Does OPEC act as a Residual Producer?

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1.1 The Backdrop

It is a standard practice to consider the world crude oil market in terms of a demand and supply model and identify the equilibrium price as the point where the demand and supply equates. Although it is not very difficult to model world oil demand and conceive of oil demand as a function of price and income, the modeling of world oil supply however is quite complex. Numerous studies that have been carried out to understand the working of the world crude market revealed that crude supply does not resemble a simple model of supply where supply is a function of cost of production and price as in a competitive framework. This is primarily attributable to the fact that world crude supply is neither fully competitive nor fully monopolistic. The main suppliers of crude in the world are OPEC (Oil and Petroleum Exporting Countries), a cartel, consisting primarily of the countries in Middle-East and own the largest pool of crude reserve. Most of the economic models that were constructed to explain OPEC behavior indicated that OPEC behaved in a monopolistic fashion and had a very high stake in determining the world oil prices. Only a handful of studies indicated that OPEC behaved in a competitive fashion. From the survey of various economic models it becomes quite clear that it is very difficult to explain and capture the actions of OPEC by any single model as OPEC did not seem to have acted in a deterministic fashion. In fact the economic models that were constructed for different set of time periods after 1973, the year of the first oil crash, could at best be considered as approximate representations of the behavioural nature of the OPEC pertaining to those time periods.

If we go down the lane to the decade of the seventies, a clear line of demarcation could be observed between OPEC, the undisputed market leader sitting on the largest chunk of proven reserves[1], and Non-OPEC, the follower in oil supply with considerably lower proven reserves. In some studies (e.g. Stevens, 1994) OPEC has been identified as the 'Core' and the non-OPEC producers as the 'Periphery'. During that time ranging from the seventies till the first half of the eighties, there was not an iota of doubt on the monopoly power of the

[1] Proven reserves are estimated quantities that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions. The proven reserves of OPEC, as of 2007, stands at 939016 million barrels which is around 78 percent of the world proven crude oil reserves.

cartel and on its ability to control world crude oil prices through production cuts or increases.

In the early eighties, however, OPEC was often accused of behaving like a 'clumsy cartel'[2] with a clear presence of non-cooperative behaviour among some of its members with relatively lower crude reserves (like Qatar, Algeria, Indonesia, and Venezuela). On account of lower reserves, these members with the intention of amassing quick profit often tried to cheat on other members of OPEC especially when oil prices were on the higher side and produced in excess of what was originally expected from them. This non-compliant behaviour was driven by their apprehension that if they postpone their production for the future, when oil prices could go down significantly, then they might just ends up as major losers[3].

However, producers like Saudi Arabia with high reserve and production capacity could afford to produce less even when oil price was on the higher side and could postpone its production for future. But as an outcome of diverse and non-compliant tendency within the OPEC, Saudi Arabia often ended up producing the residual amount. However, as a residual producer, the production level of Saudi Arabia need not always have served its interest in the best possible manner. Consequently, around the mid-eighties, Saudi Arabia refused to play the role of a residual or a swing producer and started producing just with the intention of serving its own interest driven by its expected profits.

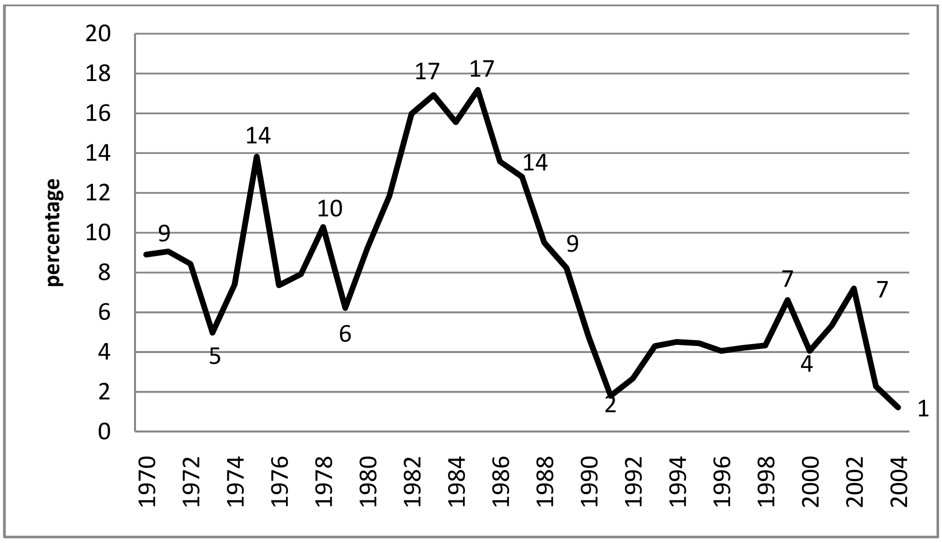
The aforementioned tendency of non-compliance within OPEC often raised questions about the cohesive capability of OPEC as a producing entity to exercise its market power through adjustment in its production. The lost confidence in the cohesiveness of the cartel and its pricing power got restored considerably after OPEC could successfully execute two successive production cuts when the oil prices nose-dived to an abysmally low level during the 1998 oil crisis. However, the unprecedented price hike of 2004 (when the crude oil prices rose above US $50 a barrel) and the inability of OPEC, especially its dominant producer

[2] This term was coined by Professor M. Adelman, the father of energy economics in 1980. See Adelman (1980) for details.
[3] Kremer and Isfahani, 1991.

Saudi Arabia, to counter that through production increases disturbed the restored confidence in OPEC once again.

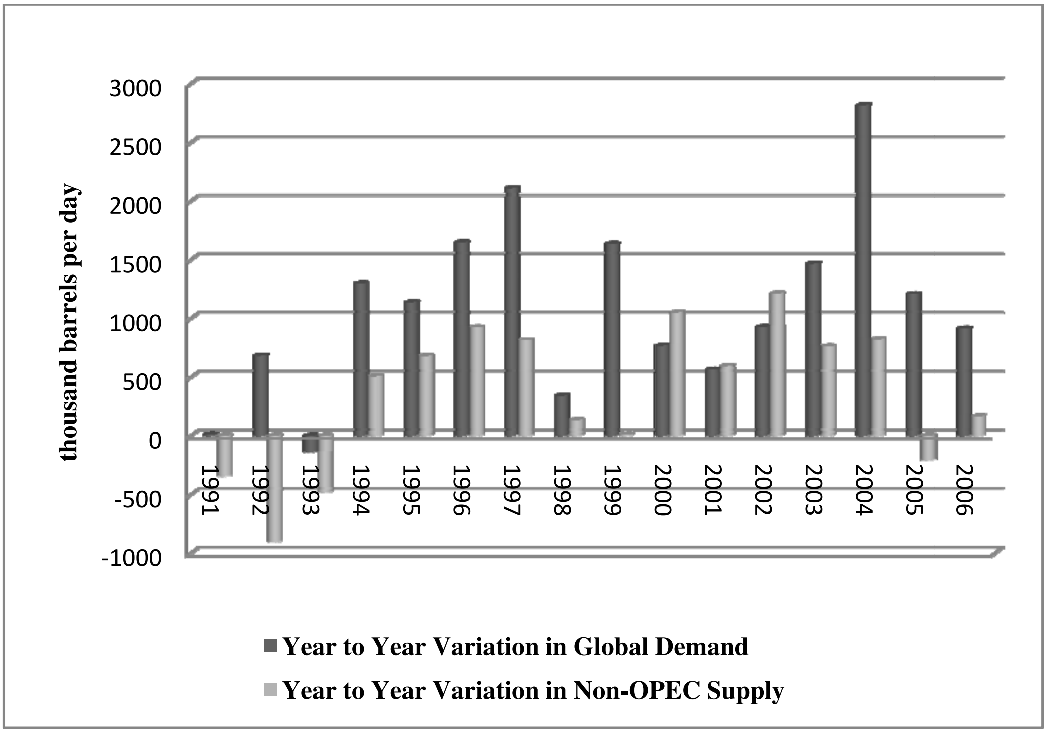
A couple of research studies that explored the causal factors behind OPEC's inability to counter spiraling prices through production increases, as mentioned above, evinced that this was attributed primarily to the erosion of their spare capacity for production of crude (Naimi, 2005; Fattouh, 2006; Mitchell, 2006). These studies underscored that the surge in Non-OPEC production coupled with a rapid decline in world crude oil demand in 1980s led to a drop in demand for OPEC crude far below expectation and eventually generated its surplus production capacity. However, since the early 1990s, spare capacity of OPEC had witnessed considerable decline (as clearly reflected in fig.1.1). This decline could be primarily attributed to accelerating global demand combined with low growth in Non-OPEC oil supply particularly over the period 1990-2004 (as shown in fig.1.2) and thus indicates a complete reversal of the trend in the 1980s.

Fig 1.1: Spare Capacity of OPEC as Percentage of World Oil Demand



Source: Calculated using data from IMF (2005) for spare capacity and various issues of Statistical Review of World Energy, British Petroleum (BP) for oil demand

Fig 1.2: Year to Year Variation in Global Oil Demand and Non-OPEC Supply



Source: Calculated by using data from various issues of Statistical Review of World Energy, BP.

Except for three consecutive years namely 2000, 2001 and 2002, when the Non-OPEC production surged due to an increase in production from Russia, the global demand has consistently outpaced Non-OPEC supply. This essentially implied that the shortfall in supply had to be met by OPEC. The consequence was an eventual erosion of OPEC's spare capacity in order to cope up with unprecedented rise in global demand. The process of erosion accelerated particularly in the 1990s and early 2000 (as shown in fig.1.1) largely due to the accelerating demand from emerging Asian economies. Furthermore, the decline in spare production capacity in the upstream (i.e. crude exploration and production) sector was accompanied by bottlenecks in investment in downstream (i.e. refining) assets such as pipelines, refineries and tankers which also failed to cope up with the rapid growth in global oil demand.

Another important factor that has assumed significance particularly since the mid 1990s is speculation. In fact the world oil pricing system has witnessed considerable changes in the last fifty years or so which saw the oil market shifting from administered oil pricing system (initially governed by the multinational oil companies and later by the OPEC) to a market related system in which oil was initially priced off the spot market and later on the basis of futures market, where only paper barrels are traded. Thus, the peculiarity of the international oil market at present is that price of a physical commodity, oil, is being fixed on the market for a class of financial assets i.e. oil futures.

Leaving aside the aforesaid causal factors that seems to have a significant bearing on erosion of OPEC's market power especially in the short run one also needs to examine in deeper details the true economic cause that lies behind the OPEC's incentive to produce (more or less), which is often missed out when the discussion is just focused on short-run spikes or collapses in oil prices. In the short-run speculation might gear up or pull down the price to an unprecedented level belying all expectations based on structural supply-demand framework but that should not lead one to hastily conclude that OPEC has no power in influencing world crude oil prices.

The NEMS (National Energy Modeling System) of Department of Energy (DoE), USA, and International Energy Agency (IEA), Paris in their modeling framework assume that OPEC is a residual supplier and the amount of oil to be supplied by OPEC could be expressed as:

OPEC output = World Oil Demand + Stock Adjustment – Non-OPEC output

These agencies begin by assuming the existence of an equilibrium price path. After calculating the world oil demand and Non-OPEC output, the latter is subtracted from the former (as shown above) after allowing for stock adjustment. This gives the excess oil demand (often referred to as 'Call on OPEC'), which is expected to be met by OPEC. These models thus assume that OPEC necessarily plays the balancing role of an equilibrator and residual producer by producing exactly the amount that is being demanded from it.

History, however, provides us with a different picture altogether and indicates that the conduct of OPEC has never followed a deterministic trajectory. Thus the OPEC has neither always supplied as per the ‘Call on OPEC’ nor has they oversupplied or undersupplied in a persistent manner. In fact, it is rather unusual to expect a rigid behavioural conduct from OPEC consisting of members with divergent views and interests. Thus, it would be unrealistic to predict the behavioural nature of the OPEC by making use of a single economic model.

In this context, an intriguing paper by Dermot Gately (Gately, 2007) deserves special mention. In that paper, he clearly demonstrated that there is no guarantee that the OPEC would always expand output as per the ‘Call’ unless that increased output level serves the interest of the OPEC and its key producers in the best possible manner. He estimated OPEC’s NPV (Net Present Value) of expected profits for different choice of OPEC’s export share in Non-OPEC consumption and for certain paths of non-OPEC supply and found that the NPV of expected profits is relatively insensitive to higher output growth. Thus, he underscored that aggressive output expansion plan as per the ‘Call on OPEC’ would yield lower payoff than if OPEC decides to maintain its market share. He further demonstrated that the increase in expected profit from higher output would be more than offset by lower prices as a result of rapid and aggressive output expansion.

In the light of this backdrop, the objective of this paper is to revisit the world crude oil market and explore whether OPEC actually plays the role of a residual producer. A thirty year span has been considered for the study ranging from 1975 to 2004. But before one goes on to a description of the model, it would be worthwhile to get a snapshot of the various economic models that have been constructed from time to time to explain the movement of world oil prices. Section 1.2 thus delves into a chronological survey of the economic models on world oil market underscoring especially on those models that vindicated the influence or otherwise of OPEC in price determination.

1.2. Economic Models of World Oil Market and OPEC's Role: A Survey of the Literature

In the aftermath of the first oil shock of 1973 a large number of theoretical and empirical studies had been undertaken to examine the structure of the world oil market and the role of the OPEC. For the sake of simplicity, these economic models explaining the world oil market and OPEC behaviour have been classified in this survey along the following lines - 1) Studies that underscored on OPEC as a single producing entity without any competition between its members; 2) Studies that recognised the role of Saudi Arabia separately within OPEC; 3) Property Rights Models; 4) Target Behaviour Models (Target Capacity Utilisation, Target Revenue Maximisation, Target Price Models); and 5) Econometric Models

1.2.1. <u>Studies that emphasized on OPEC as a single producing entity</u>

The studies along this line can be grouped into categories based on the behavioural model that they relied upon. They are 1) studies based on monolithic cartel model [Gilbert (1978) Pindyck (1978) and Salant (1976)] and studies based on competitive model [MacAvoy (1979)]

Studies relying on monolithic[4] cartel model

In this set of studies OPEC had been considered as a single producing entity without any competition among its members. Non-OPEC suppliers were considered as price-takers lying on the competitive fringe or periphery. The competitive fringe i.e. the Non-OPEC suppliers were assumed to increase their production in order to equalise their short-term marginal cost[5] with the price that was set by the OPEC. The OPEC was assumed to set the price after taking into account non-OPEC supplies and costs. The demand for OPEC oil was thus considered as the difference between the total world oil demand and non-OPEC supplies at different

[4] Monolith means residual producer.

[5] The costs of producing oil are not just the extraction costs. Marginal cost include the opportunity cost of selling the oil today instead of tomorrow, taking into account the depletable nature of a non-renewable resource.

levels of OPEC prices. In other words, OPEC was assumed to play the role of a residual producer

Gilbert (1978) considered OPEC as a dominant cartel- a Stackelberg leader and the other producers were assumed as followers and price takers. OPEC was assumed to maximise its profit by choosing an optimal production/extraction path after taking into consideration the reaction of the Non-OPEC fringe into its policies. The competitive fringe was considered to take prices as given and maximised its profit given the cartel's production path. As the total extraction would never exceed total reserve, the response of the competitive fringe was assumed to depend on the cost of extraction.

Pindyck (1978) used an intertemporal model where the demand facing OPEC at time t was considered as the difference between total world demand and Non-OPEC supply at time t. The production function of OPEC was given as:

$$Q_t^{OPEC} = f(P_t, Q^{NO}_{t-1})$$

Where Q_t^{OPEC} is the production of OPEC at time t, Q^{NO}_{t-1} is the supply of Non-OPEC in the preceding period i.e. t-1.

The objective of OPEC, as specified in the paper, was to derive the price P_t i.e. the price at point t that would maximise the sum of the discounted profits of the cartel after taking into account the rate of depletion, reserve level, and production cost (which tends to infinity as resources get exhausted).

Another study by Salant (Salant, 1976) assumed that the oil market structure was dominated by OPEC producers forming a collusive cartel that took the sales path of the competitive fringe as given and maximized their joint discounted profits. The cartel took account only of the response of consumers of oil to its policies and did not consider the response of the competitive fringe. OPEC had been considered as the residual supplier who was setting the price. The competitive fringe consisted of the non-OPEC suppliers (price takers) with limited production capacities. The power of OPEC had been assumed to depend on the elasticity of demand facing it, the elasticity of non-OPEC supply and the relative share of OPEC in world oil supply. World demand had been assumed to depend on the real price and economic activity while non-OPEC production had been assumed to depend on real price and exogenous supply variables. Accordingly, OPEC supply as a unified group had been considered to be a function of the real price of oil, economic activity and non-OPEC supply

Studies relying on competitive model

The studies that were based on competitive model were founded on the assumption that market is the primary determinant of oil price variations. The earliest along this line of research was the one by MacAvoy (MacAvoy, 1982). He analyzed the variations in oil prices by underscoring on the dynamics of supply and demand rather than the cartel behaviour. MacAvoy attributed the price increase in 1973 to speculative increases in demand on account of supply cutback. He underscored that demand and reserve conditions were far more important in influencing the oil price increases. Thus, he considered oil supply as a function of price, reserves and supply of the past period. Demand had been assumed to be a function of prices, income and past period demand. He also simulated the equilibrium prices under a number of assumptions on actual reserves, income, and elasticities. His main finding was that OPEC should not take credit for the cutback of supply, but only for restraining the supply expansion response in member countries.

Thus, according to this model, members of OPEC took the oil price as given and that changes in each member's output would not have any effect on the price level. It would simply act as a competitive exhaustible resource producer and set its price to its marginal cost plus its user cost. The oil prices were thus considered to be determined by the fundamentals of supply and demand.

1.2.2 <u>Studies that recognised the role of Saudi Arabia separately in OPEC</u>

Since there are differences among OPEC members with respect to production and pricing policies, OPEC can be divided into different groups according to their financial needs, absorptive capacities[6], costs of extraction, and the size of reserve. However, an important

[6] Absorptive capacity implies capacity to absorb and assimilate the revenue earned from exports.

aspect of OPEC relates to the role, the objective, and the policies of Saudi Arabia. Given that Saudi Arabia has always been sitting on largest chunk of world proven reserves, and also has a substantial share in world production and exports, a good number of studies in the early seventies and afterwards tried to evaluate Saudi Arabia's role separately rather than considering OPEC as a single producing entity. In fact Mabro (1975) underscored that "OPEC is Saudi Arabia". A number of studies that dealt with OPEC treated Saudi Arabia separately and emphasised on its importance as a cartel member (for instance Stevens, 1982).

In fact, there are several variants to the studies on OPEC that recognises the role of Saudi Arabia in some way or the other. These includes – 1) the two-block or three-block cartel; 2) the dominant producer model with Saudi Arabia as a swing producer

Two-block or Three-block Cartel

Hnyilicza and Pindyck (1976) considered OPEC as a two-part cartel where members were divided into two groups – 'savers' and 'spenders', according to their immediate financial needs. The 'savers' group consisted of Saudi Arabia, Kuwait, UAE, Qatar, Libya, and Iraq, and the 'spenders' group consisted of all other members. Because of the limited domestic absorptive capacity (i.e. capacity to absorb higher income) of the first group, they were assumed to have a low discount rate and the spenders were assumed to have a high discount rate. The output level for each group was determined by a division of total cartel production. After solving for optimization for two groups by considering the 'savers' and 'spenders' objective function separately, Hnylicza and Pindyck showed that the optimal price trajectory was quite different from that in the monopolistic solution. The price path had been observed to depend on the value which was determined through the use of the Nash solution and was contingent upon the negotiated agreement between the two groups. The model also suggested that spender countries would produce first because of the high discount rate, while the savers would produce last.

Geroski, Ulph and Ulph (1987) described OPEC as a cartel where the conduct of member producers varied over time in response to previous data and the co-operation of other producers. It also varied according to the producer's willingness to allow others to cheat, and the weight they had put on long-run and short run profits, which was dependent on their respective financial needs. By dividing ten major OPEC producers into four groups, (fringe, high absorbers, low absorbers and Saudi Arabia) and using quarterly data for the period 1966-1981, Geroski et.al estimated their model in two stages. First, they estimated the demand parameters. Then they imposed these parameters on the first order conditions to maximise profits and concluded that the member countries' conduct varied over time.

Studies carried out by Eckbo (1976), Houthakker (1979), Noreenge (1978), and Griffin and Steele (1986) inferred that OPEC behaviour could be explained by a three-part cartel including core members, price maximizing members and quantity maximizing members.[7]

Furthermore, a dynamic simulation model framed by Daly et al. (1982) assumed that OPEC behaved like a three-part cartel and estimated world oil demand, non-OPEC supply, and OPEC supply. For OPEC supply, they divided OPEC into: a cartel core including Saudi Arabia, Kuwait, UAE (United Arab Emirates), Qatar, and Libya; price maximisers including Iran, Algeria, and Venezuela; and output maximisers comprised of the rest of OPEC and then compared OPEC cartel behaviour in the pre and post Iranian revolution. They inferred that a price above $32 was not sustainable and would encourage conservation and induce synthetic fuels.[8] They also suggested that long run prices would more likely remain between $15 and $32.

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[7] Cartel core: Saudi Arabia, Kuwait, Qatar, UAE and Libya. Price Maximizers: Iran, Algeria,and Venezuela. Output Maximizers:Iraq, Nigeria, and Indonesia. (Griffin and Steele, 1986).

[8] The world oil price increased from $15 to $32 during Iranian revolution in 1978-79.

Saudi Arabia as a Swing Producer

As illustrated before OPEC as a monolithic cartel is capable of setting the price that maximizes its discounted profits. However, in order to maintain the monopolistic price, the output of the cartel should to be restricted through the allocation of output quotas among its members. But, the members with diverse financial needs, absorptive capacity and proven reserve position need not necessarily abide by the stipulated quota of production always and often threatens the cartel’s stability. Therefore, the cartel's stability is contingent upon some members with large revenues and limited absorptive capacity acting as swing producers in order to keep OPEC's output at a certain level and thus maintain the monopoly price.

Griffin and Teece (1982) delineated Saudi Arabia as the swing producer or the balancing wheel absorbing demand and supply fluctuations in order to maintain the monopoly price. However, they underscored that the monopoly price and the stability of OPEC would depend more on how much Saudi Arabia's share satisfied its own objective, than on the cohesion of the cartel. According to their model, Saudi Arabia would choose the price path which maximizes its wealth over time after taking into account the reaction of the fringe.

Adelman (1982) dubbed OPEC as a loosely co-operating oligopoly-cartel that was letting everybody else maximise profits individually by choosing their own production levels while the cartel had been raising prices by restricting output. OPEC was choosing its own production to maintain the cartel price and Saudi Arabia was acting as the swing producer. Adelman illustrated this with the example of output restriction in 1975, when Saudi Arabia reduced its production from an average of 8479.7 thousands barrel per day in 1974 to an average of 7075.4 thousands barrel per day in 1975 in order to maintain the price of oil at the monopolistic level.

Mabro (1975, 1986, 1987, and 1991) took cue from the dominant producer theory and underscored on OPEC as a cartel with Saudi Arabia playing the role of a Stackelberg price leader. In the seventies, Arabian Light was considered as benchmark crude and its price was determined by OPEC as single entity. The members of OPEC then set the price of their own oil, selling as much as they could, while Saudi Arabia was able to maintain its role as the residual supplier because of its relatively low absorptive capacity. However, the expansion of non-OPEC supply in the eighties led to a considerable decline in demand for OPEC oil and when this demand plummeted below the aggregate volume that could be produced by OPEC, its excess capacity increased, creating difficulties in maintaining prices. Mabro emphasized that OPEC's ability to survive was more apparent in the eighties (when demand for its oil was shrinking and the organization started allocating output under a quota system in 1982) than in the seventies.

Askari (1991) examined Saudi Arabia’s oil policy chronologically but for two different set of time periods. He mentioned that as a major player of OPEC between 1973 and 1978, Saudi Arabia provided support to the organization, but, was simultaneously reluctant to see that the price of oil rise high enough to cause any damage to the world economy. During the period 1978-1981 Saudi Arabia raised its output to the maximum sustainable capacity to prevent price increases due to economic and political factors. This was done by Saudi Arabia with the intention of avoiding further shocks to the world economy and to keep prices low in view of its own long-term interest. From 1982-1985 Saudi Arabia continued to play the role of swing producer and produced below its capacity for four years in order to maintain OPEC price levels. As fallout of this long and costly period of production cutbacks which was not rewarding for Saudi Arabia and due to an increasingly felt need for augmenting short term revenue it eventually abandoned its role of swing producer. This was followed by an oil price collapse of 1986.

Cremer and Salehi-Isfahni (1991) in their review of world oil market models also examined the role of Saudi Arabia as the dominant firm within the OPEC and underscored that although Saudi Arabia had significant market power in the short-run the influence of Saudi production was insignificant in the long run because in the long run world demand and supply of the fringe became more elastic.

1.2.3 Property Rights Model

This type of model tried to explain the effects on oil production and prices by the transfer of ownership from international oil companies to the governments of the oil-exporting countries within OPEC. The high discount rate that the international oil companies had been applying before often led them to excessive production. But this was transformed after the transfer of property rights to the governments who started applying low discount rates. The governments gave due importance to the exhaustibility of oil as a resource and valued future productions more than the international oil companies and therefore decided to produce less and preserve more for future.

Johany (1980) adopted the property rights model and argued that the sharp increase in the market price of oil that followed the October 1973 Arab Israeli War was not because of the increase in effectiveness of OPEC as a cartel capable of reducing output to raise prices. Rather, it could be attributed to a shift towards price setting directly by the governments of oil producing countries instead of through negotiations with the oil companies, as was the practice prior to October 1973. In fact the role of the oil companies after October 1973 was merely reduced to that of contractors. Moreover, as the OPEC countries were applying a lower discount rate than the companies' effective discount rate earlier, their oil output since 1973 were also far lower than what would otherwise have been if the companies had still continued as the owners of crude. This contraction of output in turn led to higher oil prices.

1.2.4 Target Capacity Utilisation (TCU) Model

The TCU model considered OPEC as a residual supplier of the world oil market and also assumed that OPEC's prices are influenced by the gap between its current capacity utilization and some target level of capacity-utilisation. In fact the TCU model associated the production of OPEC to the rate of capacity utilisation (which is measured as the production level divided by the production capacity level).

Powel (1990) used the historical behaviour of the world oil market and plotted the annual percentage change in price and capacity utilization and inferred that there was a relationship between the high capacity utilisation and price increases, and low capacity utilisation and price decreases. The explanation for this relationship was given by the TCU model. According to this model, OPEC tried to maintain capacity-utilisation close to a desired target level. If capacity-utilisation exceeded that target level then high demand provided fillip to the OPEC to raise its price. The rise in prices subsequently lowered demand and reduced capacity-utilisation back to the desired target level. If capacity-utilisation fell short of the desired target, then OPEC tried to reduce prices in order to stimulate demand and increase capacity utilisation, until the desired target was reached.

1.2.5 The Fiscal Constraint or Target Revenue Model

In this type of model OPEC member countries were conceived of as developing nations with different absorptive capacities. It was founded on the expectation that when oil revenues would exceed the needs of an OPEC member country, output level would be restricted by the country so as to make the oil revenue come in line with its needs. The proponents of this model include, among others, Ezzati (1976, 1978) and Cremer and Salehi-Isfahani (1980).

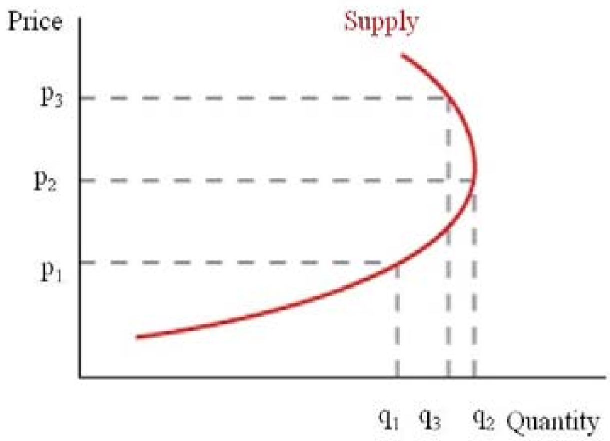
Ezzati (1976, 1978) used an analysis of OPEC in an intertemporal cartel framework by allowing for differences in the economic infrastructures of member countries and their ability to absorb oil revenue. The model was constructed mainly to assess the stability of the cartel by comparing the production of the members of OPEC at certain prices, with demand for these countries' oil. It was based on the expectation that OPEC as a residual supplier would be able to maintain future stability by eliminating the difference between the projected demand and the desired supply of OPEC oil. For each given prices, the model thus determined how much crude oil production would be required by each OPEC member country to satisfy its economic needs relative to its absorptive capacity for investment. On the basis of the findings, Ezzati inferred that there was a significant relationship between oil production and absorptive capacity of the OPEC members. He also applied the model to determine the optimal pattern of oil production for nine members of OPEC and evaluated their price and production strategies in relation to their respective absorptive capacities during the period 1960-72. The result had been used further to predict the stability of OPEC up to 1982.

Following Ezzati, Cremer and Salehi-Isfahani (1980), argued that oil revenue needs depended on the internal investment needs and the economic ability of the producing country to absorb investment. However, in contrast to Ezzati's cartel framework for OPEC, they analysed the oil market in a competitive framework. They observed that production declined in response to rising oil prices and increased in response to lower oil prices, in order to equate oil revenues with investment needs, resulting in a "backward bending supply curve'' (as shown in Fig.1.2A below). As indicated in the figure any increase in the price above P_2 would result in a cutback in production, as the producer had been desired a fixed level of revenue. According to this model, OPEC members had no incentive to increase production when the price was high and vice versa.

However, in sharp contrast to Ezzati and Cremer and Salehi Esfahani, Adelman (1993) argued that the primary objective of OPEC members was to maximise their revenue. He underscored that OPEC was a cartel that used its monopolistic power to set the price and gain the high revenue needed by its member governments. Thus, OPEC countries had cut back production to raise prices and get more money for their oil. He further argued that the member countries had less pressure to cheat as higher oil prices would make them better financially. Although he identified OPEC as "a loosely cooperating oligopoly-or cartel", he inferred that the "backward-bending supply curve" could explain OPEC behavior in the short run.

Teece (1982), however, explicitly argued that OPEC behaviour could be best represented by a target revenue model. He underscored that it might not be appropriate to identify OPEC as a wealth maximizing classic cartel as some OPEC members determined their oil production after considering their "budgetary requirements and internal and external political constraints." He suggested that some members of OPEC might even shut-in their production if their export receipts and foreign exchange earnings were adequate to cover their expenditure requirements and increase production, if otherwise. He thus stated that this relationship between the price and output could be more appropriately described by a backward-bending supply curve.

Fig.1.2A Backward Bending Supply Curve



1.2.6 <u>Target Price Models</u>

This set of studies either assumed or inferred that OPEC targets a certain price level or a price band and then maintain it through production adjustments.

Hammoudeh and Medan (1995) considered market expectations and shocks in inventories while examining OPEC oil pricing mechanism and behaviour. They investigated the oil price dynamics in two models: two-sided target zone model and asymmetric tolerance zone model.[9,10] The results of their modelling exercise established that OPEC's credibility to intervene in the market was directly associated with oil price sensitivity to changes in both the output and price expectations.

In a later paper, Hammoudeh (1997) carried out an identical study and analysed the price solutions for single and multi-target zone models. He inferred that under normal conditions, market participants formed expectations that led to price fluctuation in anticipation of OPEC interventions while under other circumstances OPEC shifted the target zone when it failed to

[9] OPEC establishes a band for the market price (with an upper and lower limit) around the target price.
[10] OPEC places a tolerance zone below the target price.

hold the line with previous targets.

Afterwards, Tang and Hammoudeh (2002) tested the same model and investigated the oil price behaviour for the period 1988-1999.[11] They observed that the OPEC tried to maintain a weak target zone regime for the oil price and inferred that the oil price was affected by both OPEC behaviour and the market's expectation of OPEC behaviour. They also suggested that during the aforesaid period OPEC became more explicit in adopting a target price zone model.

1.2.7 Econometric and Simulation Models for Investigating OPEC Behaviour

Griffin (1985) undertook econometric testing of various models of OPEC behaviour by using quarterly data for price and production for the period 1973.1 to 1983.3. However, he used simple static Ordinary Least Squares (OLS). The results of econometric testing of the cartel behaviour reaffirmed the dominant firm models with Saudi Arabia acting as the market leader. He also carried out the test for the property rights model of OPEC behaviour by assuming that production will be influenced by the percentage of government controlled production. For this testing he used annual data for the period 1971 to 1981, and the result was not significant for OPEC members especially Saudi Arabia.

Salehi Isfahani (1987) was critical of Griffin's study for the use of mis-specified regression equations especially for the target revenue model. He suggested that the use of the expected price variable rather than actual one would be able to take care of the problems that arose in Griffin's model. He thus used Griffin's model and data and allowed for expectations with a lagged price. The numerical results that he got supported the hypothesis that there might be some economic reasons to restrict oil output when prices rise to a certain level. The reasons that he identified were low absorptive capacity, imperfect capital markets and diminishing marginal utility of consumption. Thus, his results effectively supported the target-revenue model.

[11] OPEC had a target price $21 in 1986.

Dahl and Yucel (1991) tested two variants of the target revenue model, the strict and the weaker one for OPEC members using quarterly data from 1971-87. The hypotheses of both the variants were strongly rejected. They tested the swing producer model using output co-ordination between members of OPEC and the total production of OPEC, and ended up rejecting the hypothesis of co-ordination between OPEC members.

An econometric testing for the swing producer model was also undertaken by Griffin and Neilson (1994), focusing on the strategies used by OPEC to generate cartel profits over the period 1983-90. The result supported the hypothesis that OPEC adopted a swing producer strategy from 1983-85. But when Saudi Arabia's profit fell below the level of Cournot profits in the summer of 1985, it abandoned the role of swing producer, driving the prices to the Cournot level. According to Griffin and Neilson, Saudi Arabia apparently adopted a tit-for-tat strategy designed to punish excessive cheating by other OPEC members. Accordingly they tested for the tit-for-tat behaviour by including an additional non-linear equation for the punishment meted out by Saudi Arabia to other members in case of cheating. The results of the test showed that Saudi Arabia did not appear to react to low levels of cheating and might absorb some minor cutbacks, but high levels of cheating might evoke a forceful response.

Gulen (1996) relied on monthly data for thirteen OPEC members from 1965 to 1993. Using Engle and Granger's (1987) two-step cointegration tests, between individual member production and total OPEC production, and testing for different periods of the study using monthly data which are- 1965:1-1993:2 (full sample); 1965:1-1973:9 (before the oil shock); 1974:2 1993:2 (after the first oil shock); and 1982:1-1993:2 (the output rationing era). Gulen inferred that there was no-co-ordination between Saudi Arabia's output and that of the rest of OPEC even in the output rationing era.

Baldwin and Prosser (1988) developed a recursive simulation model for the world oil market. Various strategies for OPEC were tested assuming that OPEC could set either the price or the output. Both oil consumers and non-OPEC producers were assumed to be price takers where consumers maximised their benefits and non-OPEC countries maximised their profits. The findings showed that supply and demand could balance for a range of prices and OPEC output depending on the strategy that OPEC was adopting.

Another econometric model for the oil market was developed by Robert Kaufmann (1994) that integrated the effects of changes in economics, geological, political and environmental changes into the LINK model.[12] The model by Kaufmann attempted to forecast oil prices based on market condition and behavioural changes of the OPEC. The model results indicated that OPEC could influence medium and long run prices by altering their rate of capacity addition.

Gately (2004) developed a simulation model for the world oil market in the form of an Excel spreadsheet to see whether OPEC's members would more than double their production capacity in two decades as predicted by the US Department of Energy (DOE). The model simulated OPEC's payoffs for two different scenarios, a fast capacity growth at which OPEC meets the US Department of Energy's (DOE) expectations, and a slower (the normal) capacity growth. The model results showed that it would be unlikely for OPEC to expand their capacity as there would not be so much difference in the payoff for OPEC between the two scenarios.

Dees et al. (2005) elucidated a structural econometric model for the world oil market that could be used to forecast supply, demand and prices. In this model, oil demand had been explained by behavioural equations that related demand to domestic activity and the real price of oil. Oil supply for non-OPEC producers had been derived from a competitive behaviour, taking into account the effect of geological and economic variables. Oil prices had been defined by a price rule based on changes in market conditions and OPEC behaviour. In particular, OPEC had been assumed to act according to a co-operative behaviour and ensured the global equilibrium at the price determined by the price rule. In sample simulation results showed that the model satisfactorily reproduced past developments in oil markets. Policy simulations showed that the response of demand and non-OPEC supply were rather inelastic to changes in price. Finally, although OPEC had been assumed to close the model by absorbing any excess in supply or demand, the model inferred that OPEC decisions about quota and capacity utilisation had a significant, immediate impact on

[12] The "Project LINK is an econometric model of the world economy. It consists of macroeconomic models for 78 nations whose economic activity is connected by an international trade matrix." (Kaufmann, 1994, p. 165)

oil price.

Noureddine Krichene (2005) estimated a simultaneous equation model (SEM) for the world oil and natural gas markets for both short and long runs. The model was constructed to study the influence of the United States Nominal Effective Exchange Rate (NEER) and the US interest rate on the crude oil price and to estimate short and long run price and income elasticities. The results that were obtained showed that the demand for both crude oil and natural gas had been price inelastic in the short run. It also showed a significant reduction in long run supply price elasticity, suggesting a change from competitive behaviour to one of market power. The results further showed that falling interest rate and depreciating NEER could lead to a surge in the oil price.

Gately (2007) analysed the levels of oil exports that should be expected from OPEC over the next 25 years starting from 2007. The main objective of the paper was to look out for a long-term, robustly optimal strategy for production that would serve the interest of OPEC in the best possible manner. Using an annual model of the world market for oil liquids (not just conventional oil), calibrated to data from the International Energy Agency (IEA), he analysed various OPEC export strategies and their implications for OPEC export profits (export revenue less the costs of production and capacity expansion), under a wide range of assumptions about the parameter values that characterised the growth and price responsiveness of world oil demand and non-OPEC supply. He focused on market-adaptive strategies, in which the levels of both price and OPEC exports responded to changes in market conditions. For the range of cases examined, the constant-export-share strategy yielded the highest possible Net Present Value (NPV) of export profits, or within 1% of the highest, in comparison to other strategies. Although the export-share-maintenance strategy had been observed as robustly optimal, Gately underscored that the incentive for OPEC to increase its exports by enough to maintain its exports' share of non-OPEC demand would be relatively small– only a few percent in terms of discounted export profits – and it would require that OPEC should be farsighted, because the higher export profits from faster export growth would not be significant within the next decade. He further asserted that if OPEC did maintain its exports' share of non-OPEC demand, the continued rapid growth of OPEC's own oil consumption would require that OPEC oil output would have to increase 60% by 2030, which would be a major challenge.

1.3 Description of the Model and Rationale

This section intends to examine the demand and supply sides of the world crude oil market and makes an attempt to infer on whether OPEC really plays the role of a residual producer in the world crude oil market, as presumed by most of the conventional economic models especially the one that is followed by National Energy Modeling System (NEMS) of the Department of Energy, United States. The time period that has been considered for the present analysis is 1975 to 2004.

1.3.1 <u>The Demand for Oil</u>

For the world market, crude oil demand is assumed to be a function of real price of oil and real GDP which represents economic activity. The crude price is considered as the simple average of Brent, Western Texas Intermediate and Dubai crude spot prices[13].

Thus, world crude demand is expressed as-

DD = f (REALP, REALGDP)

DD = consumption of oil (in thousand barrel)

REALP = real average spot price of crude (Brent, WTI and Dubai Crude) in US $ per thousand barrels

REALGDP = GDP at PPP and at constant prices (base year- 2000)

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[13] Brent is a type of sweet crude (with less sulphur) which comes from the Ninian Basin, UK. Brent crude spot price was originally considered as a benchmark for determination of world crude oil prices. However, due to gradual decline in volume traded of this sweet crude oil produced from the Brent and Ninian basin it has been disputed as a world marker. In view of this, it is preferable to take an average of the regional markers than considering Brent spot price alone. Dubai is a sour grade crude (consisting of more sulphur) and is considered as the eastern benchmark and WTI (Western Texas Intermediate) is a high quality crude oil which contains only about 0.24 percent of sulfur (making it a “sweet” crude oil). It is the major benchmark of crude oil in USA and is often considered as western regional marker.

Computation of real price of crude

Real price of crude for a year is calculated by dividing average spot price of crude (average of WTI, Brent and Dubai) for the year by GDP deflator for that year.

Computation of GDP deflator

GDP deflator for a year is computed by dividing the GDP (PPP) at current prices for the year by GDP (PPP) at 2000 US $ for the same year. The index of GDP deflator is obtained by multiplying the ratio by 100.

1.3.2 Supply Model

As already mentioned before, the dynamics of the supply side of the world crude market is quite complex. It consists broadly of two players OPEC and Non-OPEC. OPEC is a cartel of independent producers primarily comprising the Middle-East countries. Non-OPEC producers comprise the producers from rest of the world, excluding OPEC. Lot of debates and discussion emanated from time to time around the pricing power of OPEC and the debate becomes especially relevant in the recent period in view of the increasing volatility and uncertainty in the international crude prices. Various studies have also questioned OPEC as a cartel with an inherent tendency for the members to cheat resulting in oil production often exceeding or falling short of the anticipated amount. In fact, it is really difficult to come out with an integrated behavioral model of the world crude market considered as a whole without separating the OPEC and the Non-OPEC producers.

Non-OPEC Supply

The Non-OPEC supply is expressed as -

SNOPEC = f (REALP, RESERVENOPEC)

SNOPEC denotes Non-OPEC crude supply, **REALP** indicates the real crude oil price, **RESERVENOPEC** denotes the proven reserve of Non-OPEC (for a definition of proven reserve see footnote 1).
In other words, the modeling exercise of Non-OPEC crude supply that is being undertaken here does not assume Non-OPEC supply as exogenous (as has been assumed in a large number of studies dealing with world oil market).

The relationship between world crude oil demand and supply could be expressed by a simple relationship as below

World Crude Oil Supply = World Crude Oil Demand + Stock Adjustment

If OPEC acts as a residual producer and if the world crude market is always in equilibrium, then by convenient transposition in the above identity, it could be derived that

Call on OPEC = World Oil Demand – Non-OPEC Supply + Stock Adjustment = OPEC Supply

In the light of the preceding discussion that has been carried out in the backdrop (in section 1.1) and in the survey (in section 1.2), however, it is difficult to assume that OPEC consisting of members with divergent interests and expectations would be able to stick to a rigid level of output as per the 'Call on OPEC' (i.e. demand for OPEC crude) and plays the balancing role of an equilibrator. In fact, as already mentioned before, history shows us that some of the OPEC producers mostly defected and the burden of adjustment often fell on the dominant producer within OPEC, Saudi Arabia. Thus OPEC may not necessarily comply with the 'Call', as shown in the above identity and as assumed in the model like NEMS (National Energy Modeling System of Department of Energy, USA).

It is thus really difficult to structure an exact behavioral model of supply of OPEC as the psyche and concomitant action of OPEC as a whole is unpredictable and the composite behavior of compliance or non-compliance is contingent upon the intention of the individual producers which may be affected by a plethora of factors, economic or otherwise.

Rather than constructing a separate behavioural model of OPEC, as usually done in most of the studies on world oil market, instead an investigation has been carried out here to infer on whether the world crude market actually moves in an equilibrating manner. This investigation would also help in vindicating or countering the assumption underlying the conventional economic models of the world oil market that OPEC acts as a residual producer.

The investigation begins here by estimating the world crude oil demand and Non-OPEC supply for the sample period under consideration i.e. 1975-2004. In fact, the simulated trajectories of world crude demand and that of Non-OPEC supply have been observed to be very close to the actual trajectories for the sample time span (i.e. 1975-2004). This, in a way, indicates that the simulated/projected trajectories could be used as close substitutes for the actual trajectories of world crude demand and Non-OPEC supply. The projected Call on OPEC (i.e. OPEC output demanded) has been derived in accordance with the following accounting identity

Projected Call on OPEC = Projected World Crude Demand – Non-OPEC Crude Supply

After accounting for actual stock adjustment during the sample period (1975-2004) the projected call becomes-

Projected Call on OPEC = Projected World Crude Demand – Non-OPEC Crude Supply + Stock Adjustment

The indicative trajectory of projected call on OPEC so derived for the sample period 1975-2004 (with /without stock adjustment) is then juxtaposed and compared with actual production of OPEC for the same period to infer on whether the world oil market has tended to be equilibrating in nature or otherwise.

However, it needs to be underscored at this juncture that this entire exercise based on annual data is aimed at long-run assessment of the world crude oil market and is indicative in nature. In fact the findings of this exploratory exercise could at best be considered as an approximate representation of the world crude oil market. In reality, and as elucidated before, the world crude oil market acts in a much more complex fashion and is influenced by a number of short-term or middle-term factors. However, all these factors could not be brought under the ambit of the present exercise.

Additionally, it also needs to be mentioned that as the objective of the entire exercise is to explore the veracity of the existing equilibrating mechanism, no such mechanism has been made explicit in the exercise that has been carried out, but it becomes quite obvious from the analysis that it is a quantity clearing mechanism. Thus, even if one considers an equilibrium condition in order to close the model then either OPEC supply or stock adjustment has to be autonomous, else there is under-determinacy. Clearly, the supply of OPEC has been considered and substantiated as autonomous in the exercise and has also been evinced by the literature survey on OPEC's behaviour that it is very difficult to endogenise and build up a systematic supply behaviour of OPEC. This is because its behaviour is guided by a plethora of factors that includes, among others, spare capacity, geopolitical concerns (particularly tensions in the middle east), revenue needs, absorptive capacity, reserve-production ratio, and financial factors (like speculation in the futures and forward markets of oil) amongst others. What is really noteworthy is that these factors influence the decision of different members (within OPEC) in varying degrees depending on the magnitude of their importance (or otherwise) in the policy decision of individual member countries. This also largely explains why OPEC as a whole has rarely behaved as a cohesive cartel and why its compliance with the quota decided in the OPEC meetings has consistently belied all expectations (historically the compliance with the call on OPEC has hovered around 40 per cent). In other words, this behaviour only reinforces the autonomous behaviour of OPEC as a whole in terms of its production/supply.

1.3.3 Modeling of Real Crude Price

Taking cue from Dees et.al, 2007; Kaufman (1994); and Gately (2004, 2007), and in the light of the findings of the exploratory exercise, a behavioral crude price equation has also been estimated based on potential supply and demand side behavioral variables that could have perceptible influence on crude price.

The price function is considered as:

REALP = f (CAPUTILOPEC, STKSDD)

CAPUTILOPEC indicates capacity utilization of OPEC (defined as production over capacity of OPEC[14]) and is a potential supply side behavioral variable that is usually observed as linked with movements of real crude prices and has often been observed to explain to a large extent the movement of crude prices. **CAPUTILOPEC** accounts for both compliant and non-compliant behavior of OPEC. An increase or decrease in capacity utilization may either be strategically decided (say on the basis of expected market share) or may just be for complying as a residual equilibrating producer.

STKSDD is the ratio of stock/inventory of crude oil over the demand for crude. The ratio indicates the days of forward consumption of stocks i.e. the days the stock/inventory would be able to sustain demand. Thus, any increase or decrease in demand or any increase or decrease in the level of inventories would alter the ratio and hence would exert influence upon crude price. As it is difficult to obtain accurate and consistent data on inventories of crude oil for the world as a whole, the data for OECD stocks or inventories as a proportion of its demand has been considered here instead as proxy. The choice of the proxy is also vindicated by the fact that OECD countries have historically been the largest consumer of crude oil in the international market.

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[14] The capacity of OPEC at a particular point in time is determined primarily by its proven reserve position.

1.4 Data Sources and Methodology

1.4.1 <u>Sources of Data</u>

For estimation purpose data and information have been collected from several sources. The estimation has been carried out on the basis of annual data for the sample time period 1975 to 2004. The data on crude production (supply), consumption (demand) and proven reserves have been collected from British Petroleum's Statistical Review of World Energy 2006. The International Yearbook of Energy Statistics, published by United Nations has also been consulted for information on the above variables for some years. The data on crude oil prices have been obtained from Platts (website: www.platts.com) and British Petroleum's Statistical Review of World Energy 2006 (website: www.bp.com). The data on GDP at PPP has been obtained from World Bank's 'World Development Indicators' through WDI online portal of the World Bank (www.worldbank.org/data/onlinedatabases/onlinedatabases.html). The data on OECD Stocks has been obtained from IEA, 'Oil Market Report' for various years. The data on production capacity of OPEC has been obtained from the various issues of Oil and Gas Journal published by Penn Well Petroleum Group (website: www.ogj.com) and statistical supplement of IMF for World Economic Outlook, 2005.

1.4.2 <u>Methodology</u>

The estimation that has been carried out in the paper is based on Cointegration and VECM (Vector Error Correction Model), which are techniques normally used in multivariate time-series analysis.

The approach which is often used for quantitative modeling of the demand and supply are Structural Equation Approach (SEA). The SEA is founded on economic theory to describe the relationships between several variables of interest. On the basis of the underlying theory simultaneous structural equations based model is specified in order to explain the functioning of an economic system. Thus the SEA begins by pre-judging an endogenous-exogenous divide of the variables. The model so specified is then estimated, and used to test the empirical relevance of the theory on which the modeling is founded. On the contrary, the multivariate time series approach does not presume an underlying structural or theoretical framework. In this approach, a set of variables that seems to potentially reflect agent's decision is considered as jointly endogenous and are thus conferred symmetrical treatment. The current realizations and / or future expectations of these selected variables are thus contingent upon the currently available information set[15].

Before explaining the methodology that has been used in this study namely cointegration and VECM, a brief discussion on some of the basic concepts of Time Series Analysis that are relevant to the exercise, would be useful.

Time Series

A time series is defined as a set of quantitative observations arranged in chronological order. Thus it is basically a sequence of numerical data in which each item is associated with a particular instant in time. It is possible to quote numerous examples of time series like monthly unemployment, weekly measures of money supply, daily closing price of stock indices and so on.

Stochastic Process

Formal models for time series are however developed on the basis of probability theory. Let the T-dimensional vector of random variables X_1, X_2, ... X_T be given with the corresponding multivariate distribution. Such a collection of random variables $\{X_t\}$ $\forall\, t \sim (1 \ldots\ldots T)$ is called a stochastic process or a data generating process. There may not just be one realisation of such a process, but, in principle, an arbitrary number of realisations are possible which all have the same statistical properties as they all result from the same data generating process. A time series is usually considered as one realisation of the underlying stochastic process.

[15] This short discussion is based on Coondoo and Mukherjee (2005)

Stationarity and Non-stationarity Time Series

If the common distribution function of the stochastic process does not change by a shift in time, the process is considered as *strictly stationary*. As this concept is difficult to apply or demonstrate in practice, it is a usual practice to consider *weak stationarity* or *stationarity in the second moments*. It is thus essential to define stationarity for the corresponding moments of the stochastic process $\{X_t\}$:

(i) *Mean Stationarity*: A process is mean stationary if

$$E\,[X_t] = \mu(t) = \mu \quad \forall t$$

i.e. mean is independent of time point t

(ii) *Variance Stationarity*: A process is variance stationary if

$$V\,[X_t] = \sigma^2(t) = \sigma^2 \quad \forall t \text{ and is finite.}$$

i.e. variance is independent of time point t and is finite

(ii) *Covariance Stationarity*: A process is covariance stationary if

$$Cov\,[X_t, X_s] = E\,[X_t - \mu_t]\,[X_s - \mu_s] = \nu(|s - t|)\ \forall t$$

i.e. covariance is only a function of the time distance between the two random variables and does not depend on the actual point in time t.

(iii) *Weak Stationarity*: As variance stationarity immediately results from covariance stationarity for s = t, a stochastic process is weakly stationary when it is mean and covariance stationary.

Since in statistical or econometric exercise only weak stationarity is generally considered, hence the adjective 'weak' is usually dropped.

A stochastic process (say) {ut} is called a *pure random or a white noise process*, if it has the following properties: E $[u_t] = 0$ and V $[u_t] = \sigma^2 \; \forall$ t, as well as Cov $[u_t, u_s]= = 0$ for all $t \neq s$. Apparently, this process is weakly stationary. The random variables all have mean zero and variance σ^2 and are uncorrelated with each other. Thus a white noise process is a special case of a stochastic process.

A stationary series tends to return to its mean value and fluctuate around it within a more or less constant range (i.e. it has a finite variance, as explained above), while a non-stationary series has a different mean at different points in time (and thus the concept of the mean is not really applicable) and its variance increases with sample size.

Trend Stationarity and Difference Stationarity

A time series could be trend stationary or difference stationary. The time series is considered as trend stationary (TS) if it becomes stationary after eliminating the deterministic trend from a series.

For instance, let us consider a time series Y_t which could be expressed as

$Y_t = \beta + \delta t + \varepsilon_t$ …………………(1)

$E(Y_t) = \beta + \delta t$

Thus, the series is not stationary as the expected value (or mean) of Y_t i.e $E(Y_t)$ is not time invariant and thus violates the very first condition of stationarity i.e time invariance of mean.

In order to make the series stationary we need to detrend the series. In order to detrend the series we should regress it on time and take out the residual from this regression.

In other words we need to estimate (say) $y_t = a + b.t + u_t$, and compute $u_t = y_t - a - b.t$

The estimated residual u_t is considered as a *detrended* time series and is stationary.[16]

However, a a time series Y_t could also be expressed in the form, say,

$Y_t = \beta + Y_{t-1} + \varepsilon_t$ ……………… (2)

Here the current value of the variable Y_t, depend on last period's value, Y_{t-1}, an intercept term β, plus a stochastic disturbance term ε_t.

Equation (2) can be expressed as -

$Y_t = \beta t + Y_0 + \varepsilon_0 + \varepsilon_1 + \varepsilon_2 + \ldots\ldots\ldots + \varepsilon_{t-1} + \varepsilon_t$

Thus, $E(Y_t) = Y_0 + \beta t$

and $Var(Y_t) = t\sigma_\varepsilon^2$

Thus the series is non-stationary at level

However, on taking the first difference we get: $Y_t - Y_{t-1} = \beta + \varepsilon_t$

Taking expectation we have:

$E(Y_t - Y_{t-1}) = \beta + E(\varepsilon_t) = \beta$

Also, $Var(Y_t - Y_{t-1}) = \sigma_\varepsilon^2$

Thus the difference of the series satisfies both the mean and variance condition of stationarity

Hence, Y_t could be considered as difference stationary

[16] However, it also needs to be noted that the trend can be non linear as well. For instance we can also have a trend like- $y_t = a + b.t + c.t^2 + u_t$.

If Y_t in (2) is instead generated by the following a first order autoregressive process i.e. AR(1) process (the simplest of the AR models that could be considered) given as:

$Y_t = \beta + \rho Y_{t-1} + \varepsilon_t$ …………(3)

where $\varepsilon_t \sim N(0, \sigma^2)$

then, the variable Y_t will be considered stationary if

$$|\rho| < 1$$

If, however,

$$|\rho| = 1$$

then y_t will be non-stationary.

When ρ =1, the non-stationary process is called a random walk. Table 2.1 below adopted from Mukherjee, White and Wuyts (1998) illustrates and summarises on the nature of series that result from different values of β and ρ in AR (1) model, as shown in (3).

Table 1.1: Series resulting from different values of β and ρ in AR (1) model as indicated in equation 1 above

	β =0	$\beta \neq 0$
ρ=0	Y is just random error in each year, no pattern will be discernible	Y fluctuates in random manner around the mean of β
0< ρ<1	Y fluctuates around 0 with 'some memory' resulting in short patterns	Y fluctuates around the mean of $\beta/(1-\beta)$with some patterns
0> ρ>-1	Y fluctuates around 0 in an oscillatory manner	Y fluctuates around the mean of $\beta/(1-\beta)$ in an oscillatory manner
ρ =1	Random Walk	Random walk with drift
ρ>1	Explosive(exponential) growth in Y	Explosive(exponential) growth in Y
ρ<-1	Ever larger oscillations	Ever larger oscillations

Unit Roots and Stationarity

As has been shown above, a non-stationary variable may become stationary after it is differenced (albeit not necessarily just by differencing it once). It can, however, be demonstrated that the number of times a variable needs to be differenced in order to induce stationarity depends on the number of unit roots it contains.

In fact, the question of whether a variable is difference stationary or not depends on whether it has unit root(s). In order to demonstrate that more easily let us assume a more simplified version of equation (3) by considering the intercept / drift term β as 0. By convenient transposition one can obtain

$Y_t - \rho Y_{t-1} = \varepsilon_t$…….. (4)

This could be rewritten as
$(1 - \rho L) Y_{t-1} = \varepsilon_t$

where L is the lag operator (i.e. $LY_t = Y_{t-1}$, while $L^2 Y_t = Y_{t-2}$ etc.) . Forming a characteristic equation (i.e. $(1 - \rho L) = 0$); if the roots of this equation are all greater than unity in absolute value then y_t is stationary. In this example there is only one root ($L = 1/\rho$), thus stationarity requires that:

$$|\rho| < 1$$

If a series must be differenced d times before it becomes stationary then it contains d unit roots and is said to be integrated of order d, denoted as I(d) .

Unit Root Test: Test for Stationarity

As a first step in the current exercise of estimation, the order of integration of the natural logarithm of the levels of X_t and Y_t (hence forth denoted by x_t and y_t) have been tested using the Dickey-Fuller or Augmented Dickey-Fuller test.

This is because, as explained above, the concept of cointegration is applicable only when the time series under consideration is non-stationary.

Dickey Fuller (DF) Test

The Dickey –Fuller (DF) Tests for unit roots are based on testing the null-hypothesis, Ho: $\rho = 1$ against the alternative that $H_1 : \rho < 1$ in the following equation:

$$\Delta yt = \alpha + \beta t + (\rho - 1) y_{t-1} + u_t \text{................}(4)$$

where $u_t \sim IID(0, \sigma^2)$; IID means independent and identically distributed

Here u_t's are assumed to be white noise errors (the notion of white noise is already explained before in the context of explaining the stochastic process).

Now if the simple AR(1) DF model, as specified in equation (4) is used , when in fact y_t follows an AR(p) process , then the error term will be auto-correlated to compensate for the mis-specification of the dynamic structure of y_t. Autocorrelated errors will invalidate the use of the DF distributions, which are based on the assumptions, that u_t is 'white noise' and in that case the Augmented Dickey Fuller (ADF) model will be appropriate.

Given this logic, in order to decide whether DF or ADF test is appropriate for a particular series, say y_t, we first run OLS on the DF model (1) and get the estimated residuals. In the next step we check for the existence of autocorrelation in the estimated residuals using the Breusch-Godfrey Serial Correlation LM Test (henceforth LM Test).[17]

The null hypothesis (Ho) of this test is: there is no serial correlation upto lag orders p, where p is a pre-specified integer.

Rule for the rejection Ho in LM test is as follows:

[17] The LM test is a test for checking serial correlation in the errors. Unlike the Durbin Watson test statistic for AR(1) errors , the LM Test may be used to test for higher order ARMA (Auto Regressive Moving Average) errors and is applicable whether or not there are lagged dependent variables.

If the test is conducted at the 1% or 5% level then a probability value lower than 0.01 or (0.05) is taken as evidence to reject the Ho at the 1% (5%) level of significance.

For each time series under consideration, the LM test is carried out with different number of lags.

The acceptance of Ho of LM test, implies that the estimated residuals of the DF model (1) are white-noise implying that the DF test (and not ADF Test) is the appropriate test of testing for unit root in the series under consideration. Therefore if for a particular series Ho of the LM Test cannot be rejected, then we have gone for a DF test to test for unit roots in that particular series.

If, however the results of the LM Test reject the Ho of "no serial correlation upto lag order p", then that implies that the estimated residuals of the DF model (4) are auto-correlated which in turn implies that DF Test cannot be conducted. Hence it is right to go for ADF test to test for unit root in a series for which the Ho of the LM test is rejected.

Augmented Dickey Fuller (ADF) Test

The advantage of specifying the model in the form of (4) is that: given this form, the test is equivalent to testing Ho: ν=0 against the alternative H_1: ν <0 where $\nu = \rho-1$.
In case ADF is found to be the appropriate unit root tests the ADF tests is undertaken using the following model

$$\Delta yt = \alpha + \beta t + \nu y_{t-1} + \sum_{i=1}^{p-1} \delta_i \Delta y_{t-1} + \varepsilon_t \ldots\ldots\ldots\ldots\ldots(5)$$

where $\varepsilon_t \sim$ IID $(0, \sigma^2)$

Here p indicates minimum number of lags required to generate white-noise residuals, as obtained from the LM test. Hence ε_t is white noise.

Once the lag structure is determined, this augmented specification (2) is then used to test the hypothesis: Ho: ν=0 (unit root) against H_1: ν< 0 (stationarity)

The rule for the rejection of Ho in DF/ ADF Tests:

In the DF test, the Ho of the unit root is rejected against the one-sided alternative if the t-statistic is less than (lies to the left of) the critical value.

Since the t-statistic under the null hypothesis of a unit root does not have the conventional t-distribution, the critical values for the standard t-test cannot be used. Here the Mac Kinnon (1991) critical values for rejection of hypothesis of a unit root, as reported in E-Views have been used.[18]

Comparing the value of the statistic (for a series y_t) with the Mac Kinnon Critical value if one fails to reject the Ho of a unit root then it implies that the level of the series is non-stationary. Accordingly the unit root test have been run on the first differenced data i.e. Δy_t. If now the results reject the null hypothesis of a unit root then it is concluded that in the level form the series is I (1), but in the first difference form it is I(0) (which implies stationarity)

In the present exercise all the series have turned out to be I(1).

Cointegration

Let us consider two time series Y_t and X_t, which are both I(d). In general, any linear combination of the two series will also be I(d); for example the residuals obtained from regressing Y_t on X_t are I(d). If, however there exists a vector λ, such that the disturbance term from the regression ($u_t = Y_t - \lambda X_t$) is of a lower order of integration, I(d-b) , where b > 0, then Y_t and X_t are usually defined as cointegrated of order (d, b).

The economic interpretation of cointegration is that if two (or more) series are linked to form an equilibrium relationship, then even though the series themselves may be non-stationary they will nevertheless move closely together over time and the difference between

[18] Dickey&Fuller (1979) showed that the distribution under the null hypothesis of a unit root is non-standard and simulated the critical values for selected sample sizes. More recently Mac Kinnon (1990) has implemented a much larger set of simulations than those tabulated by Dickey and Fuller. The Mc Kinnon critical values are reported by E-Views, which has been used for carrying out the exercises.

them will be stable (i.e. stationary). Thus the concept of cointegration implies the existence of a long-run equilibrium (in econometric sense and not in a pure economic sense of equilibrating demand and supply) or a stable or permanent level to which an economic system converges over time, and u_t defined above can be interpreted as the disequilibrium error (i.e. the distance the system is away from equilibrium at time t)

Multivariate VAR (Vector Auto-regression), VECM (Vector Error Correction Model) and Cointegration [19]

In the VAR approach every endogenous variable in the system is modelled as a function of the lagged values of all the endogenous variables in the system.

VAR could be represented in the mathematical form as :

$$\mathrm{Y}_t = \alpha + A_1 \mathrm{Y}_{t-1} + A_2 \mathrm{Y}_{t-2} + \dots\dots\dots\dots + A_p \mathrm{Y}_{t-p} + \varepsilon_t \quad \dots\dots\dots\dots\dots\dots\dots\dots(6)$$

where $A_1, A_2 \dots\dots A_p$ are KxK matrices of parameters; α is a $Kx1$ vector of intercepts and ε_t is a K-vector of *temporally uncorrelated* variables with $E(\varepsilon_t) = \phi$, $E(\varepsilon_t \varepsilon_t') = \Sigma$ for all t and $E(\varepsilon_t \varepsilon_s') = \phi$ for $t \neq s$.

As Y_t is integrated of order 1, (6) can alternatively expressed as

$$\Delta Y_t = \alpha + A_1 \Delta Y_{t-1} + \dots\dots + A_p \Delta Y_{t-p+1} + BY_{t-p} + \varepsilon_t \quad \dots\dots\dots\dots\dots\dots\dots\dots (7)$$

Thus (7) is basically a *VAR (p-1)* in difference with BY_{t-p} as an additional term, B being a KxK matrix of parameters[20].

Now, since $Y_t \sim I(1)$, the l.h.s. of (7) is I(0). Similarly with the exception of except BY_{t-p} all the terms of the r.h.s. are I(0).

[19] This theoretical section draws on Coondoo and Mukherjee (2005).

[20] The extra term appears because a vector of *I(1)* variables cannot have a finite-order *VAR* representation in difference.

As $Y_t \sim I(1)$, the consistency thus requires $BY_{t-p} \sim$ I(0).

This implies that each row of B should be a cointegrating vector of Y_t (the notion of cointegration has been explained before, albeit in two-variable case).

As Y_t can have at most $r \leq K-1$ linearly independent cointegrating vectors implies *rank (B) = r*.

Using the rank factorization result of linear algebra one gets, $B = CD$, where *C:Kxr* and *D:rxK* with *rank(C)=rank(D)=r*. Thus, (7) can be re-written as

$$\Delta Y_t = \alpha + A_1 \Delta Y_{t-1} + ... + A_p \Delta Y_{t-p+1} + CDY_{t-p} + \varepsilon_t \quad …….. (8)$$

where the *r* rows of *D* contain the *r cointegrating vectors* of Y_t and each of the *K* rows of *C* contains the corresponding set of *adjustment parameters.*

Each of the r elements of DY_{t-p} is a stationary random variable which measures the extent by which the realized values of the *K* variables deviates from the *long run equilibrium condition* that the corresponding cointegrating vector represents and hence these are called the *error correction terms* and the system of equations (8) is called the VECM. [21]

Johansen's procedure of cointegration test is based on the estimation of the *VECM* (as shown in eqn. 8) using the maximum likelihood method. It also needs to be noted that since the *r* cointegrating vectors as contained in *D* are non-unique[22], these have to be normalized. Typically, using the normalization, one would obtain the cointegrating vectors as the rows of a matrix $D^* = [D_1 D_2]$, where $D_1 : rxr$ with *1* in the diagonals and $D_2 : rxK$.

In some software packages the set of *r* cointegrating vectors are presented in the form $[I\ D_3]$ where $D_3 = D_1^{-1} D_2$. Suppose we partition the variables into two groups as

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[21] The system of equations (8) is usually referred to as the *Granger Representation* of a set of cointegrated *I(1)* variables .

[22] This is because for any *F:rxr* non-singular, *FD* is also a set of *r* linearly independent cointegrating vectors of Y_t.

$Y_t^* = \{Y_{1t}, Y_{2t}, ..., Y_{rt}\}$ and $X_t^* = \{Y_{(r+1)t}, Y_{(r+2)t}, ..., Y_{Kt}\}$. Then the set of cointegrating relationships can be expressed as

$$Y_t^* = -D_3 X_t^* + v_t \quad (5)$$

where v_t is a r-vector of stationary random disturbance terms. Note that (5) resembles the system of reduced form equations of a structural simultaneous equations model. Indeed, following this approach, one may try to arrive at a set of structural equations implied by the given sample data set. Such an exercise essentially involves the task of identifying the subset of (*K*-*r*) exogenous variables of the given set of variables.

Test for Cointegration

In order to carry out the Johansen's maximum likelihood approach for testing cointegration it needs to be first ensured that the series with which one is working is non-stationary and integrated of order one. As already indicated before all the series have been observed to be integrated of order 1 i.e. I(1) in the present study.

The next problem, which one faces, is that of specification of lags. It may be noted here that in contrast to some other statistical packages, EViews specifies the lags as lags of first differenced terms and not in terms of levels. For example the choice of lag (1 4) implies that the test VAR regresses Δy_t on Δy_{t-1} , Δy_{t-2}, Δy_{t-3} and Δy_{t-4}. The lag order has been chosen by using AIC (Akaike Information Criterion), reported by E-Views, with the least value of AIC being used to select the optimum lags. The lag order in the current exercise has mostly been found to be 3.

The LR test Statistic, often referred to as Trace Statistic, that is used for testing cointegration is given below

$$Q_r = -T \sum_{i=r+1}^{k} \log(1-\lambda_i)$$

For r = 0, ……, k-1. where λ_i is the ith largest eigen value (for more details see Enders, 2004 Chapter 6, sections 7 and 8 ; Kirchgässner and Wolters, 2007, Chapter 6 section 6.3).
The trace test has the null hypothesis

H_0: there are at most r positive eigenvalues

against the alternative hypothesis

H_1: there are more than r positive eigenvalues.

The test starts with r = 0 and is performed until the first time the null hypothesis cannot be rejected. The cointegration rank is given by the corresponding value of r. If the value of the trace test statistic exceeds the critical value, then the null hypothesis is rejected, otherwise accepted.

1.5 Results and Analysis

As a first step, in order to understand the nature of the data generating process (DGP) a visual inspection of the plot of the time series pertaining to variables has been carried out before conducting the formal tests for unit roots. The visual inspection helps in making out if the series resembles a pure random walk or its variants or just appears like a series with a simple deterministic trend. The visual inspection further helps in identifying if there are any structural breaks in the series or otherwise. However no structural breaks have been observed in the series. The plots of the variables in their logarithmic form that have been considered in the paper are given in Appendix 2.

In case the presence of a trend is apparent from the plot of a series, it has first been de-trended and/or differenced to see if they resemble a stationary series hovering around a mean or deviating from the mean with/without a trend etc. Appendix 1.1 illustrates a detrended and differenced series for the series WORLDDD (logarithm of world demand) which apparently consists of a visible trend at the level of the series. However detrended WORLDDD does not seem to resemble a stationary process whereas D(WORLDDD) does resemble closely a stationary process The same process has been repeated for other variables namely WORLDGDP, LSNOPEC which apparently consist of visible trends. However, none of the variables after detrending seemed to resemble a stationary process whereas the first difference of each of the series has been observed to closely resemble a stationary process. Besides the visual inspection, the formal test for non-stationary (Dickey Fuller unit root test) has also been carried out on the de-trended series on the basis of which the series has been observed to be non-stationary.

Besides, the DF / ADF unit root tests have been carried out on all the variables in their logarithmic form and on their difference. Appendix tables 1.1A and 1.1B reports the results of unit root test (DF/ADF tests) at the level and the first difference of the series for the logarithms of demand of crude for world (LWORLDDD); Non-OPEC crude supply (LNOPECS); real GDP at PPP for world (LWORLDGDP); real price of crude (LREALP); Non-OPEC Reserve (LNOPECRES), capacity utilization of OPEC (LCAPUTILOPEC); ratio of stocks to demand of crude oil (LSTKSDD) where 'L' stands for logarithms. From the unit root tests that have been carried out on all the variables in their logarithmic form, all of them have been observed to be I(1) i.e. integrated of order 1 and the first difference of the variables have been observed to be integrated of order zero.

After that cointegration test by Johansen Procedure (as explained in details in the preceding section) has been carried out on the set variables their logarithmic form in order to examine if any statistically significant cointegrating vector exists for each of the variable set under consideration for world crude demand and Non-OPEC supply.[23] If at least one cointegrating vector is found, VECM (Vector Error Correction Model) has then been estimated for the set of variables to examine the existence of interrelated short term temporal movements in the growth rate of variables.

It needs to be underscored here that cointegration has been examined separately for three subsets of variables namely (LWORLDDD, LREALP, LWORLDGDP); (LSNOPEC, LNOPECRESERVE, LREALP) and (LREALP, LCAPUTILOPEC, LSTKSDD) and separate VECM are also estimated for these set of variables. The vast body of empirical and theoretical literature that exists and partly captured in the literature survey in section 1.2 does

[23] The optimum order of VAR in the cointegration analysis has been determined by using Akaike Information Criterion (AIC) and in most cases the optimum order has been observed as 3 (lag intervals 1 to 3).

provide insights on the relationships between the variables contained in each of the subsets and thus provides motivation for choosing these subsets. The first subset tries to explore if potential long-run co-movements and an economically meaningful equilibrium relationship could be observed between world demand, the real price and the economic activity given that the real price and economic activity are usually considered as the potential determinants of world oil demand. The second subset tries to explore presence of long-run co-movements between non-OPEC supply, non-OPEC reserves and real price and if they could be captured by a linear long-run equilibrium relationship or steady state (in econometric sense). The third subset tries to examine the co-movements of real oil price with two potentially strong determinants that are very likely to influence the world price namely capacity utilisation of OPEC (which hints towards OPEC's spare capacity) and days of forward consumption of stocks (i.e. the days for which the stock of crude oil would be able to sustain the demand). The estimated VECM on the aforementioned subsets basically tried to reconcile the short-run temporal variations of these variables within the subsets with their long-run steady-state co-movements.

Appendix tables 1.2A, 1.2B and 1.2C report the results of the trace test for cointegration (Johansen Maximum Likelihood procedure) pertaining to world crude demand and Non-OPEC crude supply and real crude price respectively. Appendix tables 1.3A, 1.3B and 1.3C show the estimated cointegrating vectors. Appendix tables 1.4A, 1.4B and 1.4C show the VECM that have been estimated for world crude demand, Non-OPEC supply and real crude price respectively. Appendix table 1.5 contains the summary data of different variables that have been used for estimation of world crude demand and Non-OPEC supply.

1.5.1 Long-Run Price and Income Elasticity of Crude Demand

Appendix 1.3A shows the statistically significant cointegrating vector obtained through trace test of cointegration for the set of non-stationary variables (LWORLDDD, LREALP, and LWORLDGDP) obtained after normalization by considering the coefficient corresponding to LWORLDDD as 1. In other words, LWORLDDD has been considered as the dependent variable. The existence of cointegration between non-stationary variables, as already indicated in the section on data and methodology, implies that there exists a linear combination of these variables which can make them stationary and the linear combination could be represented by the estimated cointegrating vector.

By convenient transposition in Appendix 1.3A, LWORLDDD can come on the left hand side as dependent variable and the variables representing real price and economic activity or real income (real GDP) along with the associated coefficients can come on the right hand side. As all the variables are logarithmically transformed the coefficients associated with real price and real income basically represent the long-run elasticity of crude demand with respect to real price and real income. On the basis of the estimated cointegrating vector, the long-run price and income elasticity of demand for world could be summarized as below:

Table 1.1A Long Run Price and Income Elasticity of World Crude Demand

Variable	Price Elasticity	Income Elasticity
Crude Demand	-0.017	0. 410

From table 1.1A it is clear that crude demand is highly price inelastic in the long run for world. The responsiveness to increase in real income (real GDP) has also been found to be low. Since, the world comprises combination of economies with varying oil intensities of GDP and with varying demand for crude, the income elasticity has been found to relatively balanced and is neither on the higher side nor on the lower side. However, the primary issue of concern is the insignificant price elasticity of world crude demand. This implies that even if the crude price gears up substantially in future demand is not going to come down significantly.

1.5.2 Short-run Dynamics

The short-run dynamics of world crude demand could be analysed by using the estimated VECM. The individual equation of an estimated VECM describes the short run temporal movement of a set of co-integrated variables. All the variables are expressed in logarithms and the first difference of individual variables measure year to year growth rate of the variables. The estimated VECM equations thus basically provide explanations of the observed temporal variations of the growth rate of individual variables.

Appendix 1.4A shows the estimated VECM relating to the set of variables (LWORLDDD, LREALP, and LWORLDGDP) for the period 1975-2004. The VECM consisting of lagged difference terms as explanatory variables has been derived in its reduced form after removing the terms that have insignificant‘t’ statistic values. Figures in the parenthesis below the coefficients in the VECM indicate the value of t statistics. E(-1) denotes the normalised cointegrating equation (normalised by assuming the coefficient of LWORLDDD as 1) and is considered as the error correction term. In fact the coefficient associated with E(-1) is referred to as the ‘adjustment coefficient’ and basically reconciles the short-run realization of the value of the dependent variable (LWORLDDD here) at some preceding time point with the long-run permanent level (often referred to in the time series econometric literature as long-run equilibrium level) determined by the normalised cointegrating equation. It could be observed from Appendix 1.4A that for individual equations the measure of goodness of fit (as measured by adjusted R-squared values at the bottom of the VECM) is highest for the equation pertaining to LWORLDDD (adjusted R-squared is 0.55). For the same equation, the coefficient of E(-1), which is considered as the ‘adjustment coefficient’ is significant (t value -2.55) and negative. As the adjustment coefficient in association with the error-correction term reconciles the short run with the long run, a positive value for adjustment coefficient signifies a tendency of realised world demand to move away from long run ‘permanent level’, determined by the cointegrating equation. The negative adjustment coefficient corresponding to E(-1) on LWORLDDD may then be interpreted as the systems tendency to return to the long-run equilibrium level and hence represents a stable system. However, in the equation pertaining to world demand no other lagged difference terms for explanatory variables has been found to be significant, which in a way tend to hint towards a more autonomous nature of the world crude demand in the short run. In case of the other two equations in VECM pertaining to real world GDP and real crude price none of the explanatory lagged difference terms including the adjustment coefficient have been observed as significant.

1.5.3 Long Run Price Elasticity of Non-OPEC

Appendix 1.3B shows the normalized co-integrating vectors obtained through trace test for Non-OPEC (considering the coefficient LSNOPEC as 1).

Through normalization process and through convenient transposition in the form of equation, LSNOPEC can come on the left hand side as dependent variable and other variables can come on the right hand side as independent variables. As the variables are logarithmically transformed, the coefficients associated with these variables in Appendix 1.3B basically represent the long-run elasticity of oil supply for N-OPEC with respect to these variables. Table 1.2 below show the long-run price elasticity of Non-OPEC supply based on the estimated cointegrating vector in Appendix 3B.

Table 1.2

Long Run Price Elasticity of Non-OPEC Supply (SNOPEC)

Region	Variable	Value
Non-OPEC	Price Elasticity of Supply	0.28

As evident from the above table N-OPEC supply of crude is highly inelastic with respect to real price in the long run. This is not a very healthy sign for the world crude market as this inelasticity implies that any increase in crude oil prices in the long-run may not be accompanied by a concomitant increase in Non-OPEC Supply. Given the fact that the world crude market has become more volatile, as explained in the backdrop in section 1.1, this implies more impending plights for the heavily crude import dependent economies like India and China. This is because the insignificant price elasticity of Non-OPEC signifies a higher dependence on OPEC crude supply for meeting the needs of these emerging economies thus making them increasingly vulnerable to crude price shocks.

From Appendix table 2.3B, Non-OPEC Supply could also be observed as inelastic and negatively responsive to their proven reserve position. However such inelastic response may be explained by the phenomenal decline in production of Non-OPEC on account of disintegration of Former Soviet Union (FSU) in 1994. With the Former Soviet Union (FSU) possessing the largest (nearly 30 percent) reserve in N-OPEC before disintegration and still accounting for a large pool of reserve (nearly 40 percent), such inelastic and negative response of Non-OPEC production (which has always been dominated by FSU output) to their proven reserve position may not appear that unusual.

1.5.4 Short-run Dynamics

Appendix 1.4B shows the estimated VECM for the set of variables (LSNOPEC, LREALP, and LNOPECRESERVE). As evident from the table, corresponding to the equation for N-OPEC supply, the coefficient of E(-1) is significant and negative. Using the same line of reasoning as has been applied for Appendix 1.4A, the negative effect of E(-1) on LSNOPEC could be interpreted as the system's tendency to return to the stable or permanent level (as determined by normalized co-integrating relationship considering LSNOPEC as 1). The overall measure of goodness of fit (adjusted R^2) for the N-OPEC supply equation is however quite low. However, the coefficient indicating the responsiveness of D (LSNOPEC) to D(LRESERVENOPEC (-1)) has been found to have a t value of 2.24 associated with it and is thus significant. The value of the coefficient, albeit positive, is however less than 0.5. Thus, the rate of growth of LSNOPEC in response to rate of growth of LRESERVENOPEC in the short run has been observed as considerably low. Similarly, the responsiveness of the rate of growth in LSNOPEC with respect to the lagged rate of growth of real price (LREALP (-2)) has also been observed to be significant but of very low magnitude. This tendency of deceleration in the pace of Non-OPEC oil supply in response to an increase in the rate of growth of real price in a way tend to reinforce the inelastic and insignificant response of N-OPEC Supply to real price. For the equation pertaining to real price (LREALP) in the VECM, the adjusted R-squared has been observed to be around 0.38. However, the coefficient associated with none of the explanatory variables in their lagged differences has been observed as significant. For the equation pertaining to Non-OPEC reserve (LNOPECRESERVE), the value of adjusted R-squared has been observed as 0.25, which is quite low and the coefficient associated with D(LREALP(-2)) other than the adjustment coefficient have been observed as significant (as evinced by the t-values in parenthesis). The responsiveness of D(LNOPECRESERVE) to D(LREALP(-2)) is positive but very low. An increase in real crude price acts as a signal and provides incentive for more exploration and discovery. This only implies that the growth in real crude price in the last to the preceding period may only mildly influence the growth in Non-OPEC reserve.

1.6 Model Projections of Call on OPEC for the Sample Period 1975-2004 and Analysis

Fig. 1.5 Actual and Model Projection of World Crude Demand for 1975-2004

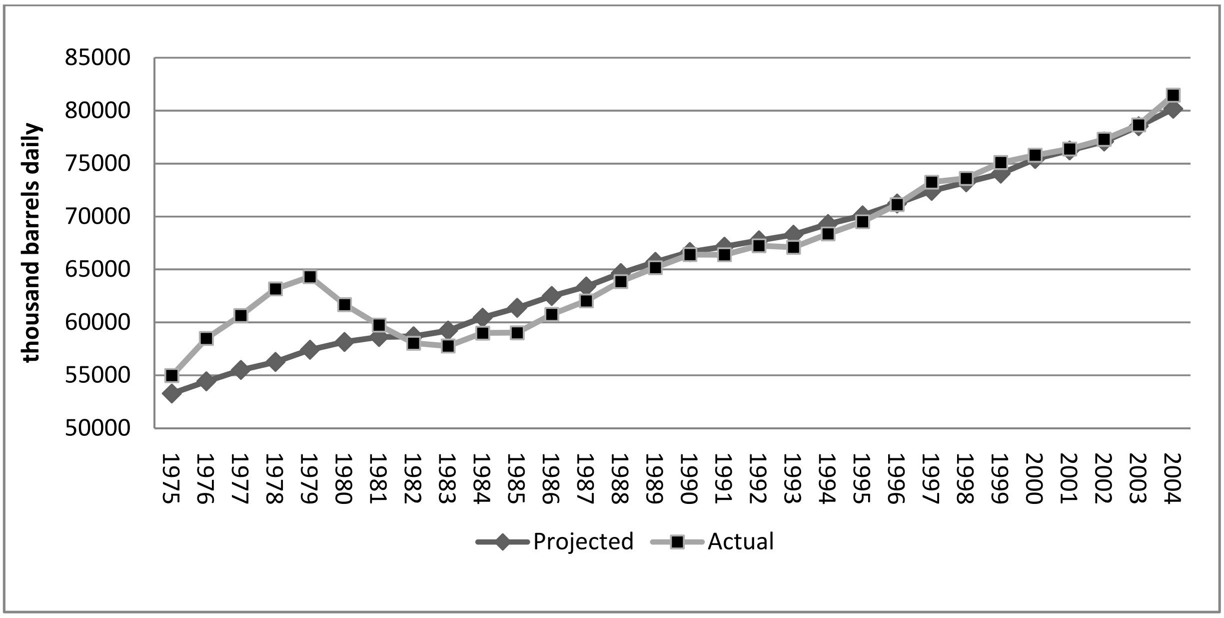

Fig. 1.6 Actual and Model Projection of Non-OPEC Crude Oil Supply for 1975-2004

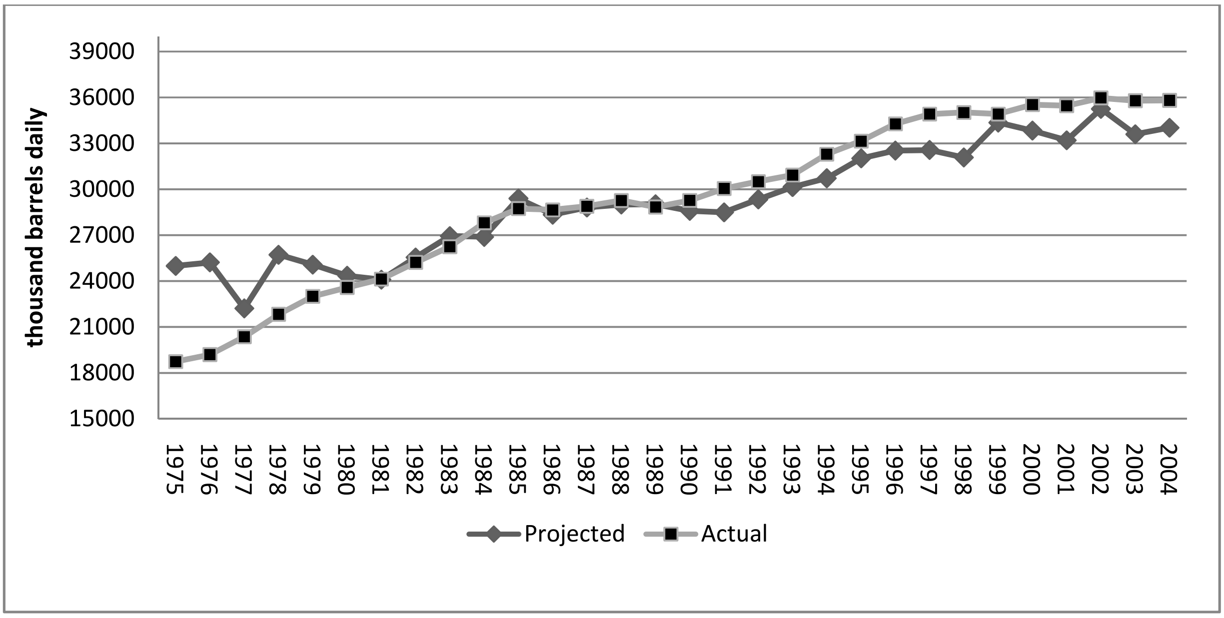

Fig. 1.5 compares the projections using the normalised cointegration equation and hence using the long-run price and income elasticity of world crude demand (over the sample period 1975-2004) diagrammatically. The projected trajectory could be observed as close to actual for most part of the time period 1975 to 2004. Thus, the projected trajectory of world crude demand could be considered as close substitute of the actual trajectory of the world crude demand for the sample period under consideration. The RMSE (Root Mean Square Error)[24] of the actual and projected series in their logarithmic form has been observed as around 0.016.

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[24] The root mean square error (RMSE) is a frequently-used measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modelled or estimated. RMSE is a good measure of accuracy. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power. The RMSE of an estimator $\hat{\theta}$ with respect to the estimated parameter θ is defined as the square root of the mean squared error:

$$RMSE(\hat{\theta}) = \sqrt{MSE(\hat{\theta})} = \sqrt{E((\hat{\theta} - \theta)^2)}$$

Fig 1.6 compares the projections of Non-OPEC crude oil supply with the actual data on crude oil supply over the sample period 1975-2004 using estimated cointegrating vector for Non-OPEC supply. Although the projected trajectory does not remain completely mingled with the actual production trajectory of Non-OPEC but remains mostly around the actual trajectory for the entire sample period. Thus, the projected trajectory of Non-OPEC crude supply could also be considered as a close substitute of the actual trajectory of Non-OPEC crude supply for the sample period. The RMSE (Root Mean Square Error) of the actual and projected series in their logarithmic form has also been observed as 0.011, which is very low.

Using the projected world crude demand and Non-OPEC crude supply, as shown in figs. 1.5 and 1.6 the projected call on OPEC output pertaining to the aforesaid period has been derived as –

Projected Call on OPEC = Projected World Crude Demand – Projected Non-OPEC Crude Supply

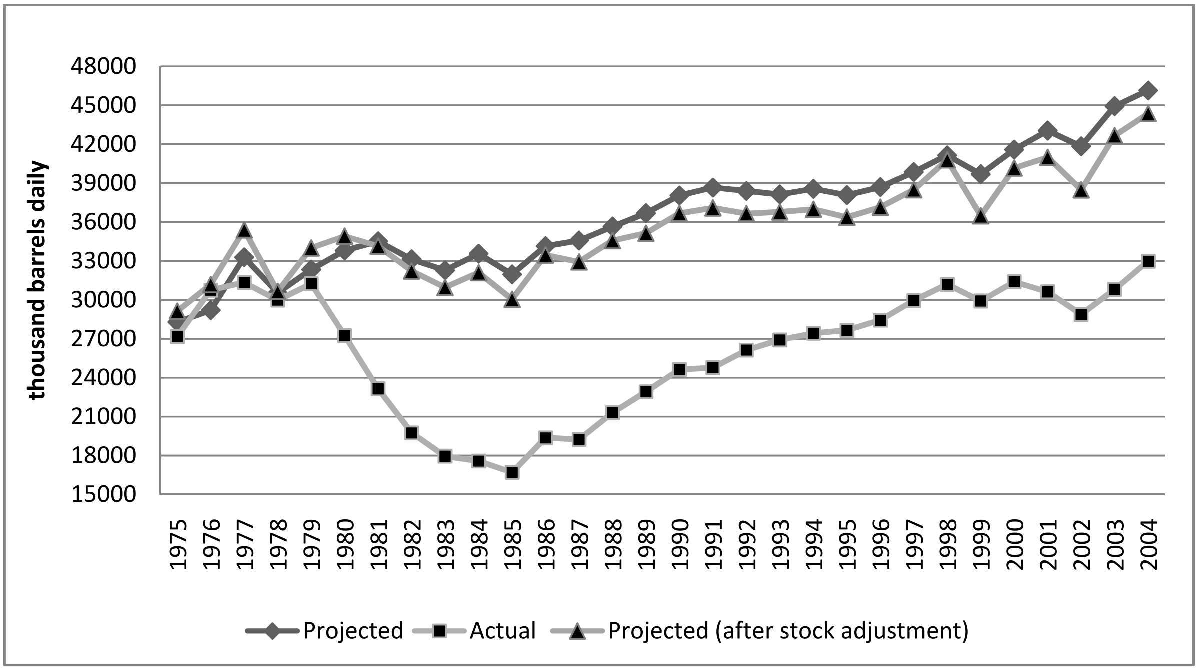
The projected call on OPEC after accounting for actual stock adjustment[25] during the sample period could be given as:

Projected Call on OPEC = Projected World Crude Demand – Projected Non-OPEC Crude Supply + Stock Adjustment

The projected series with or without stock adjustment are then juxtaposed with actual OPEC output during the period as shown in fig. 1.7.

[25] The figures on stock adjustment for the sample period have been obtained from BP (2006).

Fig. 1.7: Projected Call on OPEC and Actual OPEC Supply (1975-2004)



As evident from Fig. 1.7, the actual supply trajectory of OPEC, with the exception of the initial years, is completely digressed from the projected 'Call on OPEC' (even after accounting for actual stock adjustment during the sample period). In fact, the trajectory of actual OPEC supply has remained much below the projected call on OPEC from 1980 to 2004 which tends to reinforce the idea that OPEC might have persistently undersupplied than what had originally been demanded from them for the aforesaid time span. In other words the assumption that is often made in many economic models that OPEC acts as a residual or equilibrating producer does not seem to be validated by this exploratory exercise. This finding also implicitly hints towards the possible presence of monopolistic element and the price-making power of OPEC in the world crude oil market as the persistent undersupply may simply be with the intention of keeping the crude price high in order to serve the interest of the major producers and exporters of crude (within OPEC) in the best possible manner as underscored by Gately (2004, 2007).

The above observation, however, is not heartening from the perspective of countries which are heavily dependent on oil imports like India and China. With the Non-OPEC supply which has never been adequately responsive to world crude demand and change in prices, as indicated before, this only implies higher exposure of the oil importing countries to OPEC's discretion and price-making power.

1.6.1 Estimation of the Long Run Elasticity of Real Crude Price

The discussion carried out in the preceding paragraph delineates OPEC more as a monopolistic cartel with price-making power. Thus the capacity utilisation and production decision of OPEC may have a significant bearing on determination of real crude price.

The real crude price has been estimated here in accordance with the model described earlier in the section on model and rationale where the capacity utilisation of OPEC has been considered as a potential determinant of real crude price. On the basis of the statistically significant cointegrating vector in Appendix 1.3 C and using the same line of reasoning as in the case of world crude demand and Non-OPEC supply, a summary table has been prepared below showing the long-run elasticity of real crude price with respect to (w.r.t.) capacity utilisation of OPEC (CAPUTILOPEC) and ratio of stocks to demand of OECD countries (STKSDD), the two explanatory variables that have been considered in the equation of OPEC.

Table 2.3: Long Run Elasticity of Real Price (REALP)

Elasticity of Real Price w.r.t.	Value
CAPUTILOPEC	-1.350
STKSDD	-1.912

As evident from the table above, real price is highly elastic to changes in both capacity utilisation of OPEC and to changes in the ratio of stocks/inventory to demand. This observation reinforces the fact that the variation in capacity utilization of OPEC, irrespective of whether it is strategic or otherwise, may have a significant influence on real price. If the capacity utilisation of OPEC increases the production of OPEC increases concomitantly and thus may pull down the price in the process and vice versa for a decrease in capacity utilisation. The result, in a way, also hints towards the existence of price-making power of

OPEC reaffirming the observation in the preceding exploratory exercise through projection of call on OPEC. The level of inventories/stocks held by the consumers as a proportion of demand also seems to have a pronounced effect on the real price. If the existing level of stocks/inventories is higher as compared to demand the price may come down eventually due to lesser demand of crude oil and vice versa if the existing level of inventories are much lower as compared to demand.

1.6.2 Short-run Dynamics Pertaining to Real Crude Price

Appendix 1.4C shows the VECM for the set of variables (LREALP, LCAPUTILOPEC, and LSTKSDD). The test of goodness of fit (adjusted R^2) for the equation corresponding to D(LREALP) in the VECM is considerably high. The adjustment coefficient associated with E(-1), obtained considering the coefficient of LREALP as 1, is significant and negative indicating the tendency of the realised value of LREALP to return to the stable or permanent level. The coefficients of the autoregressive terms namely D(LREALP(-1)), D(LREALP(-2), D(LREALP(-3)) have also been observed to be significant (based on the values of t statistic). The lagged values of the explanatory variables D(LCAPUTILOPEC(-1)), D(LCAPUTILOPEC(-2)) and D(LSTKSDD(-2)), D(LSTKSDD(-3)) have also been observed as significant. As the response of real crude price to capacity utilization of OPEC need not be immediate and may occur with lags, the sign and magnitude of coefficients corresponding to D(LCAPUTILOPEC(-2)) tends to be negative although the sign of D(LCAPUTILOPEC(-1)) is positive. The difference in sign of D(LSTKSDD(-2)) and D(LSTKSDD(-3)) may also be possibly due to lagged response of growth in real price to growth in the ratio of stocks to demand.

For the equation pertaining to CAPUTILOPEC and STKSDD the adjusted R-squared has been observed to be low with the value being extremely low especially for STKSDD. Considering the autoregressive terms in the equations pertaining to the two variables, only the coefficient associated with D(LREALP(-1)) has been observed to be positive and significant but of very low magnitude. This just implies an insignificant responsiveness of the growth of STKSDD to growth in REALP in the immediate preceding period.

1.7 Some Illustrative Simulations and Implications

Fig.1.8: Simulation of Real Crude Price with Constant and Varying Capacity Utilisation of OPEC

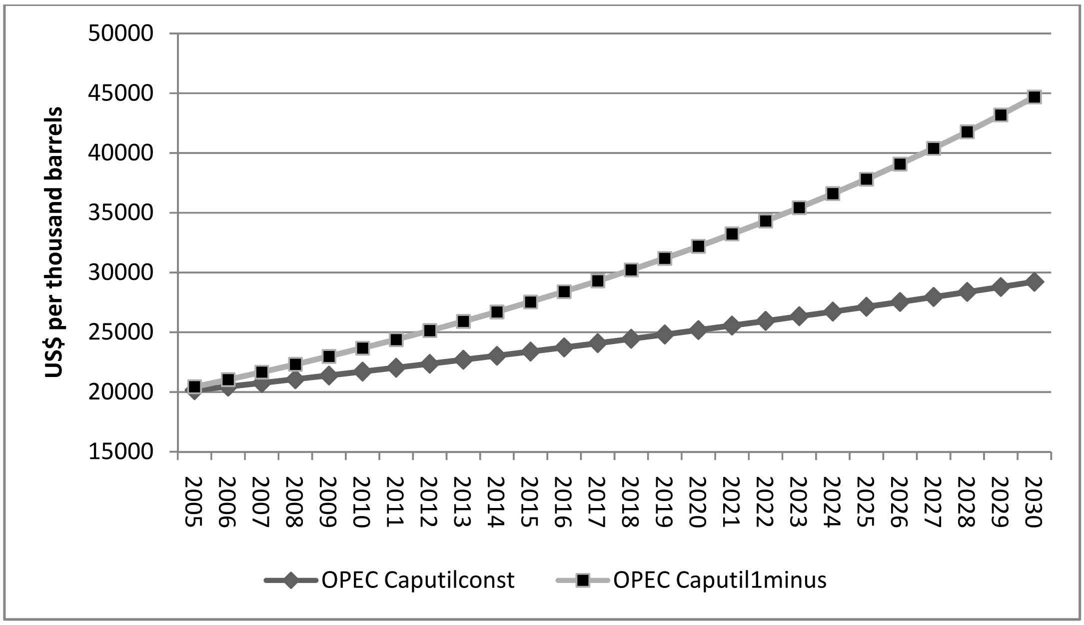


Fig. 1.8 indicates the trajectories of real crude price using long-run cointegrating relationship under two illustrative scenarios - Scenario 1 where OPEC maintains its capacity utilisation at the level of 2004, the terminal year in the sample period and Scenario 2 where OPEC progressively reduces its capacity utilization by 1 per cent every year. Fig. 1.9 shows the trajectories of world crude demand under both these scenarios and assuming a growth in real GDP at PPP of 4 per cent in consonance with the assumption of OECD World Energy Outlook 2007. It is seen from fig. 1.9 that the simulated trajectories of world crude demand under both the scenarios are almost mingled with one another. As the long-run price elasticity of world crude demand are insignificantly low, hence the variation in real crude price under the two scenarios, as shown in fig. 1.8, may not have any perceptible influence on world crude demand in future. This only implies that the crude demand is going to go up in an unabated manner without any aggressive intervention through conservationist measures

as well as energy-efficient innovation especially on sectors that are heavily dependent on petroleum globally (like transport).

Fig. 1.9 Simulated World Crude Demand under Two Scenarios

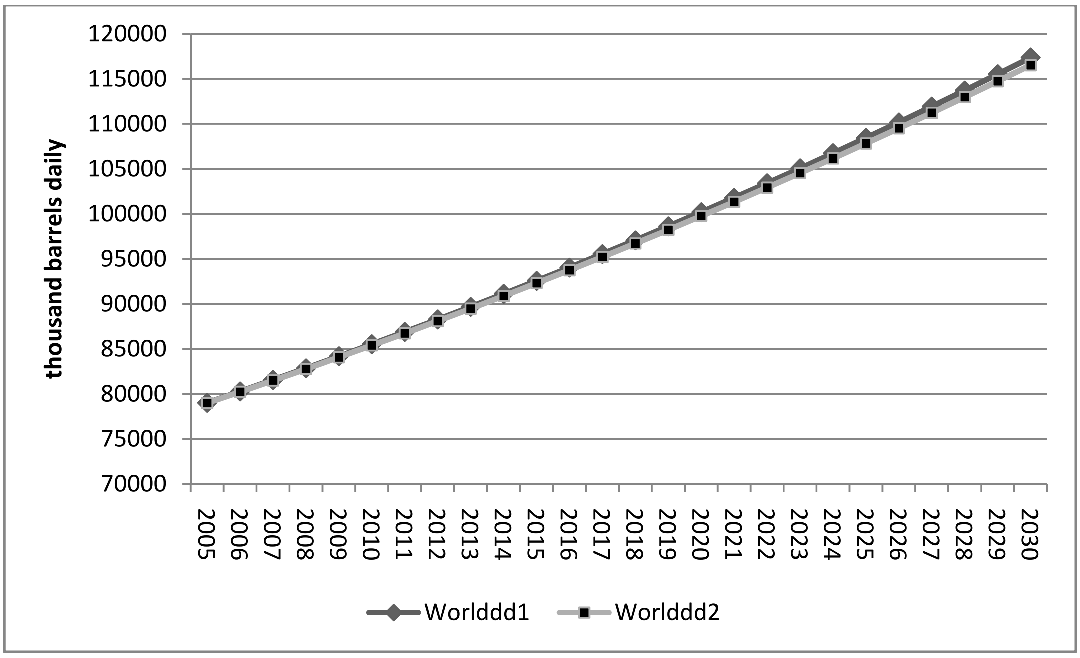


Fig. 1.10 illustrates the implication for Non-OPEC supply under the above two scenarios, assuming its proven reserve being maintained at the same level as of 2004. As evident from the figure, the crude supply of Non-OPEC increases in scenario 2 as compared to scenario 1. However, the increase is not substantial implying continued dominance of OPEC in the world crude market. In fact the projected dependence on OPEC crude supply under the two scenarios has been depicted in Fig. 1.11. Although the projected dependence on OPEC crude under scenario 2 decreases but the decrease has not been substantial due to inelastic price responsiveness of both crude demand and non-OPEC supply. Considering as a percentage of world crude demand, the dependence reduces from 77 per cent to 66 per cent in scenario 1 and from 77 per cent to 65 percent in scenario 2 for the time span 2005 to 2030. This means a reduction of just 11 to 12 per cent in a span of 25 years, which is not a favourable observation especially for heavily import dependent economies.

Fig. 1.10: Simulated Non-OPEC Supply Under Two Scenarios

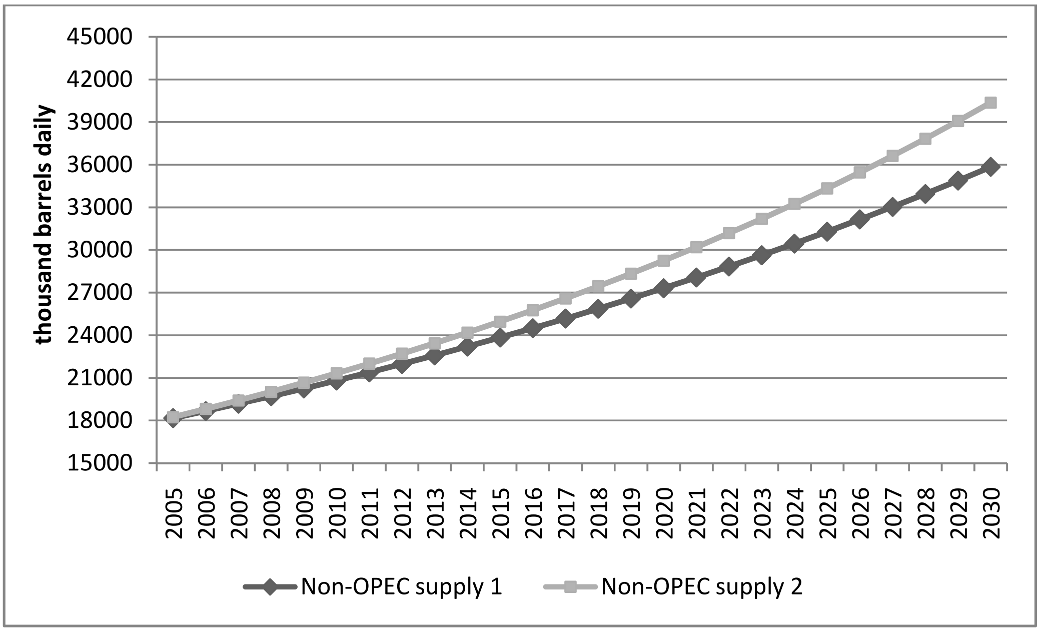
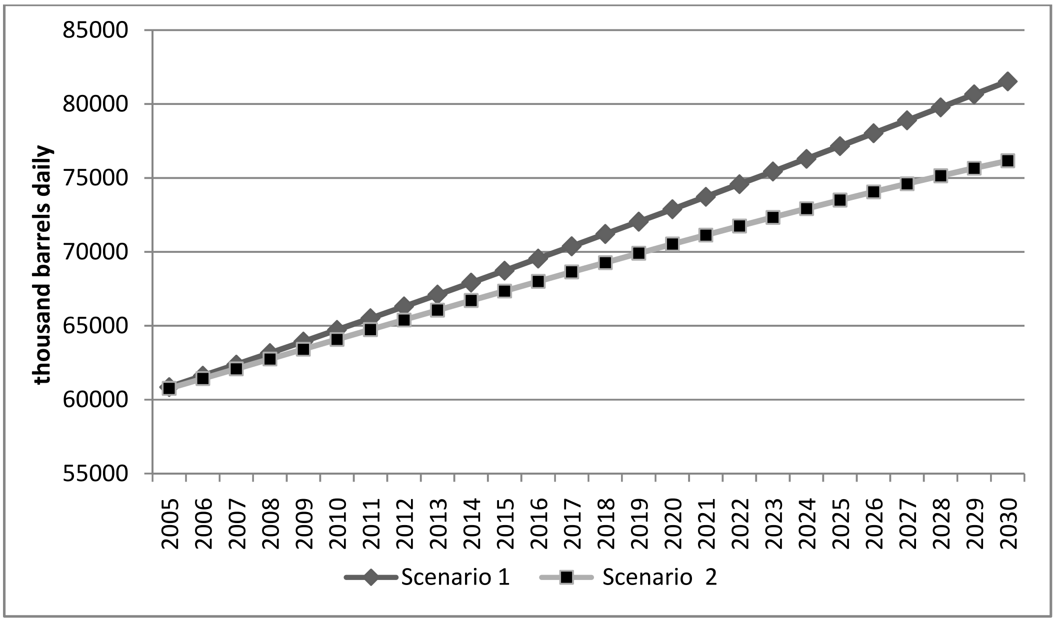


Fig. 1.11: Projected Dependence on OPEC Crude Supply Under Two Scenarios



The insensitivity of the world crude demand and Non-OPEC supply and continued dependence on OPEC for crude supply also implies that OPEC would have more flexibility in maneuvering the crude prices in order to serve its own best interest and may not necessarily always be intended for the bigger cause of stability of world crude prices, as has been observed before in the exploratory exercise for the sample period 1975 to 2004.

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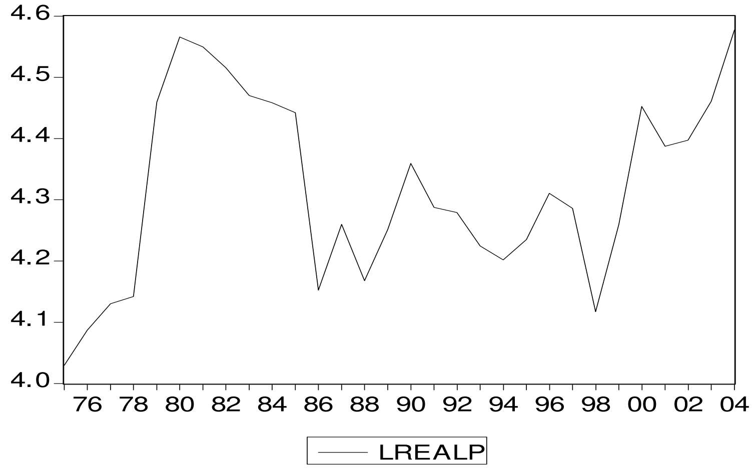
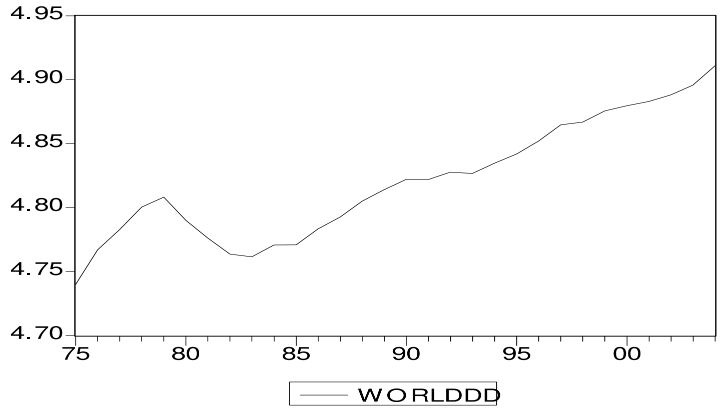
Appendix 2 : Plot of the Variables

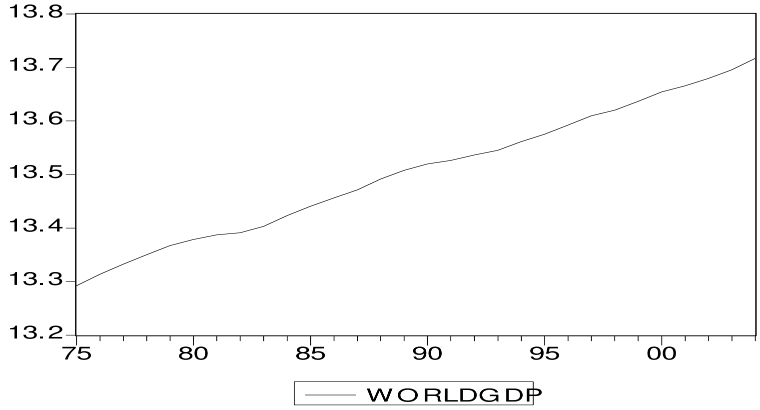
log of real price



log of World demand

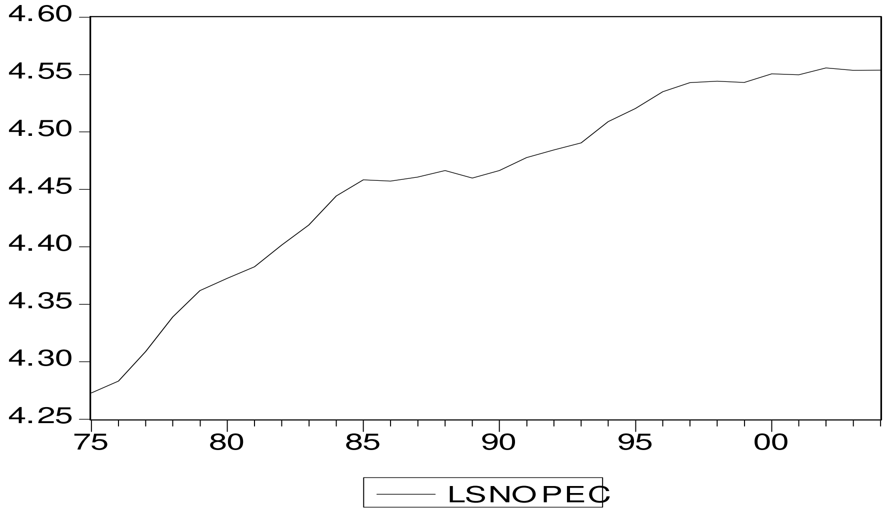


log of World real GDP

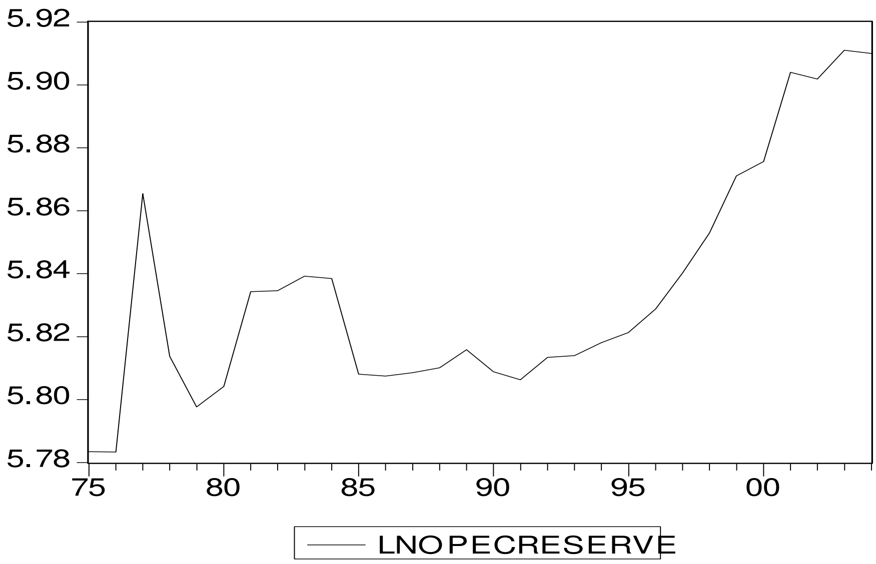


Appendix 1 (continued)

Log of Non-OPEC supply

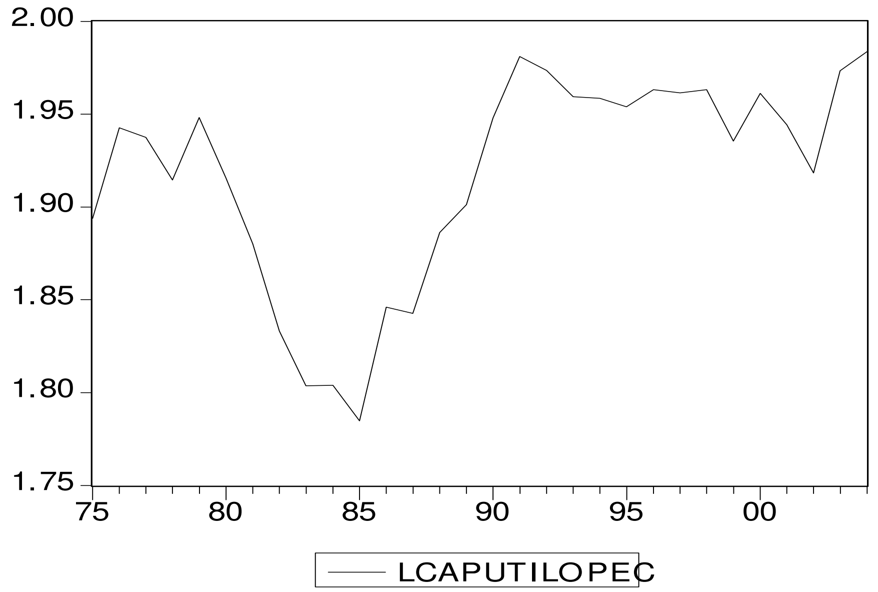


Log of non-OPEC Reserve

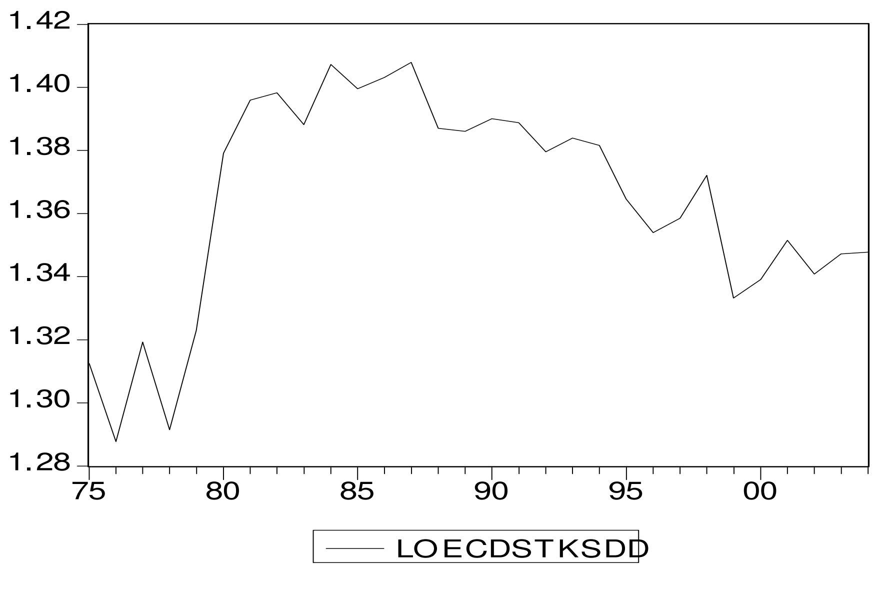


Appendix 1 (continued)

Log of capacity utilisation of OPEC



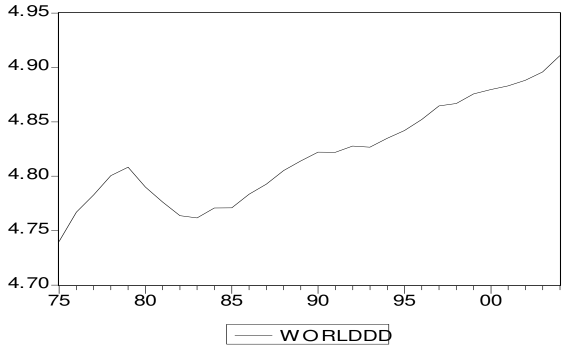
Log of ratio of OECD stocks over demand



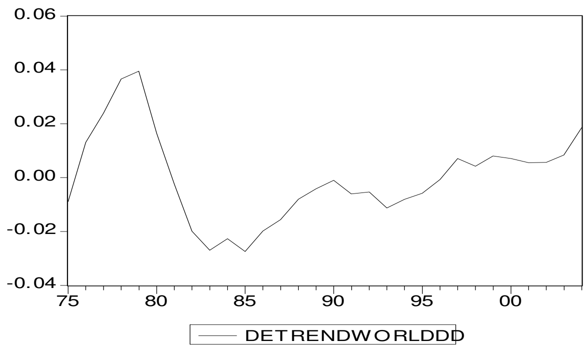
Appendix 1.1

Illustration of Detrending and Differencing for the series Worlddd

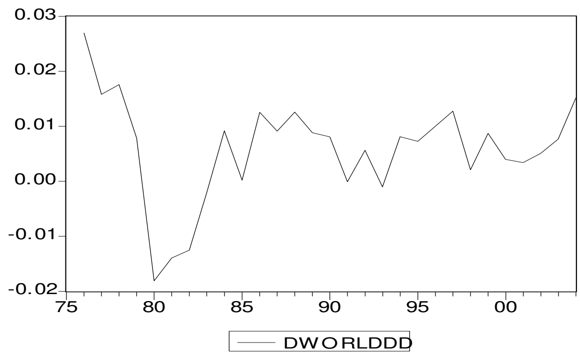
Log of world demand for oil



Detrended log of world demand for oil



First difference of the log of world demand for oil



Appendix 1.1A

Results of Unit Root Test on the Level of Series

Series	Values of Test Statistic (DF/ADF)
LWORLDDD	-2.786690**
LWORLDGDP	-3.266922*
LREALP	-2.248015**
LSNOPEC	-1.568386**
LNOPECRESERVE	-2.076463**
LCAPUTILOPEC	-1.575103**
LSTKSDD	-1.774751**

*indicates significance at 1 per cent level ** indicates significance at 5 per cent level

Appendix 1.1B

Results of Unit Root Test on the First Difference of the Series

Series	Value of Test Statistic (DF)
D(LWORLDDD)	-2.859861**
D(LWORLDGDP)	-3.156319*
D(LREALP)	-5.072143**
D(LSNOPEC)	-3.742505*
D(LNOPECRESERVE)	-6.374500**
D(LCAPUTILOPEC)	-5.079988**
D(LSTKSDD)	-5.865275**

D indicates first difference, * indicates significance at 5 per cent level and ** indicates significance at 1 per cent level

Appendix 1.2A

Results of Trace Test for the set of variables- (LWORLDDD, LREALP, LWORLDGDP)

Hypothesized No. of Cointegrating Equations	Eigenvalue	Likelihood Ratio
None	0.655186	38.10491**
At most 1	0.221379	10.42141
At most 2	0.139802	3.915403*

*(**) denotes rejection of the hypothesis at 5%(1%) significance level

L.R. test indicates 1 cointegrating equation at 5% significance level

Appendix 1.2B

Results of Trace Test for the set of variables- (LSNOPEC, LNOPECRESERVE, LREALP)

Hypothesized No. of Cointegrating Equations	Eigenvalue	Likelihood Ratio
None	0.754294	50.29225**
At most 1	0.341986	13.79818
At most 2	0.106107	2.916410

** denotes rejection of the hypothesis at 1% significance level

L.R. test indicates 1 cointegrating equation at 5% significance level

Appendix 1.2C

Results of Trace Test for the set of variables- (LREALP, LCAPUTILOPEC, LSTKSDD)

Hypothesized No. of Cointegrating Equations	Eigenvalue	Likelihood Ratio
None	0.644250	46.62930**
At most 1	0.500890	19.75758
At most 2	0.062912	1.689419

** denotes rejection of the hypothesis at 1% significance level

L.R. test indicates 1 cointegrating equation at 5% significance level

Appendix 1.3A

Estimated Cointegrating Vector for the Variable Group (LWORLDDD, LREALP, LWORLDGDP)

Variable Group	Sample Period	Estimated Coefficients of*			
		Intercept	LWORLDDD	LREALP	LWORLDGDP
LWORLDDD, LREALP, LWORLDGDP	1975-2004	0.655367	1	0.016757 (0.02479)	-0.410548 (0.00929)

*Figures in the parenthesis are standard errors and 'L' stands for logarithms

Appendix 1.3B

Estimated Cointegrating Vector for the Variable Group (LSNOPEC, LREALP, LNOPECRESERVE)

Variable Group	Sample Period	Estimated Coefficients of*				
		INTERCEPT	TREND	LSNOPEC	LREALP	LNOPECR-ESERVE
LSNOPEC, LREALP, LNOPECRESERVE	1975-2004	-6.59	-0.01 (0.001)	1	-0.282 (0.135)	0.598 (0.372)

*Figures in the parenthesis are standard errors and 'L' stands for logarithms

Appendix 1.3C

Estimated Cointegrating Vector for the Variable Group (LREALP, LCAPUTILOPEC, LSTKSDD)

Variable Group	Sample Period	Estimated Coefficients of*			
		INTERCEPT	LREALP	LCAPUTILOPEC	LSTKSDD
LREALP, LCAPUTILOPEC, LSTKSDD	1975-2005	-9.553650	1	1.349482 (0.32119)	1.912909 (1.11338)

*Figures in the parenthesis are standard errors and 'L' stands for logarithms

Appendix 1.4A

Estimated VECM for the set of variables (LWORLDDD, LREALP, LWORLDGDP)

Explanatory Variables	Dependent Variable		
	D(LWORLDDD)	D(LREALP)	D(LWORLDGDP)
E(-1)	-0.530942	6.898931	0.098950
	(-2.55026)	(1.64992)	(0.74159)
D(LWORLDDD(-2))	0.499187	-7.565862	0.230517
	(1.42616)	(-1.07623)	(1.02758)
D(LREALP(-3))	0.008846	-0.361198	-0.005692
	(0.47523)	(-0.96612)	(-0.47709)
D(LWORLDGDP(-3))	0.173277	-9.331176	-0.032894
	(0.25950)	(-0.69578)	(-0.07686)
Adj. R-squared	0.553771	-0.187493	0.321284

*Figures in the parenthesis indicate the value of t statistics and 'L' indicates logarithms

Appendix 1.4B

Estimated VECM for the set of variables (LSNOPEC, LREALP, LNOPECRESERVE)

	Dependent Variables		
Explanatory Variables	D(LSNOPEC)	D(LREALP)	D(LNOPECRESERVE)
E(-1)	-0.213887 (-2.12915)	1.208078 (1.06902)	0.411106 (3.00557)
D(LREALP(-2))	0.047519 (2.12798)	0.142270 (0.56634)	0.118816 (3.90774)
D(LREALP(-3))	0.026232 (1.22688)	0.077678 (0.32295)	0.057356 (1.97019)
D(LNOPECRESERVE(-1))	0.465569 (2.23585)	0.696666 (0.29741)	-0.542991 (-1.91515)
C	0.004332 (1.18076)	0.040632 (0.98439)	0.001448 (0.28974)
Adj. R-squared	0.113228	0.383660	0.251296

*Figures in the parenthesis indicate the value of t statistics and 'L' indicates logarithms

Appendix 1.4C

Estimated VECM for the set of variables (LREALP, LCAPUTILOPEC, and LSTKSDD)

	Dependent Variables		
Explanatory Variables	D(LREALP)	D(LCAPUTILOPEC)	D(LSTKSDD)
E(-1)	-0.952208 (-3.49294)	0.025916 (0.21926)	-0.098288 (-1.32388)
D(LREALP(-1))	0.557972 (3.00428)	0.029274 (0.36354)	0.127437 (2.51948)
D(LREALP(-2))	0.425327 (2.06115)	-0.113236 (-1.26565)	0.096820 (1.72282)
D(LREALP(-3))	0.588285 (2.63571)	-0.035425 (-0.36607)	0.074218 (1.22098)
D(LCAPUTILOPEC(-1))	2.661676 (3.47783)	0.133488 (0.40229)	0.093439 (0.44830)
D(LCAPUTILOPEC(-2))	-1.634449 (-2.10607)	0.221609 (0.65861)	-0.072657 (-0.34377)
D(LSTKSDD(-2))	2.328071 (2.10613)	0.152948 (0.31914)	-0.141501 (-0.47004)
D(LSTKSDD(-3))	-2.272158 (-2.15327)	-0.157438 (-0.34412)	0.345228 (1.20131)
Adj. R-squared	0.673892	0.229872	0.099254

*Figures in the parenthesis indicate the value of t statistics and 'L' indicates logarithms

Appendix 1.5

Summary table of the values of list of variables used for estimation

Year	WORLDDD (thousand barrels daily)	REALP (US$ per thousand barrels)	WORLDGDP (US $)	SNOPEC (thousand barrels daily)	NOPECRESERVE (thousand barrels daily)	CAPUTILOPEC (per cent)	STKSDD (days)
1975	54962	10702	19599999938781	18741	607350	78.30	21
1980	61678	36827	23899999947822	23580	637024	82.33	24
1985	59015	27691	27599999868753	28734	642842	60.91	25
1990	66390	22892	33099999712232	29275	643921	88.70	25
1995	69506	17180	37599999573377	33151	662723	89.93	23
2000	75779	28354	45099999804980	35535	751009	91.44	22
2001	76379	24396	46299999891477	35463	801664	87.97	22
2002	77280	24976	47800000372882	35968	797822	82.85	22
2003	78655	28894	49600000400848	35787	814822	94.06	22
2004	81444	37796	52099999604174	35805	812863	96.32	22