*)
Answering the question of major sources driving the speculation could help us to understand the impact of speculative behaviour on the long run equilibrium of prices.
"If permanent or structural factors dominate the level of speculation, then it should affect the long run equilibrium price of oil (a key factor in the supply response). However, if speculation is based on geopolitical concerns, or is the result of non-fundamental factors, then the impact on prices should fade away." (*A. Merino & Á. Ortiz*)

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[69] *Merino & Ortiz used again de-trended relative inventories as a proxy for gasoline situation.*
[70] *A proxy for risk aversion;*

3.5 Some Final Remarks With Respect to the Presented Methods of Oil Price Modelling

The major purpose of all presented methods of oil price modelling was to unveil the impact parameters. The concluding Section of this thesis will be used to sum them up and to establish a complex set of oil price impact parameters.

Some methods selected for the purpose of presentation, such as studies of A. Al-Faris and F. Wirl, not only offer the possibility to capture and sum up the major oil price impacting parameters but also provide the chance to follow the process of price formation - the study of F. Wirl is especially interesting, since it considers a long-run problematic. Other presented studies, such as those of M. Zamani and Kaufmann *et al*, used to model the oil price trajectory choosing determining variables by means of empirical analysis. These are so-called quarterly models.

Statistical and econometric approaches, as important tools of oil price modelling, were pushed in background as much as possible during my discussion.

Consequently, error correction mechanisms used to get dynamic price models have not been considered at all.

But, the performance of every single modelling method has been tested by means of statistical estimations, and so I was forced to introduce some of estimation results obtained by authors, without describing thereby used approaches extensively, in order to follow and argue the statistical amount of relevance of selected parameters impacting the crude oil price.

4 Conclusions

In this final Section of my study I will try to recapitulate results collected so far.

In previous Chapters I tried to systematically depict the problem of oil price modelling. After discussing the oil market basics I suggested three sets of oil price impact parameters being fundamental. To remind you, these are: a set of demand parameters, a set of parameters determining the OPEC market power, and a set of parameters impacting the production costs. As a supplement to this consideration, I decided to present some selected methods of oil price modelling in order to meet impact parameters common used in practice. Thereby, I was seeking to analyze not only short-run quarterly models but also some long-run considerations. Finally, being convinced of great importance of speculation relating to the risk trading, I concluded to present the statistical evidence of speculation's relevance - none of selected modelling methods seriously considered the impact of markets for risk trading on the oil price behaviour.

The major objective of this concluding section of my thesis is to sum up and systematically present the major findings of my study. Thus, I was tending to postulate the complex set of oil price impact parameters. In order to do so, I firstly used to sum up all impact variables that had been obtained in the Section 3 dealing with selected methods of oil price modelling. Additionally, I used the findings of the Section 2 explaining the oil market fundamentals and offering some basic microeconomic view on process of price formation to categorize them. *See Table 5!*

The following tables reveal the summary of obtained parameters impacting the crude oil price, which have been subdivided into three fundamental sets:

- Demand related impact parameters;
- Parameters determining the costs of producing;
- Parameters explaining the market power;

Table 5: *Summary of Obtained, Demand Related, Oil Price Impact Parameters*

Correspond. Authors / **Impact Parameters**	*Al-Faris A.* (Short-Run Consideration)	*Bacon R.* (Long-Run & Short-Run Consider.)	*Wirl F.* (Long-Run Consideration)	*Kaufmann et al* (Econometric Model)	*Zamani M.* (Econometric Model)
Econ. Activity in Industr. Countr. (GDP)	+	+ SR&LR	-	-	-
Time Trend	-	+ LR	+	-	-
Inflat. R. – OECD	+	-	-	-	-
Rel. Prices – Comp. Forms of Energy	-	+ LR	-	-	-
Exchange Rates: US dollar vis-à-vis Currencies of Industr. Countries	+	+ SR	-	-	-
Non OECD Dem.	-	-	-	-	+
Rel. Commercial Invent. - OECD	-	-	-	-	+
Rel. Government Invent. - OECD	-	+ SR	-	-	+
Days of Forward Cons. Of OECD Oil Stocks	-	-	-	+	-
Seasonal Dummies	-	+ SR	-	+	-

Analysis of R. Bacon (1991):

- *SR: Parameters thought to be relevant in the Short Run;*
- *LR: Parameters thought to be relevant in the Long Run;*

Note*: Compared to other presented considerations, Bacon (1991) did not postulate the modelling equations, but he rather made some theoretical comments on parameters impacting the crude oil price. Thereby, he recognized the problematic if tending to model some of his impact parameters, such as relative prices of competing forms of energy.*

Table 6: *Summary of Obtained Oil Price Impact Parameters Explaining the Market Power of OPEC*

Correspond. Authors / **Impact Parameters**	*Al-Faris A.* (Short-Run Consideration)	*Bacon R.* (Long-Run & Short-Run Consider.)	*Wirl F.* (Long-Run Consideration)	*Kaufmann et al* (Econometric Model)	*Zamani M.* (Econometric Model)
Concentration Ratio	+	+ SR	-	-	-
Wealth in Oil Prod. Countries	+	-	-	-	-
OPEC Quota	-	-	-	+	+
OPEC Overproduction	-	-	-	+	+
Exchange Rates: US dollar vis-à-vis Currencies of Oil Producing Countries	+	-	-	-	-
Extraction Strategy – Depletion Date (OPEC)	-	+ LR	+	-	-
The Interest Rate (OPEC)	-	+ LR	+	-	-

Table 7: *Summary of Obtained Oil Price Impact Parameters Determining the Costs of Production*

Correspond. Authors / **Impact Parameters**	*Al-Faris A.* (Short-Run Consideration)	*Bacon R.* (Long-Run & Short-Run Consider.)	*Wirl F.* (Long-Run Consideration)	*Kaufmann et al* (Econometric Model)	*Zamani M.* (Econometric Model)
Producers Initial Resource Stock	-	+ LR	+	-	-
Extraction Strategy – Depletion Date	-	+ LR	+	-	-
Cumulative Production up to the Period t	-	+ LR	+	-	-
Investment in Exploration	-	+ LR	-	-	-
OPEC Capacity Utilisation	-	-	-	+	-
Time Trend - Exploration	-	+ LR	-	-	-

Table 8: *Summary of Obtained Oil Price Impact Parameters not being involved into Fundamental Sets*

Correspond. Authors / **Impact Parameters**	*Al-Faris A.* (Short-Run Consideration)	*Bacon R.* (Long-Run & Short-Run Consider.)	*Wirl F.* (Long-Run Consideration)	*Kaufmann et al* (Econometric Model)	*Zamani M.* (Econometric Model)
Dummies For Supply Shocks	+	+	-	+	+
Spot Price	+	-	-	-	-
Speculation *Meas. by the Long Positions held by Agents not Involved in the Prod., Process. Or Merchand.*	*None of Selected Models Considers This Parameter - Evidence For the Impact of Speculation Provided by Merino A. & Ortiz Á*				

In order to illuminate the way of categorization I used, let me shortly discuss three arbitrary chosen fields of presented matrices:

1. *"GDP" as Demand related Parameter used in Model of Al-Faris A. (1991) – See Equation (18) implying:* $D = f(GDP)$*;*
2. *"OPEC Capacity Utilization" as the Parameter determining the costs of producing used in Model of Kaufmann et al (2004) - See Figure 3, Function of Marginal Costs of Producing: Marginal costs are increasing following increased rate of capacity utilization (quantity supplied);*
3. *"OPEC Overproduction" as the Parameter explaining the Market Power of OPEC used in Model of Zamani M. (2004) - See Figure 3, Disruption of Cartel Discipline: Overproduction is a measure for disruption of cartel discipline, and so a measure for cartel's ability to practice the market power;*

Other parameters, such as dummies for supply shocks or speculation, couldn't be assigned to any of these fundamental groups. But, speculation practiced by agents not involved in the production, processing or merchandising and the lagged impact of spot price are rather oil market directly related financial parameters, and so these are to distinguish from external factors, such as supply shocks.

If using obtained impact parameters for the purpose of modelling, it is especially important to notice the nature of every particular parameter. Those parameters relating to long-run considerations, such as investment, are rather parameters not being appreciable in the short run - therefore also not being applicable for the short-run models. Oppose to that, some others, such as exchange rates, seem to be relevant only for short-run considerations.

Moreover, some obtained impact parameters are results of different approaches to analyzing the oil prices, and so these are not to combine if developing the modelling method. For instance, recent studies developing econometric quarterly models used to present the complex set of demand impacting parameters by means of inventory situation - applying of relative inventory variables incorporates, and so automatically excludes from observation, the effects of all other demand impacting parameters, such as GDP or time.

All these remarks imply that, even if restricting on modelling the short-run / long-run price behaviour, the findings presented in tables 5, 6, 7; and 8 do not suggest the optimal solution for the method of oil price modelling.

But let me at the end of this concluding section express my personal point of view if searching for optimal modelling method.

The majority of recent studies on this issue suggest the use of inventory situation for the purpose of modelling the demand side of the oil market, and application of variables describing OPEC production quota and OPEC overproduction for the purpose of modelling the cartel production behaviour. Furthermore, the variable presenting the capacity utilization seems to be relevant proxy for the marginal costs of producing. Such modelling approaches were proved to be consistent with real oil price trajectory over most of the time in the 1990's, and they seem to be simpler relative to those traditional approaches incorporating all basic demand and market power related parameters - the use of variables presenting the stock situation excludes from observation all other demand related parameters, and so the problematic of modelling partly endogenous parameters, such as GDP, seems to be eliminated.

But such econometric modelling methods confront with some difficulties if considering the current situation on the oil market. First, high oil prices persisting since summer 2003 were the incentive for the majority of oil producers to invest strongly into extension of production capacities.[71] Thus, introducing of parameters describing investment into exploration should not be neglected if intending to model the future price behaviour. Second, the use of inventory situation for the purpose of modelling appears to be more difficult since the major developing economies – China, India, Brazil, and Mexico – do not belong to OECD, and so focusing on their oil stocks seems to be problematic and partly also irrelevant. Creating stocks in these countries and additionally presenting reliable data is a crucial condition for the possibility of accurate modelling of the oil price behaviour by means of such econometric models in the future. Finally, the significance of financial parameters directly relating to the oil market - such as speculation in the futures market, NYMEX – was taboo for all previous studies of oil price modelling. But the importance of this problematic that is steadily increasing in recent times cannot be neglected anymore, and so one of the major tasks for all future studies on the issue of oil price modelling should be to find out the satisfiable way of modelling such financial parameters.

[71] *OPEC production capacity in 2004 was essentialy the same as it was in 1973!*

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