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The drivers of oil prices: The usefulness and limitations of non-structural models, supply-demand frameworks, and informal approaches

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## ABSTRACT

*This paper discusses three main approaches for analysing oil prices: non-structural models, the supply-demand framework, and the informal approach. Each approach emphasises a certain set of drivers of oil prices. While non-structural models rest on the theory of exhaustible resources, the supply-demand framework uses behavioural equations that link oil demand and supply to its various determinants. The informal approach focuses on the specifics of oil market history in explaining oil prices. Although all approaches provide useful insights on how the world oil market functions, they suffer from major limitations especially when used for long-term projections. Thus, pushing hard for policies based on such projections defeats the purpose of such models and may result in misguided policies.*

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# The drivers of oil prices: the usefulness and limitations of non-structural models, supply-demand frameworks, and informal approaches

## 1. Introduction

Understanding oil price behaviour has received special attention in the current environment of rapidly rising prices and marked increase in oil price volatility. It is widely believed that high oil prices can slow down economic growth, cause inflationary pressures and create global imbalances. Volatile oil prices can also increase uncertainty and discourage much needed investment in the oil sector. High oil prices and tight market conditions have also raised fears about oil scarcity and concerns about energy security in many oil importing countries.

Some observers argue that the oil market has undergone structural transformations that have placed oil prices on a new high path. The adherents of this view point to the erosion of spare capacity in the entire oil supply chain, the emergence of new large consumers – mainly China (and India to a lesser extent), the new geopolitical uncertainties in the Middle East following the US invasion of Iraq, and the re-emergence of oil nationalism in many oil-producing countries. Others interpret the recent oil price movements in terms of the cyclical behaviour of commodity prices. Like all raw materials, the rise in oil price stimulates oil production and slows oil demand growth. This would cause oil prices to go down which, in turn, would stimulate demand and increase the oil price. These different views about the oil market clearly reflect divergent expectations about the future evolution of oil prices (Stevens 2005).

Oil price behaviour has been analysed using three main approaches: the economics of exhaustible resources, the supply-demand framework, and the informal approach. Most analyses based on the theory of exhaustible resources conclude that oil prices must exhibit an upward trend (see Krautkraemer 1998 for a review). The insights from this literature have resulted in the derivation of non-structural models of oil price behaviour that do not explicitly model the supply and demand for oil and other factors affecting them (see for instance Pindyck 1999 and Dufour *et al.* 2006). In contrast, in the supply-demand framework, the oil market is modelled using behavioural equations that link oil demand and supply to its various determinants, mainly GDP growth, oil prices, and reserves (Bacon 1991 and Dees *et al.* 2007). And then, the informal approach is usually used to identify economic, geopolitical, and incidental factors that affect demand and supply and hence oil price movements within specific contexts and episodes of oil market history.

These different approaches are frequently used to make projections about oil prices and/or global demand and supply either for the short term or for the very long-term horizon, often over twenty years. Various players such as governments, central banks, and international oil companies rely on these projections for planning energy policy, evaluating investment decisions and analysing the impact of various supply and demand shocks hitting the oil market. Although the above frameworks are useful in improving our understanding of how the different elements of the oil market function, any attempt to use these models to predict oil prices or project oil market conditions in years to come would certainly result in errors. It is not only that these models cannot adequately capture the various shocks that can influence the oil market. But equally important, these long-term projections and long-run oil price forecasts are highly sensitive to the assumptions of the underlying model.

This paper is divided into five sections. In Section 2, we discuss oil price behaviour within the context of the economics of exhaustible resources. In section 3, we discuss the main building blocks of the supply-demand framework and discuss the limitations of using this approach for making projections. In section 4, we use the informal approach to discuss the main factors that may have affected oil prices



**Bassam Fattouh**

in the current context and whether the influence of these factors is transitory or permanent. Rather than listing a wide catalogue of potential factors, we focus our analysis on four: the erosion of spare capacity, the role of OPEC, speculation, and inventories. Section 5 concludes.

## 2. The exhaustible-resources framework

There is a very wide theoretical research that deals with oil price behaviour within the theory of exhaustible resources (see Krautkraemer 1998). An important characteristic of an exhaustible – that is, non-renewable – resource is that it is not replaceable or replaced at a very slow rate such that once it is used or extracted, the resource is no longer available for use or extraction within a reasonable time horizon. Another important characteristic is that the supply of the non-renewable resource is limited relative to demand. Oil has both these features and thus is treated in this literature as a classic example of a non-renewable resource.

The essential implications of exhaustibility are twofold. First, oil production and consumption in one period affect production and consumption in future periods. Thus, the oil market should be analysed within a dynamic context. Second, oil as a non-renewable resource should command a resource rent. Thus, unlike standard goods, the market price for non-renewable resource is not equalised with the marginal cost. This positive premium, also called the scarcity rent, is the reward the resource holder gets for having kept her stock up until today.

Hotelling's pioneering work (1931), which forms the basis of the literature on exhaustible resources, is mainly concerned with the following question: given demand and the initial stock of the non-renewable resource, how much of the resource should be extracted every period so as to maximise the profit of the owner of the resource? Hotelling proposes a very intuitive and powerful theory to address this question. Assuming no extraction costs and given a market price per unit of the resource and a risk-free real interest rate on investment in the economy ( $r$ ), Hotelling shows that in a competitive market, the optimum extraction path would be such that the price of the non-renewable resource (the price of oil in our context) will rise over time at a rate equal to the interest rate  $r$ . This theory has also an important implication on the exhaustibility of the resource. Specifically, as the price of the resource keeps rising, demand is slowly choked off and eventually when the price reaches very high levels, the demand for the resource disappears. This point occurs when the exhaustion of the resource is complete.<sup>1</sup>

***The theory of exhaustible resources has had a bearing on many economists' view of oil price behaviour.***

The theory of exhaustible resources has had a bearing on many energy economists' view of oil price behaviour. Most analysts using this theory conclude that the oil price must rise over time. Empirically, this meant that oil prices must exhibit an upward trend (Berck 1995). This gradually rising price trend continued to dominate forecasting models even in the 1980s and 1990s. In a sense this is surprising – not only because these decades witnessed many occasions of sharp oil price falls, but also because most empirical studies have shown that mineral prices have been trend-less over time (see Krautkraemer 1998). As argued by Lynch (2002):

“...for many years, nearly every oil price forecast called for such a trend; as the forecasts proved erroneous, the trend was retained but applied to the new lower point ... the combination of these theoretical arguments with the oil price shock of 1979 gave credence to these rising price forecasts, and it has proven difficult to convince casual observers that although prices might rise, it is neither inevitable nor preordained by either economic law or geology” (pp.374-375).

<sup>1</sup> It is important to note that by following the optimum extraction path, the owner of the resource maximises the discounted income stream accruing from extracting the resource over time.

**Many oil price forecasting models are based on the theory of exhaustible resources.**

Pindyck (1999) is an interesting example on how the Hotelling model has been used to construct forecasting models of energy prices. He suggests that rather than using structural models that take into account a wide array of factors – including supply and demand factors, OPEC and non-OPEC behaviour, technological advances and regulatory factors – it might be preferable to use simple non-structural models that examine the stochastic behaviour of oil prices. Non-structural models are quite flexible and allow oil prices to be modelled as a geometric Brownian motion or mean reverting process, or a related process with jumps. Using a simple Hotelling model, Pindyck (1999) shows that oil prices revert to an unobservable trending long-run marginal cost with a fluctuating level and slope over time. The forecasting performance of his model is highly mixed and especially poor for the period 1974-85 where there was wide variation in oil prices. But Pindyck (1999) argues that “putting aside the forecasting performance over the past two decades, the model captures in a non-structural framework what basic theory tells us should be driving price movements” (p. 22).

Since the pioneering work of Hotelling (1931), the theory of non-renewable resources has developed further and a number of simplifying assumptions has been relaxed to make models of non-renewable resources more realistic. More recent models allow for extraction cost to be a function of cumulative production, introduce perfect substitutes for the non-renewable resource, permit marginal extraction to vary over time, and allow for varying demand and monopolistic market conditions. Reflecting these modifications, oil prices may trend downward or follow a U-shaped path (Slade 1982; Moazzami and Anderson 1994). For instance, Khanna (2001) finds that the price trajectory can be decreasing, increasing, increasing first and then decreasing depending on whether the growth in demand is higher than the growth in marginal cost of extraction.

In any event, although the Hotelling model predicts the net price to rise exponentially, it does not imply that the market price paid by the consumer (known as the user cost) has to rise. The user cost is the sum of the scarcity rent and marginal extraction cost and the price trajectory will depend on the interaction between these two variables. If extraction costs fall faster than the increase in the scarcity rent, the user cost might decline over a period of time. However, as the resource is extracted, the scarcity rent rises rapidly and eventually dominates the fall in the marginal extraction costs causing the user cost to rise. Khanna (2001) considers six different scenarios in the simulation analysis. The oil price declines in only one of them, but only for a short period of time. Khanna (2001) argues that this scenario fits well with the declining price trend during 1975-85.

Slade (1982) finds that the price of a non-renewable resource exhibits a U-shaped path. Technological change that lowers extraction costs generates a decreasing path but continuous resource depletion with diminishing return to technological innovation will eventually cause the price to shift upward. In his empirical exercise, Slade (1982) finds that the minimum point of the U-path occurs during the sample period (in 1978), indicating that oil prices should have followed an upward trend from the late 1970s onwards. However, oil prices did not trend upward after the 1970s. In fact, more recent empirical studies conclude that non-renewable resource prices have a stochastic trend and that the property of increasing prices for most non-renewables is not clear, reducing “the prediction of price increase from near certainty to maybe” (Berck and Roberts 1996, p. 77). This, however, is not the last word on the issue. In more recent work, Lee *et al.* (2006) find support for characterising natural resource prices as stationary around deterministic trends but with structural breaks.

Despite its main contributions, many economists consider that the literature on exhaustible resources does not provide any insights into the oil price issue. The main criticism is directed towards the foundations of the Hotelling model: the very concept of resource exhaustibility and that of a fixed stock of resources (Adelman 1990; Watkins 1992 and 2006). Rather than assuming a fixed stock, Adelman (1990) suggests that oil reserves should be treated similar to inventories that are continuously

depleted through extraction and augmented through exploration and development.<sup>2</sup> Thus, according to this view the issue is not one of exhaustibility, but investment in accumulating inventories and costs involved in finding new reserves. An important implication of this view is that there is no such thing as a scarcity rent, and models based on such a concept do not provide an accurate description of prices in the real world.

Between these two extreme positions, Mabro (1991) argues that when oil is perceived to be plentiful, Adelman's main argument holds. However, when oil is perceived to be in limited supply, Hotelling's basic proposition that current prices might be influenced by price expectations might be useful. Mabro (1991) argues that the cycle of perceptions will fluctuate depending on oil price behaviour – among other factors. Specifically, an increase in oil prices will stimulate exploration and development, thus shifting perception towards abundance. This might cause prices to fall, thereby leading to an increase in demand and, eventually, a shift in perception towards scarcity.

In our view, Hotelling's original model was not intended to and did not provide a framework for predicting prices or analysing the time series properties of prices of exhaustible resource, aspects that the recent literature tends to emphasise. Furthermore, the application of Hotelling's model to the entire oil industry reduces its usefulness especially when there is no clear idea about the size of reserves and what should be included in the reserve base. As Watkins (2006) argues, the application of Hotelling's model to the oil industry "distorts Hotelling's insightful work, work directed more at the firm level where the focus is on a deposit of known, fixed quantity" (p. 512).

### **3. The demand-supply framework**

*The most widely used approach to modelling the oil market is the demand-supply framework.*

The most widely used approach to modelling the oil market is the supply-demand framework (Bacon 1991 and Dees *et al.* 2007). After all, it is the interaction between demand and supply for oil that ultimately determines the oil price in the long run. However, the special features of the oil market make the modelling exercise quite complex due to various types of uncertainties. Some of them are due to unknown future events such as geopolitical factors, supply disruptions, environmental disasters, and technological breakthroughs. Other uncertainties arise due to the lack of knowledge about factors such as the long-run price and income elasticity of demand, the response of non-OPEC supply, and above all OPEC behaviour.

#### **3.1 The demand for oil**

The starting point of most structural models is the demand-for-oil equation, which is modelled as a function of world economic activity and oil prices. The hypotheses presented are straightforward: higher economic activity should be associated with higher oil demand while higher oil prices should be associated with lower demand for oil. The bulk of the empirical literature has focused on estimating the price elasticity and income elasticity of demand both in the short run and the long run and across a large number of countries.

##### **3.1.1 Price elasticity of crude oil demand**

The relationship between the demand for crude oil and its price is usually examined by estimating the price elasticity of demand. Suffice it to refer here to a few recent studies to show the wide variation in estimated price elasticity. As Table 1 shows, estimates for the short-run and long-run price elasticity

<sup>2</sup> The reserves issue will be discussed in more detail in Section 3.2.

of demand range from 0 to -0.64. Despite this wide variation, it is possible to draw some general conclusions regarding the link between demand and price. First, changes in oil prices have a small and usually insignificant effect on demand for crude oil, especially in the short run. Second, the long-run price elasticity of demand is higher than the short-run elasticity due to substitution and energy conservation, but the elasticity is still quite low.

**Changes in oil prices have a small and usually insignificant effect on demand for crude oil, especially in the short run.**

**Table 1. Recent estimates of the price elasticity of crude oil demand**

	Short-run estimates	Long-run estimates	Sample
Dahl (1993)	-0.05 to -0.09	-0.13 to -0.26	Developing countries
Pesaran <i>et al.</i> (1998)	-0.03	0.0 to -0.48	Asian countries
Gately and Huntington (2002)	-0.05	-0.64	OECD
	-0.03	-0.18	Non-OECD
		-0.12	Fast growing non-OECD
Cooper (2003)	0.001 to -0.11	0.038 to -0.56	23 countries
Brook <i>et al.</i> (2004)		-0.6	OECD
		-0.2	China
		-0.2	Rest of the world
Griffin and Schulman (2005)		-0.36	OECD
Krichene (2006)	-0.02 to -0.03	-0.03 to -0.08	Various countries

Some recent studies have modelled an asymmetric response of demand to a change in crude oil prices. For instance, Gately and Huntington (2002) argue that the short-run price elasticity depends on whether prices rise or fall. Specifically, an increase in oil prices could reduce oil demand, but that a subsequent drop in oil prices would reverse the decline in demand is not necessarily true. The increase in price may induce investment in more energy-efficient equipment, thereby reducing demand for oil – and this decrease in demand would not be reversed by a subsequent drop in prices. Gately and Huntington also hypothesise that the demand response to an all-time price peak is different from the response to a price recovery from a low point. When testing their hypothesis, the authors indeed find that price elasticities are significantly different across price falls and prices increases and that the most elastic demand response is due to new price peaks.

Despite the attractiveness of this explanation, Griffin and Schulman (2005) argue that the asymmetric model has the unintended consequence of creating price volatility, thus shifting inward the intercept of the demand-for-oil equation. The authors note that this is observationally equivalent to a shift in the intercept due to an energy-saving technical change. Griffin and Schulman (2005) conjecture that the findings of Gately and Huntington (2002) might capture energy-saving technical change rather than an asymmetric response of oil demand to changing oil prices. Thus, Griffin and Schulman (2005) opt for a fixed effects model of oil demand in which time dummies account explicitly for technical change. Using a panel of OECD countries, the authors find that the hypothesis of price symmetry cannot be rejected after controlling for technical change.

### 3.1.2 Income elasticity of crude oil demand

Similar to price elasticities, estimates for the income elasticity of crude oil demand vary widely according to the method used, the period under study, and the country sample (for instance, developing countries or OECD countries). As can be seen from Table 2, which summarises some recent findings, estimates range from as low as 0.2 to estimates larger than one. Despite this range, it is possible to draw some general conclusions. First, oil demand is more responsive to income than prices. Second,

the long-run income elasticity of oil demand is higher than the short-run income elasticity. Third, there is large heterogeneity in estimated income elasticity across countries and/or regions, with developing countries exhibiting higher income elasticity than OECD countries. Finally, in OECD countries, the responsiveness of oil demand to income has been declining over time.

**Table 2. Recent estimates of the income elasticity of crude oil demand**

	Long-run	Sample
Ibrahim and Hurst (1990)	>1.0	Developing countries
Dahl (1993)	0.79 to 1.40	Developing countries
Pesaran <i>et al.</i> (1998)	1.0 to 1.2	Asian countries
Gately and Huntington (2002)	0.56	OECD
	0.53	Non-OECD
	0.95	Fast growing non-OECD
Brook <i>et al.</i> (2004)	0.4	OECD
	0.7	China
	0.6	Rest of the world
Krichene (2006)	0.54 to 0.90	Various countries

### 3.1.3 Elasticity of gasoline demand

Rather than examining crude oil demand, many studies have looked at various finished petroleum products, gasoline in particular (see Dahl and Sterner 1991, Dahl and Duggan 1996, and Graham and Glaister 2002 for surveys). Despite its retreat in most other sectors, crude oil and petroleum products (gasoline, diesel oil, and jet fuel) remain the dominant fuel in the transport sector.

It would go far beyond the purpose of this paper to review this literature. Suffice it here to offer insights from the meta-study by Espey (1998), which covers a wide array of studies published between 1966 and 1997. First, empirical studies suggest that short-run price elasticity estimates for gasoline demand range from 0 to -1.36, with a mean of -0.26, while long-term price elasticity estimates range from 0 to -2.72, with a mean of -0.58. Short-run income elasticity range from 0 to 2.91, with a mean of 0.47, while long run income elasticity range from 0.05 to 2.73, with a mean of 0.88. Second, the author finds that the estimated elasticities are highly sensitive to the behavioural model underlying demand. In this respect, his results indicate that the exclusion of vehicle ownership as an explanatory variable would bias upwards estimates of short-run and long-run income elasticity. Third, he finds that estimates using US data are very different from those using data sets that include other OECD and European countries. This is not surprising since the dependence on cars is higher in the United States than in other countries, largely because the population density and reliance on public transport in this country is relatively low. That being said, the price elasticity of gasoline demand in OECD countries is still very low. This is in large part due to high taxes that most OECD governments impose on oil products, which weaken the link between international oil prices and gasoline demand. Since taxes represent a large percentage of the price paid by consumers for gasoline, a rise in international crude oil prices would increase gasoline prices by only a fraction of the increase.

### 3.1.4 Demand projections

The relationship between oil demand, prices, and income has been used extensively to project global or regional oil demand. Table 3 – which summarises often used projections – shows that demand projections differ considerably. A number of points are worth emphasising. First, the projections are highly sensitive to underlying economic growth assumption. Second, they are highly sensitive to the

***There is large heterogeneity in estimated income elasticity across countries and/or regions, with developing countries exhibiting higher income elasticity than OECD countries.***



income and price elasticity used. Third, they are sensitive to the oil price path chosen. To appreciate the sensitivity of the results to some of these assumptions, it is useful to know that in the IMF (2005) projection a change in economic growth by  $\pm 0.5$  percentage points changes projected oil demand by around  $\pm 4$  percent. And then, a hypothetical oil price shock at the beginning of the projection period can cause oil demand to decline by almost 6 percent compared to the baseline projection. Fourth, there is the issue of endogeneity of prices and income. Most studies implicitly assume that the price is exogenous – probably set by OPEC, but as will be argued in Section 4 this is not a realistic assumption. Finally, most empirical studies ignore the potential relationship between oil price shocks and growth. An extensive literature on oil price shocks and growth suggests a feedback mechanism in which oil prices can have a large and significant impact on growth (see for instance Jones *et al.* 2004 and Barsky and Kilian 2004 for a review of this literature). However, the insights and results from these writings have not been so far integrated into the empirical literature on the income and price elasticity of oil demand, and these two strands of literature have grown independently from each other.

**Table 3. Projected oil demand (in million barrels per day)**

	2003 (actual)	2010	2015	2020	2025	2030
IMF (2005)	79.8	92.0	102.4	113.5	125.5	138.5
EIA (2006)	80.0	92.0	98.0	104.0	111.0	118.0
IEA (2006)	82.5	91.3	99.3	—	—	116.3

Sources: IMF (2005), World Economic Outlook, April 2005, Table 4.5; Energy Information Administration (EIA), International Energy Outlook 2006, Figure 26; International Energy Agency, World Energy Outlook 2006, Table 3.1.

Note: IEA figure in first column refers to 2004 and not 2003.

### 3.2 Non-OPEC oil supply

Modelling oil supply is much more complex than modelling demand, reflecting the controversy surrounding the level of reserves and the behaviour of various oil suppliers. As to the latter, it is useful to distinguish between OPEC and non-OPEC suppliers. While it is usually assumed that non-OPEC suppliers behave competitively, OPEC behaviour is much more multifaceted, and there are diverse and competing theories describing its behaviour (see Gately 1984 and Crémer and Salehi-Isfahani 1991 for a review). Although non-OPEC suppliers are fairly diverse – comprising national oil companies, large international oil companies, and smaller, independent firms – empirical studies typically do not distinguish between them, but normally aggregate oil production outside OPEC.

**Modelling oil supply is much more complex than modelling demand.**

In what follows, we will first review two main approaches that are used to shed light on non-OPEC oil supply: the geophysical approach – also called the Hubbert approach – and economic-based models. We will then briefly turn to hybrid models, which combine elements of the main approaches, and conclude with non-OPEC supply projections. The supply of oil by OPEC will be examined in sub-section 3.3.

#### 3.2.1 The geophysical approach

The geophysical approach, which is mainly based on the work of Hubbert (1956), stresses geophysical factors in determining non-OPEC oil supply. According to this approach, production is governed by historical cumulative production and the size of ultimately recoverable reserves (URR), with the production profile of an oil region following three phases: production increase, stagnant production at a 'peak', and declining production as and when reserves approach depletion. More specifically, assuming that cumulative production follows a specific logistic curve, the annual rate of production during these phases fits a symmetric bell-shaped curve.

Hubbert's approach of modelling oil supply became very popular in the 1970s (mainly because of its success in forecasting annual production of the lower 48 US states), but it has been recently widely criticised (see for instance, Lynch 2002 and Watkins 2006). A major criticism concerns the treatment of URR as a static variable while in reality it is dynamic and has expanded over time due to economic and technological advances. Another weakness is the tendency of the geophysical approach to overestimate the depletion effect. Lynch (2002) reviewed various predictions and finds that most of them have overstated the depletion effect. Thus, far from being symmetrical, the Hubbert curves are skewed to the right, indicating that other factors such as new investments, the discovery of new fields, or a combination of the two prevent – or postpone – the decline in production.

***In geophysical models, the assumptions made about oil reserves are central for forecasting non-OPEC oil supply.***

It is clear from the above that assumptions made about reserves are central in modelling oil production. The issue of reserves, however, is highly contentious and there is substantial disagreement on the size of global reserves. The estimates range from less than 2 trillion barrels of oil equivalent (tboe) (Campbell 1989 and Campbell and Lahererre 1998), to between 2-4 tboe (USGS 2000), and to reserve estimates in excess of 4 tboe (Odell and Rosing 1983 and Shell 2001)<sup>3</sup>. This range arises due to a number of factors, including different estimation methodologies, 'vested interests', and differences in defining reserves and oil (conventional vs. unconventional oil).

Regarding the definition of reserves, the World Petroleum Congress and the Society of Petroleum Engineering have adopted a new approach, which introduces elements of probability, allowing a distinction between proved and unproved reserves. Proved reserves are quantities of petroleum (i) that are commercially recoverable from known reservoirs given current economic and regulatory conditions and (ii) for which there is 90-percent probability that the quantities recovered will be equal to, or greater than, estimated proved reserves. Unproved reserves are estimated on the basis of similar geological and engineering data as proved reserves, but because of contractual, economical, regulatory, or technical factors they cannot be treated as proved. Unproved reserves can be divided into probable reserves (unproved reserves with a 50-percent probability that quantities actually recovered will equal or exceed the estimate) and possible reserves (unproved reserves with a 10-percent probability that quantities actually recovered will equal or exceed the estimate).<sup>4</sup>

Identifying the underlying assumption about the size of reserves is important because it forms the basis for projecting oil supply. Pessimists predicted that oil would 'peak' in the 1990s (see Campbell 1989, for instance). The wrongness of such predictions led to a variety of modifications to the underlying model, allowing – for instance – for multimodal rather than unimodal production curves. Other studies based on the USGS data predict the peak in non-OPEC production to occur between 2015 and 2020 (Cavallo 2002). And then, studies using still higher reserve estimates suggest that peak production will take much longer to come. For instance, Odell (1998), who estimates 3 tboe of conventional oil and 3 tboe of unconventional oil, suggests a peak for conventional oil in 2020 and for unconventional oil around the year 2060 (see Ahlbrandt 2006).

It is important to stress that despite regular discussions of a looming oil shortage, the ratio of proved reserves to annual production has increased over the last 30 years, indicating strong growth in reserves. Table 4 shows that while total production increased from 59 million barrels of oil per day (mbd) in 1973 to 77 mbd in 2003, reserves over this period rose by more than 500 billion barrels, suggesting that reserves have become more plentiful compared to 30 years ago (see Watkins 2006 for a more detailed discussion). The bulk of this growth is not due to new discoveries but mainly to reserve

<sup>3</sup> This classification is based on Ahlbrandt (2006).

<sup>4</sup> For more details see Ahlbrandt (2006) and Seba (1998), for instance.

(or field) growth.<sup>5</sup> For instance, Ahlbrandt (2006) reports that in the last 15 years reserve growth has added 85 percent of reserves in the United States. Studies applied to world reserve growth also show that the contribution of reserve growth of existing fields has been more important than the discovery of new fields.

The reserve growth can be explained by initial conservative estimates and the use of better exploration, development, and drilling technologies. Regarding the latter, Verma (2000) emphasises the importance of enhanced oil recovery where new technologies, such as water flooding and gas injection, have led to dramatic improvements in recovery rates, increasing from, say, 30 percent of the original oil in place to 50 percent (and more).

**Table 4. World oil reserves, production, and reserve-production ratio**

	1973	1983	1993	2003
Reserves (billion barrels)	635	723	1,024	1,148
Annual production (mbd)	59	57	66	77
Reserves/annual production (years)	30	35	42	41

Source: Watkins (2006), Table 1.

Note: mbd = million barrels per day

### 3.2.2 Economic-based models

Many have argued that since the Hubbert model is based on the wrong concept of ultimate recoverable reserves, it should not be used for modelling oil supply. The model has also been criticised for its neglect of the role of economic factors and technology.

Economic-based supply models have emphasised that economic factors – for instance, real oil prices and costs, regulatory factors such as the fiscal system and the concession terms, and technology – play an important role in determining investment and hence oil supply. Taking economic factors into account, various studies have attempted to estimate the price elasticity for non-OPEC oil supply. They have shown that the response of non-OPEC production to oil prices is very low, especially in the short run. For one thing, producers do not necessarily increase production when oil prices rise. For another, a price decline does not induce producers to reduce production. For instance, during the 1970s, prices soared and production did not rise as fast. But in the 1980s, prices fell dramatically but production continued to increase, suggesting a negative price elasticity of non-OPEC supply during this period.<sup>6</sup>

Although the long-run price elasticity is found to be positive, many studies suggest low elasticities. For instance, Krichene (2006) reports a long-run price elasticity for non-OPEC supply of 0.08, and Al Hajji and Huenter (2000) report one of 0.29. Gately (2004) reports a wide band of price elasticity, varying from 0.15 to 0.58 while Dahl and Duggan (1996) estimated a price elasticity of 0.58.

Other more elaborate attempts to estimate oil-supply functions have been made. Watkins and Streifel (1998) estimate a model in which reserve additions are regressed on some inferred price of discovered but undeveloped reserves and a time variable that is meant to capture a range of factors – including the net impact of changes in prospectivity, depletion effects, cost efficiency, and technology. The main purpose of their exercise was to test whether the supply function has been moving outward

***Economic-based supply models have emphasised that economic factors – for instance, real oil prices and costs, regulatory factors, and technology – play an important role in determining oil supply.***

<sup>5</sup> Reserve growth is defined as an increase in the estimated size of a (oil-)field over time.

<sup>6</sup> It is worth noting that economic-based models could also include the notion of an exhaustible resource in which case supply will be determined by inter-temporal optimisation. Specifically, supply will not only depend on current prices, but also on future prices (Crémer and Salehi-Isfahani 1991).

(i.e., expanding) in response to new discoveries and cost-saving technologies or moving inward (i.e., contracting) due to depletion effects. Their results indicate that outside North America, non-OPEC supply has been expanding while in North America it has been contracting. The authors warn that the latter result does not indicate that reserves will not be added in North America, but that the diminishing returns on exploration have not been offset by technological or efficiency advancements. It is clear that in such economic-based models, ultimate recoverable reserves play no role in determining the oil supply and are treated as irrelevant, non-binding constraints (Adelman 1990).

### 3.2.3 Hybrid models

In general, economic models of oil supply that focus on price elasticity were not very successful, not even when applied to non-OPEC production, where producers are assumed to be competitive price takers. This is mainly due to complex interaction between geological factors (reserves, depletion, discovery, etc.), economic factors (oil prices, technical change, etc.), regulatory factors (fiscal system, concession agreements, etc.) and political factors (sanctions, political turmoil, and so on).

**Hybrid models combine geophysical with economic factors to forecast non-OPEC oil supply.**

Against this background, there have been a number of attempts to construct models that combine geophysical with economic factors, referred to as hybrid models (Kaufmann 1995, Moroney and Berg 1999, and Kaufmann and Cleveland 2001). An early attempt was Kaufmann (1991) who in the first step constructed the difference between the actual production curve and the predicted production curve based on Hubbert's model. The difference was then regressed on number of economic and regulatory variables. Moroney and Berg (1999) model oil supply as a function of the stock of reserves, the real price of oil, and dummy variables to account for regulatory factors. They use a partial adjustment model to account for the fact that producers react gradually to changes in the determinants of supply. For the United States, the authors find a wide band of price elasticity estimates ranging from 0.057 to 0.19. Their results also indicate a unitary long-run elasticity of production with respect to lagged reserves.

### 3.2.4 Projections of non-OPEC supply

Given the different models and the wide range of elasticity estimates, it is no surprise that non-OPEC supply projections differ considerably across studies and over time. Table 5 below reports most recent EIA and IEA projections of non-OPEC supply. While the EIA expects a relatively high non-OPEC supply growth, the IEA is more conservative about the potential contribution of non-OPEC suppliers. The large difference in the projections is mainly due to differences in the responsiveness of non-OPEC supply and unconventional oil supply to oil prices and different assumptions as to whether or not non-OPEC oil supply reaches a peak during the projection period. In fact, the large EIA revision in 2006 is partly due to the more optimistic view about the potential of unconventional oil, which could become highly economical if oil prices remain high – as currently projected. The EIA's 2006 International Energy Outlook predicts that unconventional supplies will reach 9.7 mbd in 2025 and 11.5 mbd in 2030. This is a substantial upward revision from the 2005 Outlook, which projected unconventional oil supply to reach 5.7 mbd in 2025.

**Table 5. Projected non-OPEC oil supply (in million barrels per day)**

	2010	2015	2030
EIA (2006)	54.4	58.6	72.6
EIA (2005)	56.6	61.7	66.2
IEA (2006)	53.4	55.0	57.6

Sources: Energy Information Administration (EIA), International Energy Outlook 2005 and 2006. International Energy Agency (IEA), World Energy Outlook 2006.

### 3.3 OPEC oil supply

#### 3.3.1 A plethora of approaches to modelling OPEC supply

Studying the behaviour of OPEC in supplying oil is crucial for understanding the oil market and long-run oil prices. However, OPEC behaviour is very complex to model (see Fattouh 2007a for a recent review). Many conflicting theoretical and empirical interpretations of the nature of OPEC and its influence on world oil markets have been proposed. The debate is not centred on whether OPEC restricts output, but on the reasons behind these restrictions.

Some studies emphasise that OPEC production decisions are made in reference to budgetary needs, which, in turn, depend on the absorptive capacity of members' domestic economies (Teece 1982). Others explain production cuts in the 1970s with the transfer of property rights from international oil companies to governments, with the latter having lower discount rates than the former (Johany 1980 and Mead 1979). And then there are studies that see coordinated actions of OPEC members as a main determinant of output. Within this literature, the view of OPEC behaviour ranges from classic text book cartel, to two-block cartel (Hnyilicza and Pindyck 1976), to clumsy cartel (Adelman 1980), to dominant firm (Salant 1976 and Mabro 1991), to loosely co-operating oligopoly, to residual firm monopolist (Adelman 1982), and – most recently – to bureaucratic cartel (Smith 2005). Finally, some studies suggest that OPEC oscillates between various positions but always acts as a vacillating federation of producers (see for instance Adelman 1982 and Smith 2005). The existing empirical evidence has not helped narrow these different views.

*The view of OPEC behaviour ranges from classic text book cartel, to two-block cartel, to clumsy cartel, to dominant firm, to loosely co-operating oligopoly, to residual firm monopolist, and – most recently – to bureaucratic cartel.*

There has been an extensive debate on the usefulness and limits of the various models. This debate is beyond the scope of this paper. What is important to emphasise though is that each of these theories implies a different OPEC behaviour and hence supply decisions and pricing rule. Let us look at two theories to clarify this point. For one thing, there are models that consider OPEC as a monopoly owner of an exhaustible resource. In these circumstances, the organisation's behaviour is highly predictable: it would choose prices or quantities so that the difference between marginal revenue and marginal extraction cost will increase at the rate of interest (Pindyck 1978). For another, there is the target-revenue theory, which hypothesises that OPEC countries typically respond to a rise in oil price by cutting production and to a fall in prices by expanding output. The underlying intuition behind this theory is simple. Supply decisions are determined by a country's national budget requirements, which are a function of the economy's ability to absorb productive investment. Thus, if many OPEC countries follow such a target-revenue rule, an exogenous increase in oil prices will trigger simultaneous cuts in production in these countries even without any coordination from OPEC members (Teece 1982).

Whatever theory is chosen, modelling OPEC supply creates a serious challenge for the supply-demand framework. Simply put, it is problematic to describe OPEC as a cartel, or oligopoly, while at the same time use a competitive supply-demand framework for analysing the long-run behaviour of oil markets. A standard way to close the model has been to treat OPEC supply decision as a residual often referred to as the 'call on OPEC', which is the hypothetical amount that OPEC needs to produce to close the gap between oil demand and non-OPEC supply. In other words, projections about OPEC supply are not based on behavioural analysis but derived from a simple accounting formula that balances world demand after taking into account various factors. This approach has been widely used to project OPEC supply.<sup>7</sup>

<sup>7</sup> The demand-supply framework has also been used to study the impact of various shocks on oil prices. For instance, in the model of Dees *et al.* (2007), a 10-percent increase in OPEC's quota triggers a decrease in the price of oil which, in turn, boosts demand. After a series of oscillations, in which demand and oil price react to each other, the price of oil is simulated to settle some 10 percent below its starting value. Using a similar model, Brook *et al.* (2004) examine the impact of a serious supply disruption on oil prices. In a bad-case scenario, they find that a 7-percent oil supply shock would raise the oil price by around \$20 in the first year, but it would fall back to the baseline relatively quickly. These types of exercises are very useful, but they are highly sensitive to the various parameters and the way the model is closed.

Table 6 below shows various projections on the call on OPEC. As can be seen from this table, the projections vary widely (with the difference between the lowest and highest estimate in 2030 reaching around 43 mbd) and even for a given projection the difference between its upper and its lower bound can be substantial, as indicated by the difference of 20 mbd in the EIA projection for 2030.

**Table 6. Projections of OPEC supply (million barrels per day)**

	2010	2020	2025	2030
EIA (2006)	32.9-37.9	29.3-43.3	29.8-46.9	30.9-51.0
IMF (2005)	30.6-32.7	43.5-49.2	51.6-61.0	61.3-74.4
IEA baseline scenario (2006)	35.9	—	—	56.3

Sources: Energy Information Administration (EIA), International Energy Outlook 2006. International Energy Agency (IEA), World Energy Outlook 2006. International Monetary Fund (IMF), World Economic Outlook, April 2005.

Note: Based on 'call-on-OPEC' models

Although calculating OPEC supply as a residual overcomes the problem of modelling OPEC's complex behaviour, this approach suffers from two major limitations: it assumes that OPEC has the incentive to expand output and that the necessary investment to increase capacity materialises.

### 3.3.2 Incentive for OPEC to expand output

**Calculating OPEC supply as a residual suffers from two major limitations: it assumes that OPEC has the incentive to expand output and that the necessary investment to increase capacity materialises.**

The above projections implicitly assume that OPEC has the incentive to increase market share regardless of oil prices. Specifically, there is no analysis whether the projected output path will serve the interests of OPEC. Gately (2004) analyses whether OPEC producers have the incentive to expand oil output and increase their market share. Rather than calculating the OPEC supply as a mere residual, Gately (2004) calculates the OPEC's net present value (NPV) of profits for different choices of OPEC's market share. His main finding is that profits are relatively insensitive to higher output growth. In fact, aggressive plans to expand output can yield a lower payoff than if OPEC decides to maintain its market share. This result is quite intuitive. Given certain assumptions about the model parameters, the increase in the NPV of expected profits from higher output would be more than offset by lower prices as a result of a rapid output expansion. Gately (2004) thus concludes that the projections of rapid increases in OPEC output and market share (such as those summarised in Table 6) are implausible and "are likely to be contrary to OPEC's own best interests" (p.88). He notes that the incentive to increase capacity at a rapid pace might exist only if one assumes a high price elasticity of both world oil demand and non-OPEC supply.<sup>8</sup>

To shed more light on the link between the market share of OPEC and its profitability, we draw on IMF (2005), which suggests that the optimal strategy for OPEC is to maintain its market share between 41 percent and 46 percent. This is well below the shares implied by the projections shown in Table 6. To illustrate, in the IMF baseline scenario, world oil demand is projected to reach around 139 mbd in 2030. For the same year, the upper bound for the 'call on OPEC' is projected at around 74 mbd, implying a market share (54 percent) well above the level that would maximize OPEC profits.

### 3.3.3 The investment problem

Even if OPEC has the incentive to increase market share, the investment needed to attain those shares is substantial and it may not materialise for a number of reasons. There is no scope in this paper to

<sup>8</sup> In a separate paper, Gately (2001) reaches the same conclusion regarding Persian Gulf oil producers.

offer a comprehensive assessment of investment bottlenecks in the oil sector, such as that provided by Fattouh and Mabro (2006). Instead, a few general observations are useful to emphasise non-price factors that might prevent OPEC from increasing its capacity in the future. First, unfavourable geopolitical factors and sanctions could create an investment climate that is detrimental to capacity expansion in many OPEC countries. In the past, economic sanctions hindered investment and deferred the development of projects in Libya, Iraq and Iran.

Second, in OPEC countries where the state controls the hydrocarbon sector, the relationship between the government and the national oil company can result in an unfavourable environment for investment. Specifically, given the competing and increasing demands for economic, social, and infrastructure projects, national companies' budgets are likely to be kept tight, preventing them from undertaking investment, acquiring technological capabilities, and enhancing their managerial expertise.

Third, investment is also complicated by another relationship: that between the governments and/or national oil companies and the international oil companies. Many consider that restriction of access to reserves is an important barrier to investment. However, access is not the central issue since such access is effectively restricted only in Saudi Arabia, Mexico and Kuwait, with the latter developing plans to open its sector to foreign investment through Project Kuwait. What matters most is the nature of the relationship between the two parties. Experience has shown that even in countries where access to reserves is allowed, there may be important obstacles that could delay or prevent investment by international oil companies. As markets have tightened, the terms and conditions demanded by the owners have been hardening over time.

Finally, many OPEC officials consider that uncertainty about demand for oil constitutes a very important obstacle to investment. This has led OPEC members to call for security of demand in face of concerns about security of supply. Security of demand cannot be achieved in the current market structure, and the idea that uncertainty has to be resolved before making an investment is highly unrealistic. Instead, investment decisions can only be made in the context of uncertainty. As the literature of irreversible investment suggests, uncertainty increases the option value of waiting, that is, delaying the investment until new information about market conditions arrive. For OPEC, the option to wait is very valuable. After all, the decision to wait and not to invest is more profitable than to invest and increase production in the face of falling global demand. In other words, it is more profitable for OPEC to err on the side of under-investing in new capacity as opposed to expanding capacity because forgone oil sales can be compensated by higher oil prices in tight market conditions.

*It is more profitable for OPEC to underinvest than to overinvest.*

### **3.4 A synthesis of the supply-demand framework**

The supply-demand framework explains oil market behaviour in terms of factors that determine demand (income and price) and supply (price, reserves, and OPEC behaviour). Although this approach is useful for gaining a better understanding of the oil market, using this framework to project oil prices is likely to result in mistakes for a number of reasons. First, price projections are highly sensitive to the assumptions made about income and price elasticity of demand, the price elasticity of supply, the role of reserves, and OPEC behaviour – the latter being essential to close models. Second, the above framework cannot capture the impact of unexpected shocks. These shocks are central to understanding the behaviour of oil prices since evidence suggests that shocks can be persistent (Cashin *et al.* 1999). One important implication of shock persistency is that “it is incorrect to view shocks to commodity prices as generally being a temporary phenomenon that largely reflect short-lived variability in supply interacting with relatively unchanging demand” (p.39). Instead, these shocks are

long lived, have enduring effects, and – indeed – may shift oil prices to a new path. Third, the above framework does not take into account the geopolitical context and general market conditions in which oil prices are determined. It is true that demand and supply determine the oil price in the long term, but they do so in a specific context. Unfortunately, the supply-demand framework analyses oil prices and makes projections in a ‘neutral context’. Considering the specific context in which oil prices evolve is a salient feature of the informal approach to analysing the drivers of oil prices – as we will see next.

#### **4. Drivers of oil prices in the current context: an informal approach**

*The increase in oil prices and oil price volatility experienced in the last three years led many analysts to argue that factors other than changes in elasticities or reserves influence oil market developments.*

The increase in oil prices, and oil price volatility, experienced in the last three years led many analysts to argue that factors other than changes in elasticities or reserves influence oil market developments – at least in the short run. The list of factors include unexpectedly strong demand (mainly of emerging economies), lack of spare capacity, distributional bottlenecks, OPEC supply response, geopolitical and weather shocks, and an increasing role of speculators and traders in price formation. This section discusses some of these factors – notably the role of OPEC, eroding spare capacity, speculators and traders, and of inventories and the term structure of oil prices – and concludes with an assessment of whether the influence of these factors on the oil market is temporary or permanent.

##### **4.1 The pricing power of OPEC**

Views about the pricing power of OPEC diverge and have changed over time (Fattouh 2007a). Perceptions range and have been shifting from one extreme, where OPEC is believed to play no role at all in pricing or only a very limited one, to the other extreme where OPEC is seen as a price setter. The shift in perception became very apparent in the events that surrounded the oil price collapse in 1998 and the oil price hike in 2004. In 1998, when the Dubai oil price approached \$10 per barrel, many observers claimed that OPEC had lost its ability to defend oil prices and quite a few of them predicted its demise. This view reversed only few months later, however, with many observers arguing that the 1998 price collapse induced greater cooperation among OPEC members, thereby marshalling a new era for the organisation.<sup>9</sup> That said, high oil prices in 2004 gave rise to yet another switch in perception, with doubts about the pricing power of OPEC re-emerging.

Cognisant of variations in the actual, or perceived, pricing power of OPEC over time, it is true that while OPEC has successfully defended the oil price on many occasions, cutting output with a view to stabilising prices has sometimes proved to be unsuccessful. Because of different features, needs, bargaining power, and divergent interests of OPEC members, they usually fail to agree on the allocation of production cuts (see for instance Kohl 2002 and Libecap and Smith 2004). These problems are more acute when the required cuts are large because small OPEC members regularly find it difficult to reduce their production on a pro-rata basis – the usual system adopted by OPEC over the years. In these circumstances, market participants might doubt the credibility of OPEC’s decision to cut production and ignore the signal that OPEC is trying to send. This holds especially if there are deep divisions and political rivalries among OPEC members.

Increasing output in the face of growing global oil demand can also be problematic though for different reasons. Although agreements to increase quotas are easier to reach and implement when global demand is rising, OPEC might not respond fast enough to buoyant demand because

<sup>9</sup> See for instance, Stanley Reed, “Cheap Oil? Forget It”, Business Week. 3/8/2004, Issue 3873 and Weston and Christiansen (2003).



of imperfect information and uncertainty about future demand. After all, the decision to wait and not to raise output is more profitable than to increase output and subsequently realise that demand expectations turn out to be false. Anticipating this response, market participants may ignore the signal of an agreement to boost output because they judge such an agreement unlikely to be adhered to. A rise in global demand for oil can affect OPEC pricing power through another channel: the erosion of spare capacity. This became evident in 2004 when doubts about the ability of OPEC's dominant producer, Saudi Arabia, to deliver additional crude oil of the required quality rendered any OPEC announcements of production increases ineffective.

All in all, OPEC's pricing power is not straightforward. It varies over time and can occur both in weak and tight market conditions. This does not imply that market participants can afford to ignore OPEC. In fact, OPEC has often cut output successfully with a view to preventing a decline in oil prices. This being said, output policies aimed at influencing prices have become more complicated with the growing importance of the futures market for the oil price discovery process (Fattouh 2007b).

## 4.2 Erosion of spare capacity

The oil price hikes in 2004 and 2005 revealed an oil market with much less flexibility and capacity to deal with supply shocks or large unexpected (or even expected) increases in global oil demand. For most of the 1980s and 1990s, OPEC's spare capacity, chiefly that of Saudi Arabia, helped offset large demand and supply shocks. Spare capacity however has witnessed a gradual decline since the early 1990s. Many observers argue that the conditions responsible for the emergence of a large spare capacity cushion in the mid 1980s – mainly the surge in non-OPEC supply accompanied by a decline in global demand – cannot be repeated and thus spare capacity is a thing of the past. For advocates of peak oil, spare capacity is a myth. International institutions such as the IMF and IEA argue that the erosion of spare capacity has been the result of worldwide under-investment in the oil sector and hence they call for removing barriers to investment in order to restore spare capacity in all parts of the supply chain. Others such as Goldman Sachs (2005) are more pessimistic about the realisation of investments, arguing that “demand destruction will be needed to recreate a spare capacity cushion in order to return to a period of lower energy prices” (p.18). Saudi Arabia's declared policy of maintaining a volume of spare capacity of around 2 mbd could be achieved, but this spare capacity is too small compared to global demand. It is interesting to note that although these views are fundamentally different, they all seem to agree on one thing: we have entered a 'new era' in which oil market's ability to rely on spare capacity to absorb shocks has greatly diminished.

*Recent oil price hikes have revealed an oil market with much less flexibility to deal with supply shocks or large increases in global oil demand.*

This situation, if it turns out to be correct, would have strong implications both on price levels and the dynamic behaviour of crude oil prices. Given that the crude oil market is characterised by low price elasticity of supply, any increase in demand cannot be met by an increase in oil supply, especially in the short run. Thus, in the absence of spare capacity, demand shocks would require a large change in prices to clear the market. In particular, when capacity constraints become the driving force in the market, the following price dynamics are likely to emerge: an accelerated rise in the average level of oil prices, more frequent spikes in crude oil prices, and an increase in the volatility of oil prices. The behaviour of oil prices in the last three years is consistent with these price dynamics where we witnessed an accelerated rise in oil prices and many frequent oil price hikes. Volatility has also increased and reached high levels in the last two years. We used a GARCH (1,1) model to estimate the conditional volatility of weekly spot price returns of Western Texas Intermediate (WTI) crude oil from January 1995 to November 2006. Figure 1 plots the estimated conditional variance. As can be seen from this graph, volatility rose markedly especially in 2004 and remained high until the end of our sample period – in particular compared to the mid and late 1990s.

**Figure 1. Conditional volatility of crude oil price (in percent)**



Notes: Based on GARCH (1,1) model; weekly data of spot WTI price; January 1995–November 2006.

### 4.3 Speculation

***Tight market conditions, geopolitical uncertainties, and very limited spare capacities have made some of the bets on potential supply shocks extremely attractive.***

In a number of articles in energy publications and international policy reports, many observers have raised concerns about the possible impact of speculators on the recent rises in oil prices.<sup>10</sup> It is often argued that in recent years, a large number of speculators have entered the oil market lured by the market's high returns. The BIS Quarterly Review (2004) notes that "the rapid increase in oil prices in recent months has focused attention on the role of speculators in the oil market. With prices in most major equity, bond and credit markets moving sideways or even declining, investors in search of higher returns have reportedly turned to commodity markets, oil in particular" (p.6). In a similar vein, Greenspan (2006) has noted that "when in the last couple of years it became apparent that the world's industry was not investing enough to expand crude oil production capacity quickly enough to meet rising demand, increasing numbers of hedge funds and other institutional investors began bidding for oil" (p.3). Tight market conditions, geopolitical uncertainties, and very limited spare capacities have made some of the bets on potential supply shocks extremely attractive. For instance, although the probability of a supply shock might not have changed compared to previous years or might have increased only slightly, the upside potential in the event of such a shock can be extremely high in the absence of sufficient spare capacity. Although inventories have risen, investors believe that in case of such a supply shock, the current level of inventories would not be enough to absorb the price rise.

Many observers hold the view that the new players trade on noise and sentiment rather than on fundamentals – with adverse effects on the functioning of oil markets. Black (1986) defines noise traders as agents who sell and buy assets on the basis of irrelevant information rather than on market fundamentals or the arrival of new information. These are usually contrasted with arbitrageurs, rational speculators, or 'smart money' that trade on the basis of information and thus tend to push prices towards fundamentals. Although noise traders may be active in financial markets, the traditional view has been that speculators trading on noise can be ignored in models of price formation because they

<sup>10</sup> See for instance United States Senate (2006), Staff Report on "The Role of Market Speculation in Rising Oil and Gas Prices: A Need to Put the Cop Back on the Beat", June 27, 2006.

will continuously lose money and will eventually exit the market. This argument was forcefully made by Friedman (1953) who states that “people who argue that speculation is generally destabilizing seldom realize that this is equivalent to saying that speculators lose money since speculation can be destabilizing in general only if speculators on average sell low and buy high” (p.175).

This traditional view has been challenged recently. Shleifer and Summers (1990), for instance, argue that on average noise traders may be more aggressive than arbitrageurs, either because they are more optimistic or overconfident, and thus are likely to bear more risk. If higher risk is rewarded in the market, then noise traders can earn higher expected returns on average and hence as a group they need not disappear from the market. Kogan *et al.* (2003) find that irrational traders can affect prices even if trading decreases their wealth over time implying that the price impact of irrational traders does not rely on their long-run survival.

***If higher risk is rewarded in the market, then noise traders can earn higher expected returns on average and hence as a group they need not disappear from the market.***

However, even if we assume that noise traders survive in the market, the question is whether changes in demand due to noise trading are big enough to affect prices and destabilise the market. Many have argued that herding behaviour can lead to such a situation. Herding results from investors’ decision to follow the trading strategies of others. If the shifts in demand are correlated across noise traders and do not cancel each other out, noise trading is capable of influencing market prices. Furthermore, the potential for herding implies that arbitrage is not riskless and hence arbitrageurs will not necessarily always be able to arbitrage away the noise trade. In fact, the arbitrageurs may not have the incentive to counter shifts in demand by noise traders and may instead decide to ride the wave in the hope that they can dispose of the assets near the top before the noise traders. In an interesting study, Brunnermeier and Nagel (2004) show that rational traders may have the incentive to trade in the same direction as irrational traders in the short run (i.e., rational traders herd too) if convergence is expected to be slow.

There are many explanations as to why investors may decide to engage in herding.<sup>11</sup> One approach explains herding in terms of investors’ irrational behaviour (De Long *et al.* 1990; Froot *et al.* 1992). Another approach tries to explain why fully rational profit maximising investors may be influenced by other investors’ decision and decide to reverse their investment strategy and follow the herd. Several reasons are given, the most important of which are informational asymmetries (Bikchandani *et al.* 1998), compensation structures of money managers (Roll 1992), and reputation concerns (Scharfstein and Stein 1990). Despite the richness of these theoretical discussions, the empirical evidence on herding lags behind. In reviewing the literature, Sias (2005) notes that that out of the eleven studies reviewed, four did not find any momentum trading (that is, herding), five did find weak evidence of institutional momentum trading, while two found strong evidence of momentum trading. He concludes that “as a whole, extant evidence of institutions momentum trading is, at best very weak” (p.2).

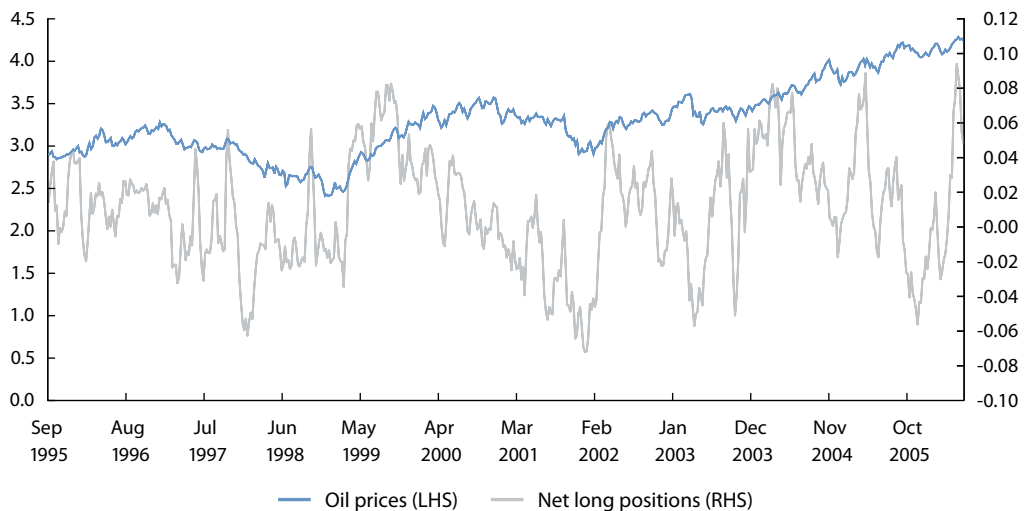
Empirical studies applied to oil market have mainly focused on the changes in non-commercial traders’ net long position and have noted that these have tended to coincide with changes in the oil price. Figure 2 below plots the net long positions of non-commercial traders and the spot price. Based on this graph, it is possible to make three broad generalisations. First, prices appear to be less volatile than speculative positions. Second, there is no common trend between prices and speculation. In other words, there is no persistent pickup in net long positions coinciding

<sup>11</sup> This should be distinguished from ‘spurious herding’ where investors facing the same information decide to undertake the same investment decisions. Spurious herding is efficient whereas intentional herding may be inefficient. In practice, it is very difficult to distinguish between the two forms of herding (Bikchandani and Sharma 2000).

**Evidence that changes in non-commercial traders' net long position have tended to coincide with changes in the oil price could be the result of a change in fundamentals that affect both oil prices and futures position of speculators.**

with an upward trend in oil prices. Finally, changes in non-commercial traders' net long positions may coincide with changes in oil prices. But this observation does not establish that speculators necessarily influence oil prices. Evidence that changes in non-commercial traders' net long position have tended to coincide with changes in the oil price could be the result of a change in fundamentals that affect both oil prices and futures position of speculators. That is why the BIS when commenting on the role of speculators in the oil market has been careful in noting that "it is also possible that shifts in activity in the futures market were driven by changing perceptions of fundamental imbalances in the supply of and demand for oil, including the changing perceptions of commercial traders" (p.6). When speculators react and change their position in response to new information, speculation is not necessarily destabilising. In fact, if speculators have superior information that enable them to respond fast to the arrival of new information, then they may even improve the functioning of the market by speeding up the price adjustment process. Consistent with this, Fleming and Ostdiek (1998) find an inverse relationship between open interest in crude oil futures and spot market volatility. They interpret these findings as evidence that trading improves the depth and liquidity of the underlying market.

**Figure 2. Oil prices and net long positions of non-commercial traders**



Source: International Monetary Fund (2006)  
 Notes: Spot price in log scale (left scale); net long positions in millions of contracts (right scale).

In a more recent study, Haigh *et al.* (2005) use a unique dataset from the Commodity Futures Trading Commission to examine the role of hedgers and speculators in the crude oil market. The disaggregated data allow the authors to examine the role of hedge funds, considered by many as responsible for the recent heightened speculative activity. Interestingly, the authors find that these funds provide liquidity to hedgers and not the other way around. They also find evidence that these large speculators have little influence on oil prices. Finally, they find that the evidence of herding is very weak and even if it exists, herding is not destabilising in the sense that traders do not buy when prices are low and sell when prices are high and hence do not cause the overshooting of oil prices.

#### **4.4 Inventories and the term structure of oil prices**

The last three years have witnessed a high build-up of inventories in the United States and other OECD countries. To illustrate, total commercial inventories in the United States amounted to around

1,022 million barrels – almost 47 million barrels more than the five-year average. This rapid rise in inventories raises two key questions: why have inventories risen so fast in recent years and what has been the impact on oil prices?

Some have argued that the current build-up of inventories is a sign of oversupply in the crude oil market. When supply exceeds (effective) demand at any point in time, the difference would be added to inventories. This explanation however suffers from a major drawback: why would customers want to lift more crude oil than what they effectively need? Unless there is an incentive for them to hold inventories, customers are under no obligation to absorb the oversupply from the oil producers. Supply does not create its own demand!

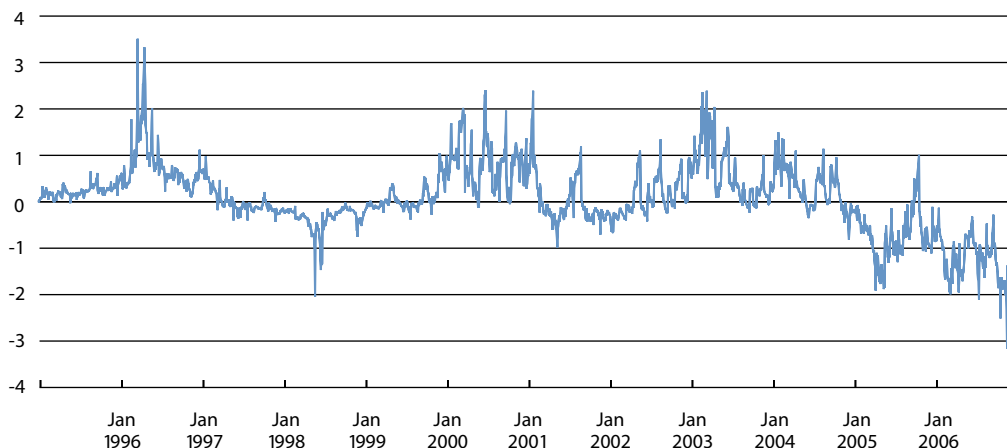
Others have argued that the current build-up is driven by the demand for precautionary inventories in the face of tightness throughout the oil supply chain. For instance, Petroleum Argus (19 June 2006) argues that the market is signalling that “just-in-time inventories are no longer appropriate as OPEC has lost the spare capacity that enabled it to act as a buffer, shifting stock risk management down the crude supply chain to refiners”. This explanation implies that private oil companies would keep inventories even when it is costly for them to do so. It also implies a fundamental shift in the behaviour of oil companies and refineries towards a new inventory policy. Under pressure to maximise shareholder value, international oil companies have undergone major cost-cutting exercises. In contrast to what the Petroleum Argus seems to suggest, cost-cutting has included slashing inventories to their lowest possible level and shifting to a ‘just in time inventory policy’. In this new era, oil companies rely on OPEC’s large holdings, consuming countries’ strategic petroleum reserves, and on a developed spot market for immediate deliveries. Thus, a shift back towards holding precautionary inventories would imply a structural break in the oil market. There is nothing to suggest that this has happened. The shift in inventory policy would also imply a fundamental change in international oil companies’ behaviour. Given that international oil companies are under pressure to maximise shareholder value, the proponents of the ‘structural shift in inventory policy’ must show how holding precautionary inventories would maximise shareholder value even when it is not commercially profitable to hold inventories.

***The recent rapid rise in inventories raises two key questions: why have they risen so fast and what has been the impact on oil prices?***

A more plausible explanation is that the recent build-up of inventories is due to the term structure of oil prices. In an influential article, Litzenberger and Rabinowitz (1995) noted that 80-90 percent of the time the oil forward curve is in backwardation, i.e., futures prices are lower than spot prices. The authors explain backwardation as follows. Ownership of oil reserves constitutes a call option – that is, producers have the option of extracting and selling oil, but they also have the option of leaving it in the ground – extracting and selling it in the future. Postponing extraction makes sense if discounted futures prices are higher than spot prices and if extraction costs grow by no more than the interest rate. But if all producers wait, there will be a shortage of oil today causing the spot price to rise. The net result is backwardation in which the oil price rises today to offset the advantage of postponing oil extraction. Thus, according to this explanation, weak backwardation is a necessary condition for current production.

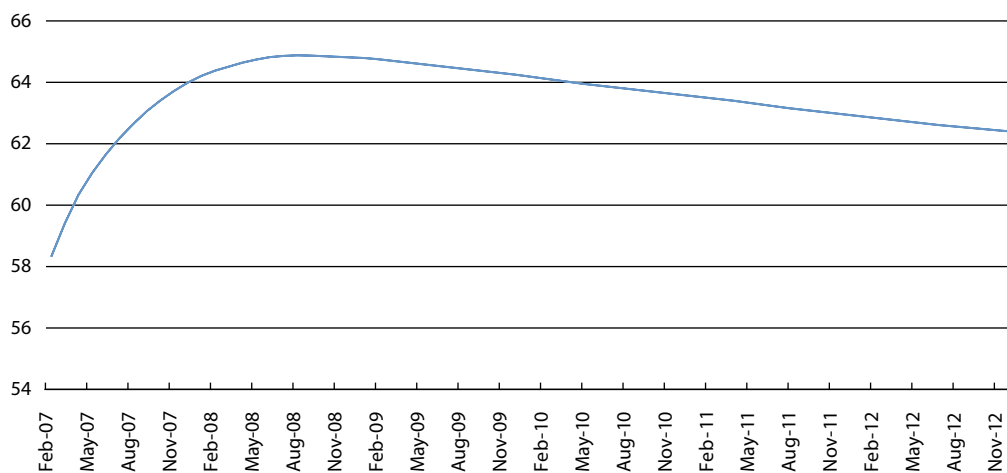
However, a striking feature of recent times has been a prolonged contango in the oil market, that is, a situation where future prices are higher than spot prices. Figure 3 shows that during the last 20 months or so, the first-month futures contracts for WTI oil have been trading at a discount to the second-month futures contract. Figure 4, which plots the WTI forward price curve, shows a very steep slope, with the nearby contract trading at a discount of almost \$7 to the August 2008 contract.

**Figure 3. First-month vs. second-month futures contract for WTI**



Source: EIA website <http://www.eia.doe.gov/>  
 Notes: \$/barrel on the vertical axis. Years on horizontal axis show data for March.

**Figure 4. WTI forward price curve (as of 3 January 2007)**



Source: NYMEX website <http://www.nymex.com/index.aspx>

***If oil for future delivery is trading at a large premium over immediate delivery, the cost of carrying inventories is covered.***

Given this oil price term structure, it is no surprise that commercial inventories have been rising fast. If oil for future delivery is trading at a large premium over immediate delivery, the cost of carrying inventories is covered, prompting market participants with storage facilities to accumulate inventories, stock up their tanks, and make a profit by selling contracts in the futures market. Finding a buyer to take the other side of the bet is not a problem in an environment where the crude oil market is expected to be tight in the future and where geopolitical uncertainties and very limited spare capacities have made financial bets on potential supply shocks extremely attractive.

Let us then turn to the question of how the build up in inventories affects oil prices. As Figure 3 shows, the last time the crude oil market entered in a prolonged contango (lasting for more than 12 months) was in 1998. Contrary to the current contango, the 1998 episode was associated with a downward price trend and it shows that contango can become self-reinforcing. This is because it might encourage market participants with storage facilities to accumulate inventories. If the market interprets rising inventories as an increase in crude oil supply relative to demand, the spot price of oil would go down, thereby widen the size of the contango. This, in turn, might induce a further increase

in inventories and, if interpreted as a sign of ample supply, reduce prices for immediate delivery. This self-reinforcing contango can continue for a while, causing sharp falls in spot crude oil prices. In sum, as the 1998 episode has shown, contango can be associated with falling oil prices and rapidly increasing inventories.

This time round the situation is quite different, however: until very recently, the contango and the associated rise in inventories occurred together with an upward trend in oil prices. In explaining this, some observers argue that large inventories are no longer seen as a sign of oversupply and hence do not exert downward pressure on prices.<sup>12</sup> Given the decline in OPEC spare capacity, the argument continues, the market's perception of what constitutes a high level of inventories has changed so much that current inventories – although high by historical standards – are not seen to signal oversupply in the oil market.

A more plausible explanation is that the relationship between inventories and oil prices has remained unchanged. Higher-than-expected inventories still cause oil prices for immediate delivery to decline. However, other factors are pushing spot prices in the opposite direction, disguising the impact of inventories on oil prices.

#### **4.5 Have there been structural changes in the oil market?**

Are the above drivers cyclical or structural in nature or, to put the question differently, are the observed changes in the oil market temporary or permanent? The informal approach adopted here cannot provide a quantitative assessment of changes in the oil market – such as changes in price and income elasticity or the inventory-price relationship (Stevens 2005). That being said, the informal approach allows a qualitative assessment of whether the market has witnessed structural changes with a lasting impact on oil price behaviour and whether the recent strength in the oil prices has been mainly due to temporary drivers. In what follows we focus on two aspects: spare capacity and the greater reliance on the futures market for price discovery.

The most obvious change has been the gradual decline of spare capacity to a very low level, especially when compared to the mid 1980s and early 1990s. As discussed above, low spare capacity implies that in the case of shocks, prices will bear the bulk of the adjustment. This raises an important question: will the spare capacity in the upstream oil be re-established to its previous high level? To answer this question, it is important to stress that the spare capacity that has provided a large cushion against oil market shocks has not been the outcome of a rational investment decision. Instead, it has emerged as result of specific market developments in the mid 1980s and early 1990s that left OPEC member countries with large spare capacity. Most observers suggest that these market conditions will not come back and, hence, an increase in spare capacity will not materialise unless new investments are made. But who should bear the costs of investment in spare capacity? The international oil companies have no interest in bearing them since investment in spare capacity implies that companies would hold idle assets, which would run counter to maximising shareholder value. As far as national oil companies are concerned, most of them may not be able to invest in new capacity due to a variety of financial and political constraints. The exception here might be Saudi Aramco, the national oil company of Saudi Arabia, whose declared policy is to maintain a spare capacity of 2-3 mbd, which is not really a lot – representing only around 2 percent of global production. The obstacles facing investment in the oil

*The most obvious change in the global oil market has been the gradual decline of spare production capacity to a very low level.*

<sup>12</sup> Edward Morse, for instance, argues that “key truisms of the old market are that prices fall in a contango and that stock builds will undermine any price rise. However, in a structurally tight market, these ‘truisms’ may not be valid.” See Edward Morse, “The Global Oil Market Outlook: Ten Lessons About the Petroleum Sector”, presentation given at the 2006 Summer Fuels Outlook Conference Washington, D.C., April 11, 2006.

sector and the failure to address the complicated issue of who should bear the costs of creating spare capacity simply mean that the required investment in spare capacity is unlikely to materialise. It seems that the 'international oil order' – where non-OPEC supplies most of the incremental global oil demand and OPEC provides the capacity cushion – has been shaken in recent years with probably permanent implications for oil markets.

A less obvious transformation has been the increasing importance of futures markets, in lieu of spot markets, for the price discovery process (see Fattouh 2006). This has increased the role of financial investors and traders in influencing oil prices. While this may have lasting effects on short-term movements in oil prices and volatility, it is unlikely to affect the long-run behaviour of oil prices. All in all, any long-term trends in oil prices will continue to be dictated by market fundamentals rather than investors' sentiment.

The shift to the futures market may also affect the market through its impact on OPEC behaviour. When deciding on its output, OPEC now needs to consider a wide range of factors such as the level of inventories, the shape of the forward curve, the size of speculative positions in the futures market, and the sentiment (bearish or bullish) of traders. As we argue elsewhere in greater detail (Fattouh 2007b), this poses dilemmas for OPEC and greatly complicates its decision making for the simple reason that OPEC has only one policy tool at its disposal (that is, choosing its output) with which it would like to achieve a wide range of objectives. This may have undesired consequences on oil price fluctuations, inducing volatility and causing sharp rises or falls in oil prices in some instances.

To wrap up, this section has taken an informal approach to analysing oil price behaviour – an approach that emphasises the specific economic and political context in which prices evolve. Although this approach is essential for understanding current and past developments in the oil market, it can only provide a cursory view about how the market and prices might develop in the future.

## **5. Conclusions**

***Pushing hard for policies based on projections resulting from the approaches presented in this paper defeats their purpose and may result in misguided policies.***

This paper discusses three main approaches for analysing oil prices: the exhaustible resources, the supply-demand, and the informal approach. Each approach suggests a certain set of drivers of oil prices. However, we have emphasised that they all suffer from major limitations especially when used to make predictions. This is not to say that current frameworks for analysing oil prices should be avoided. They usually provide useful insights into the functioning of the world oil market and how it might evolve in the future. Expecting these approaches to offer accurate predictions about oil market developments will inevitably result in disappointment, however. Various players in the oil market – such as international organisations, oil companies, and governments – should keep this in mind when making their investment decisions or policy recommendations. Pushing hard for policies based on projections following from these approaches defeat their purpose and may result in misguided policies – not to say dangerous ones.



## References

- Adelman, M.A. (1980). "The clumsy cartel". *The Energy Journal*, (1:1), pp. 43-53.
- Adelman, M.A. (1982). "OPEC as a cartel", in Griffin, J. and Teece, D. (eds.), *OPEC Behavior and World Oil Prices*. Allen and Unwin, London, UK.
- Adelman, M.A. (1990). "Mineral depletion, with special reference to petroleum". *Review of Economics and Statistics*, (72:1), pp.1-10.
- Ahlbrandt, T.S. (2006). "Global petroleum reserves, resources and forecasts", in Mabro, R. (ed.), *Oil in the twenty-first century: Issues, challenges, and opportunities*, Oxford University Press, Oxford, UK.
- AlHajji, A. and Huenter, D. (2000). "The target revenue model and the world oil market: Empirical evidence from 1971 to 1994". *The Energy Journal*, (21:2), pp. 121-144.
- Bacon, R. (1991). "Modelling the price of oil". *Oxford Review of Economic Policy*, (7), pp. 17-34.
- Bank for International Settlement. (2004). "International banking and financial market developments". *BIS Quarterly Review*, (September).
- Barsky, R. B. and Kilian, L. (2004). "Oil and the macroeconomy since the 1970s". *Journal of Economic Perspectives*, (18:4), pp. 115–134.
- Berck, P. (1995). "Empirical consequences of the Hotelling principle", in Bromley, D.W. (ed.), *Handbook of Environmental Economics*, Blackwell Publishing, Oxford, UK.
- Berck, P. and Roberts, M. (1996). "Natural resource prices: Will they ever turn up?". *Journal of Environmental Economics and Management*, (31:1), pp. 65-78.
- Bikhchandani, S., Hirshleifer, D., and Welch, I. (1998). "Learning from the behavior of others: Conformity, fads and informational cascades". *Journal of Economic Perspectives*, (12), pp.151- 170.
- Bikhchandani, S. and Sharma, S. (2000). "Herd behavior in financial markets: A review". IMF Working Paper WP/00/48.
- Black, F. (1986). "Noise". *Journal of Finance*, (41), pp. 529-543.
- Brook, A., Price, R., Sutherland, D., Westerlund, N., and Andre, C. (2004). "Oil price developments: Drivers, economic consequences and policy responses". OECD Economic Outlook No. 76.
- Brunnermeier, M.K., and Nagel, S. (2004). "Hedge funds and the technology bubble". *Journal of Finance*, (59), pp. 2013-40.
- Campbell, C.J. (1989). "Oil price leap in the nineties". *Noroil*, (12), pp. 35-38.
- Campbell, C.J. and Laherrère, J.H. (1998). "The end of cheap oil". *Scientific American*.
- Cashin, P., Liang, H., and McDermott, J. (1999). "How persistent are shocks to world commodity prices?". IMF Working Paper No. 80.

- Cavallo, A.J. (2002). "Predicting the peak in world oil production". *Natural Resources Research*, (11), pp.187-195.
- Cooper, J.C.B. (2003). "Price elasticity of demand for crude oil: Estimates for 23 countries". *OPEC Review*, (27), pp. 1-8.
- Crémer, J. and Salehi-Isfahani, D. (1991). *Models of the oil market*, Harwood Academic Publishers, New York, USA.
- Dahl, C. (1993). "A survey of oil demand elasticities for developing countries". *OPEC Review*, (17:4), pp. 399-419.
- Dahl, C. and Sterner, T. (1991). "Analyzing gasoline demand elasticities: A survey". *Energy Economics*, (3:13), pp. 203-210.
- Dahl, C. and Duggan, T. (1996). "U.S. energy product supply elasticities: A survey and application to the U.S. oil market". *Resource and Energy Economics*, (18:3), pp. 243-63.
- De Long, J.B., Shleifer, A., Summers, L.H., and Waldmann, R.J. (1990). "Noise trader risk in financial markets". *Journal of Political Economy*, (98), pp. 703-738.
- Dees, S., Karadeloglou, P., Kaufmann, R.K., and Sanchez, M. (2007). "Modelling the world oil market: Assessment of a quarterly econometric model". *Energy Policy*, (35:1), pp. 178-191.
- Dufour, J.M., Bernard, J.T., Khalaf, L., and Kichian, M. (2006). "Structural change and the dynamics of energy prices: Identification-robust test for time-varying parameters". Université de Montréal CIRANO and CIREQ Discussion Paper.
- Energy Information Administration. (2005). *International Energy Outlook 2005*, EIA, Washington, D.C., USA.
- Energy Information Administration. (2006). *International Energy Outlook 2006*, EIA, Washington, D.C., USA.
- Espey, M. (1998). "Gasoline demand revisited: An international meta-analysis of elasticities". *Energy Economics*, (20), pp. 273-295.
- Fattouh, B. (2006). "The origins and evolution of the current international oil pricing system: A critical assessment", in Mabro, R. (ed.), *Oil in the twenty-first century: Issues, challenges, and opportunities*. Oxford University Press, Oxford, UK.
- Fattouh, B. (2007a). "OPEC pricing power: The need for a new perspective", in Helm, D. (ed.), *The new energy paradigm*. Oxford University Press, Oxford, UK. forthcoming.
- Fattouh, B. (2007b). "OPEC's dilemma". *Oxford Energy Forum*. forthcoming.
- Fattouh, B. and Mabro, R. (2006). "The investment challenge" in Mabro, R. (ed.), *Oil in the twenty-first century: Issues, challenges, and opportunities*, Oxford University Press, Oxford, UK.
- Fleming, J. and Ostdiek, B. (1998). "The impact of energy derivatives on the crude oil market". *Energy Economics*, (21), pp.135-67.

- Friedman, M. (1953). *The case for flexible exchange rates: Essays in positive economics*, Chicago University Press, Chicago, USA.
- Froot, K.A., Scharfstein, D.S., and Stein, J.C. (1992). "Herd on the street: Informational inefficiencies in a model with short-term speculation". *Journal of Finance*, (67), pp. 1461-1484.
- Gately, D. (1984). "A ten-year retrospective: OPEC and the world oil market". *Journal of Economic Literature*, (22:3), pp.1100-1114.
- Gately, D. (2001). "How plausible is the consensus projection of oil below \$25 and Persian Gulf oil capacity and output doubling by 2020?". *The Energy Journal*, (22:4), pp. 1-27.
- Gately, D. (2004). "OPEC's incentives for faster output growth". *The Energy Journal*, (25:2), pp. 75-96.
- Gately, D. and Huntington, H. (2002). "The asymmetric effects of changes in price and income on energy and oil demand". *The Energy Journal*, (23:1), pp.19-58.
- Graham, D. and Glaister, S. (2002). "The demand for automobile fuel: A survey of elasticities". *Journal of Transport Economics and Policy*, (36), pp.1-26.
- Greenspan, A. (2006). Statement of Alan Greenspan before the United States Senate Committee on Foreign Relations, June 7, 2006.  
<http://foreign.senate.gov/testimony/2006/GreenspanTestimony060607.pdf>
- Griffin, J.M. and Schulman, G.T. (2005). "Price asymmetry in energy demand models: A proxy for energy-saving technical change". *The Energy Journal*, (26:2), pp. 1-21.
- Haigh, M.S., Hranaiova, J., and Overdahl, J. (2005): "Price volatility, liquidity provision and the role of managed money traders in energy futures markets". US Commodity Futures Trading Commission Working Paper.
- Hnyilicza, E. and Pindyck, R.S. (1976). "Pricing policies for a two-part exhaustible resource cartel: The case of OPEC". *European Economic Review*, (8), pp.139-154.
- Hotelling, H. (1931). "The economics of exhaustible resources". *Journal of Political Economy*, (39), pp.137-175.
- Hubbert, M.K. (1956). "Nuclear energy and the fossil fuels", in American Petroleum Institute (ed.), *Drilling and Production Practice*. Washington, D.C., USA.
- Ibrahim, I.B. and Hurst, C. (1990). "Estimating energy and oil demand functions: A study of thirteen developing countries". *Energy Economics*, (12:2), pp. 93-102.
- International Monetary Fund (2005). "Will the oil market continue to be tight?" in *World Economic Outlook: Globalization and external imbalances*. IMF, Washington, D.C., USA.
- International Monetary Fund (2006). "The boom in nonfuel commodity prices: can it last?" in *World Economic Outlook: Financial systems and economic cycles*. IMF, Washington, D.C., USA.
- International Energy Agency (2006). *World Energy Outlook*, IEA, Paris, France.

- Johany, A. (1980). *The myth of the OPEC cartel - The role of Saudi Arabia*, John Wiley and sons, New York, USA.
- Jones, D., Leiby, P., and Paik, I. (2004). "Oil price shocks and the macroeconomy: What has been learned since 1996". *Energy Journal*, (25:2), pp. 1-32.
- Kaufmann, R.K. (1995). "A model of the world oil market for Project LINK: Integrating economics, geology, and politics". *Economic Modeling* (12:2), pp. 165-178.
- Kaufmann, R.K. and Cleveland, C.J. (2001). "Oil production in the lower 48 states: Economic, geological, and institutional determinants". *Energy Journal*, (22), pp. 27-49.
- Khanna, N. (2001). "On the economics of non-renewable resources". Binghamton University Department of Economics Working Paper No. 0102.
- Kogan, L., Ross, S.A., Wang, J., and Westerfield, M.M. (2003). "The price impact and survival of irrational traders". MIT Sloan Working Paper No. 4293-03.
- Kohl, W.L. (2002). "OPEC behaviour, 1998–2001". *The Quarterly Review of Economics and Finance*, (42:2), pp. 209-233.
- Krautkraemer, J.A. (1998). "Nonrenewable resource scarcity". *Journal of Economic Literature*, (36), pp. 2065-2107.
- Krichene, N. (2006). "World crude oil markets: Monetary policy and the recent oil shock". IMF Working Paper No. 06/62.
- Lee, J., List, J.A., and Strazicich, M.C. (2006). "Non-renewable resource prices: Deterministic or stochastic trends?". *Journal of Environmental Economics and Management*, (51:3), pp. 354-370.
- Libecap, G.D. and Smith, J.L. (2004). "Political constraints on government cartelization: The case of oil production regulation in Texas and Saudi Arabia", in Grossman, P. (ed.), *How cartels endure and how they fail: Studies of industrial collusion*. Edward Elgar Publishing Ltd, Cheltenham, UK.
- Litzenberger, R. and Rabinowitz, N. (1995). "Backwardation in oil futures markets: Theory and empirical evidence". *Journal of Finance*, (50), pp.1517–45.
- Lynch, M.C. (2002). "Forecasting oil supply: Theory and practice". *The Quarterly Review of Economics and Finance*, (42), pp. 373-389.
- Mabro, R. (1991). "OPEC and the price of oil". *The Energy Journal*, (13), pp. 1-17.
- Mead, W.J. (1979). "The performance of government energy regulation". *American Economic Review*, (69), pp. 352-356.
- Moazzami, B. and Anderson, F.J. (1994). "Modelling natural resource scarcity using the 'error-correction' approach". *Canadian Journal of Economics*, (27:4), pp. 801-812.
- Moroney, J.R. and Berg, M.D. (1999). "An integrated model of oil production". *Energy Journal*, (20:1), pp. 105-124.

- Murti, A., Singer, B., Ahn, L., Stein, J., Panjabi, A., and Podolsky, Z. (2005). "Super spike period may be upon us: Sector attractive". Goldman Sachs US Investment Research Report on US Energy: Oil (30 March 2005). <http://www.oilcast.com/pdfs/superspike.pdf>
- Odell, P.R. (1998). "Oil and gas reserves: Retrospect and prospect". *Energy exploration and exploitation*, (16), pp. 117-124.
- Odell, P.R. and Rosing, K.E. (1983). *The future of oil - World oil resources and use*. Kogan Page, 2<sup>nd</sup> edition, London, UK.
- Pesaran, M., Smith, R., and Akiyama, T. (1998). *Energy demand in Asian developing economies, a World Bank study*, Oxford University Press, New York, USA.
- Pindyck, R.S. (1978). "Gains to producers from the cartelization of exhaustible resources". *Review of Economics and Statistics*, (60), pp. 238-251.
- Pindyck, R. (1999). "The long-run evolution of energy prices". *The Energy Journal*, (20:2), pp. 1-27.
- Roll, R. (1992). "A mean/variance analysis of the tracking error". *Journal of Portfolio Management*, (18), pp. 13-22.
- Salant, S. (1976). "Exhaustible resources and industrial structure: A Nash-Cournot approach to the world oil market". *Journal of Political Economy*, (84), pp. 1079-1093.
- Scharfstein, D.S. and Stein, J.C. (1990). "Herd behavior and investment". *American Economic Review*, (80), pp. 465-479.
- Seba, R. (1998). *Economics of worldwide petroleum production*, OCGI Publications, Houston, USA.
- Shell Global Business Environment, Environment and External Affairs. (2001). "Energy needs, choices, and possibilities. Scenarios to 2050". Exploring the future. Shell International 2001.
- Shleifer, A. and Summers, L.H. (1990). "The noise trader approach to finance". *Journal of Economic Perspectives*, (4), pp. 19-33.
- Sias, R.W. (2005). "Reconcilable differences: Momentum trading by institutions". Washington State University Paper.
- Slade, M.E. (1982). "Trends in natural resource commodity prices: An analysis of the time domain". *Journal of Environmental Economics and Management*, (9), pp. 122-137.
- Smith, J.L. (2005). "Inscrutable OPEC? Behavioral tests of the cartel hypothesis". *The Energy Journal*, (26:1), pp. 51-82.
- Stevens, P. (2005). "Oil markets". *Oxford Review of Economic Policy*, (21:1), pp. 19-42.
- Teece, D. (1982). "OPEC behaviour: An alternative view", in Griffin, J. and Teece, D. (eds.), *OPEC behaviour and world oil prices*, Allen and Unwin, London, UK.
- United States Senate. (2006). "The role of market speculation in rising oil and gas prices: A need to put the cop back on the beat". Staff Report, June 2006. <http://levin.senate.gov/newsroom/supporting/2006/PSI.gasandoilspec.062606.pdf>

US Department of the Interior. (2000). "U.S. geological survey world petroleum assessment 2000 - Description and results". *US Geological Survey Report*.

Verma, M.K. (2000). "The significance of field growth and the role of enhanced oil recovery", U.S. Geological Survey Fact Sheet FS-115-00. <http://pubs.usgs.gov/fs/fs-0115-00/>

Watkins, G.C. (1992). "The Hotelling principle: Autobahn or cul de sac?". *Energy Journal*, (13:1), pp. 1-24.

Watkins, G.C. (2006). "Oil scarcity: What have the past three decades revealed?". *Energy Policy*, (34), pp. 508-514.

Watkins, G.C. and Streifel, S. (1998). "World crude oil supply: Evidence from estimating supply functions by country". *Journal of Energy Finance and Development*, (3:1), pp. 23-48.

Weston, P.J. and Christiansen, M.R. (2003). "OPEC: Market stabiliser or disruptive influence?". Paper presented at the 2003 British Institute for Energy Economics Conference. <http://www.biee.org/downloads/conferences/WestonChristiansen%20Paper.pdf>

