OPEC and political considerations when deciding on oil extraction

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Abstract

Two oil price shocks changed the pattern of cheap oil. The first was the Arab embargo on oil exports in 1973. Oil prices rose five fold. In 1978, the second was the fall of Shah Iran. Prices soared to \$80-\$100 a barrel in today's prices. In 1960, OPEC was established and since then it has been a considerable political and economical force in the oil market. Two thirds of the world's oil reserves belong to OPEC members. OPEC is accused of being responsible for most of the price increases due to their production cuts and market power. This paper provides a general framework to examine the role of OPEC in affecting oil prices through the extracted quantities. A mathematical model is developed to explore the objective function of OPEC, which includes economic and political considerations. The idea is that OPEC members consider both the political support of their citizens and profits when determining oil extraction rates. This support is represented by a "harm function" which was added to the objective function of OPEC. The solution of the model lends some support for inclusion of this harm function, through which OPEC benefits from the cuts in production aimed at harming the western countries. For this harm function to be meaningful empirically, OPEC members should have a high harm indicator, α_t. With high harm indicator values, OPEC harms itself financially. The results suggest that OPEC appears to be accepting considerable monetary setbacks to appease its citizens' taste for harming the West. At different discount rates, the monetary losses range from about 10-20%.

Solving the mathematical model required estimation of the residual demand that OPEC faces plus the cost function that applies to OPEC production. This paper reports the results of these estimations.

Keywords: OPEC, optimal control, cost estimation, demand estimation, resource economics
JEL Classification: C02, C20, C51, Q31, Q32, Q34, Q41

I. Introduction

OPEC represents a considerable political and economic force. Two-thirds of the oil reserves in the world belong to OPEC members; likewise, OPEC members are responsible for half of the world's oil exports. According to its statutes, OPEC's main goal is to unify and protect the interests of oil-producing countries. It allows oil-producing countries to guarantee their income by coordinating policies and prices among members. OPEC is the best known cartel in the world which controls the oil market by limiting production, thus creating "shortages" and forcing oil prices up.

Oil is the world's main source of energy, and its price has a substantial impact on all economies. Crude Oil prices ranged between $2.50 and $3.00 from 1948 through the end of the 1960s. By the end of 1973 the price of oil had quadrupled to over $12, when the Arab oil producers imposed the 1973 oil embargo against the U.S. and Western Europe (supported by production cuts from other OPEC members). After that, prices stayed flat, ranging from $12.21 to $13.55 per barrel until 1979, when the Iranian revolution occurred. The combination of the Iranian revolution and the Iraq-Iran War caused crude oil prices to more than double, increasing from $14 in 1978 to $35 per barrel in 1981. These higher prices resulted in increased exploration and production outside OPEC. Between 1980 and 1986, non-OPEC production increased 10 million barrels per day. This caused crude oil prices to drop below $10 per barrel by mid-1986.

The price of crude oil spiked in 1990 due to what was known as the first "Gulf War". However, after the war, crude oil prices entered a period of steady decline until 1994. After that, prices started to recover again until 1997 (price of crude oil reached $25), because the U.S. economy was strong and the Asian Pacific region was booming, but then prices dropped to $16 in 1999. By the end of 2001, oil prices started to steadily increase, reaching $40-50 by the end of 2004. Then crude oil prices surged to a record high above $60 in June 2005, over $77 in July 2006, above $90 in October 2007, and reaching a new record high of $147 in July 2008. However, since then, oil prices have declined. Figure 1 summarizes the time trend in oil prices.

When we look at the trend of oil prices over the past years, one would argue that OPEC is responsible for most of these increases due to their production cuts and market power. Others believe that OPEC is not to be blamed for the price increases, since OPEC's ability to control the price of oil diminished somewhat after the 1973 oil crisis, due to the subsequent discovery and development of large oil reserves in the Gulf of Mexico and the North Sea, the opening up of Russia, and market modernization.

Figure 1

There is a rich literature on the process of oil price determination, but the question of whether OPEC is a cartel or not remains hotly debated. Economists have devoted much attention to this issue, since it reflects different arguments regarding OPEC's role in determining oil prices. Some economists have assumed OPEC as a monopolist and others use models that regard OPEC as a dominant firm.[1] In this paper, OPEC is assumed to act as a dominant firm, and non-OPEC countries are regarded as fringe firms. The main concern here is to explore the objective function for OPEC, and how OPEC determines the time path of production. This is done by applying optimal control theory in studying the dynamics of oil prices and therefore the time path of quantities extracted. We develop a model that explores the objective function of OPEC, which includes economic as well as political considerations. We determine the optimal extraction quantities of oil under this model, and compare them to actual quantities to check the validity of the model. Also we provide policy guidance to decision makers around the world.

The paper aims to contribute to a further understanding of the real dynamics of OPEC production behavior and its impacts on the world oil market. It contributes to the literature in several ways. From a technical standpoint, one of the important additions is the estimation of the residual demand curve for oil that OPEC faces in the market. Previous economic studies that have applied optimal control theory have not used any specific estimated demand equation, but rather employed general demand equations to show analytical solutions. Non-optimal control models though did estimate different types of demand functions, using lagged prices and/or lagged quantities. However, these exercises in econometrics appear to have little or no foundation in traditional demand theory.

It also provides estimates of the oil production cost function for OPEC members, which has not been done previously. The estimation of both the demand function and the cost function for OPEC allows one to apply the mathematical model that is developed here using optimal control theory. Finally, another important addition is the test of political economic

[1] A good review of this literature can be found in Alhajji & Huettner (2000).

considerations. The test looks at the hypothesis that OPEC has another objective, beyond just maximizing profits, in deciding on extracted quantities of oil. This other goal is the desire to achieve political support among citizens of OPEC countries. This support comes from the level of harm or damage to western countries' economies, by affecting the world oil market through high oil prices.

The remainder of the paper is structured as follows. Section II reviews the literature. Section III describes the theoretical model and assumptions used in estimating the residual demand for oil and the cost function for OPEC. Section IV describes the theoretical optimal control model and the solution of this model. Finally, Section V summarizes the main findings of the research and offers some concluding remarks

II. Literature Review

Since 1973, economists have devoted considerable attention to analyzing how oil prices are determined. This previous work has generally focused on two theoretical approaches, either the optimal control analysis of pricing of a depletable resource, or OPEC as a monopolist setting oil prices to maximize net present value. The methodologies employed in these studies include: the theory of exhaustible resources; game theory; simulation; industrial economics; and the economic efficiency hypothesis (Mabro; 1992). Griffin and Xiong (1997) examined OPEC's production behavior when some members cheat on quotas. MacAvoy (1982) used market fundamentals (demand and supply) to explain changes in oil prices. Griffin (1985) expanded the analysis by looking at four different production models for OPEC members using data for the period 1971-1983. These models are the competitive; cartel; target revenue; and property rights models. Jones (1990) updated Griffin's cartel and competitive models using data from 1983 to 1988. Due to the limitation that Griffin's analysis covered a period when oil prices increased, and because the rapid growth of non-OPEC supply after 1988 was accompanied by the rapid decline in oil prices during the 1980's and 1990's, Watkins and Streifel (1998) renewed interest in the competitive model of oil production.

The theory of exhaustible resources was pioneered by the work of Hotelling (1931). He showed that the price of the resource minus the marginal cost should grow at a rate equal to the discount rate, under competitive markets and constant marginal extraction costs. This result is known as the "Hotelling rule". Extensions to Hotelling's model allowed for variable costs due to resource depletion and changing reserves. Pindyck (1978) allowed for exploration and variable average cost of production. Hotelling also extended the model by looking at monopolistic pricing compared to a competitive price Hotelling (1931). Salant (1976) accounted for industrial organization of the world oil market by looking at fringe firms with the cartel. Stiglitz (1976) found that the monopolist's ability to use its market power depends on the price elasticity of demand. Polasky (1992) analyzed the value of information generated through exploration activity. The theory of exhaustible resources was also used in looking at the role of international trade in oil prices, since a great part of trade in natural resources is international in scope. This issue was investigated using models of resource-exporting countries. In these models, the resource-rich countries are assumed to maximize utility that is derived from consumption and they are constrained by the balance of payments.[2] Several attempts have been made to test the Hotelling rule; some show that the rule is a good depiction of the real world, and others question the reliability of the rule. Slade (1982) and Moazzami and Anderson (1994) found evidence that the price path follows a U-shape, and this means that resource prices will eventually increase, complying with the Hotelling rule. Krautkraemer (1998) argued that the basic Hotelling model of finite availability of nonrenewable resources does not adequately explain the observed behavior of nonrenewable prices. Cynthia Lin (2008) employed an updated data set on world oil and allows for market structure and different demand elasticities for different periods: 1965-1973, 1973-1981, 1981-1990, and 1990-2006. She acknowledges the fact that the basic Hotelling model does yield useful insights and several realistic results. Heal and Barrow (1980) analyzed the markets for several metals using long time series of prices. They introduced the formation of expectations concerning the discount rate. They found no evidence that the discount rate affects the rate of price change. Rauscher (1991) explained why the Hotelling rule is not supported by empirical evidence. He summarizes several issues that contributed to this confusion. The Hotelling rule assumes perfect information about the parameters of the model by whether agents or the social planner, and these parameters are assumed to remain constant; but in real life this is not true. There are: changes in the size of the resource stock; changes in the market structure itself (from competitive to cartel); changes in property rights (from control by the "Seven Sisters" to OPEC-member control of exploration and extraction); backstop technology; and other additional variables that would affect the price path and extraction decisions including taste and taxation variables that affect the demand.

[2] For a good review see Rauscher (1991).

Another approach in the literature examined the demand, supply and price volatility in the oil market. Several attempts were made to estimate the demand for petroleum products in many countries. Baltagi and Griffin (1983) looked at the demand of some petroleum products in the OECD. Wasserfallen and Guntensperger (1988) studied the relationship between gasoline consumption and vehicle stock in Switzerland. Blum, Foos, and Gaudry (1988) studied the relationship between gasoline demand and other macroeconomic variables in Germany. Dahl and Sterner (1990) provided another survey of the gasoline demand models. Garbacz (1989) looked at the demand in Taiwan. McRae (1994) estimated the gasoline demand for several developing Asian countries by using econometric models. Ramanathan (1999) estimated the relationship between petroleum consumption and macroeconomic variables in India. Eltony and Al-Mutairi (1995) looked at the relationships between production and consumption of petroleum products in Kuwait using cointegrating econometric methodologies. Kaufmann et. al. (2004) investigated the relationship between real oil prices and OPEC behavior. They found that there is a significant correlation between real oil prices, OPEC capacity utilization, OPEC quotas, the amount of cheating, and OECD stocks. Similar results were found by Mazraati and Jazayeri (2004). Target revenue theory (TRT) also received important attention in the literature. This theory shows that OPEC reduces or increases oil production simultaneously with real price increases or decreases in order to equate revenues with domestic investment needs. This theory was examined by many studies, including Hammoudeh (1996), Tang and Hammoudeh (2002), Chapman and Khanna (2000, 2001), and Horn (2004). Ramcharran (2001) tested this theory using data from 1973 to 2000 and concludes that it does not apply. Some attempts to define structural models of world oil prices were unsuccessful due to ignoring important factors that affect the behavior of world oil prices, such as political and military variables.[3] Smith (2005) rejected all traditional explanations of OPEC behavior (competitive, Cournot, dominant firm, etc.) in favor of a bureaucratic, consensus-making cartel hypothesis.

Political decisions may produce short-term deviations from the economic path. For example, destructive events, such as wars or revolutions, may remove capacity from production, and generate unexpected jumps in the price of oil. This is noticed in the oil market through the Iraq-Iran War, the Iranian Revolution, and the Gulf War. The behavior of OPEC in most cases is explained and tested using economic models that portray the behavior of economic agents. The

[3] A good review can be found in Tang and Hammoudeh (2002).

fact that the cooperation within OPEC is among countries (members), not between firms, could cause these models to be incapable of fully explaining OPEC's behavior. Recognizing the fact that OPEC's members are national governments not private businesses requires that economic analysis of cartels must be blended with political analysis. The rationale of governments is different from the rationale of firms. Governments have a more complex set of interests and tend to emphasize security interests. Furthermore, governments are more complex organizations that contain more potential for internal conflicts over aims and means. Finally, governments have to pay attention to aspects at the social level in a way that firms do not (Willet, 1979). Wirl (2008) investigated different models that can help to explain oil price changes. One approach is political motives. This approach applies political reasoning to OPEC decision makers. The assumption is that politicians are much less concerned about profits than businessmen, since political markets may reward decisions that harm the economy.[4] Politicians must strive for popular support, so unity can become an important part of their goals. Countries considered as allies to the West (e. g. Saudi Arabia) have repeated with increasing emphasis their intention to use oil as a weapon to change American and European policy toward the Arab-Israeli conflict. This gives political reward to the leaders of OPEC countries who need popular support, by playing on anti-Western sentiments. Wirl formulates a model that assumes OPEC decision makers maximize the net present value of benefits, which consists of current profit and political support. Political support is represented by 'harming' the West, a strategy that pays off in many Middle East and Latin American countries.

At this point, a good question can be raised about the accuracy of this argument. Do OPEC members really seek to harm the U.S. and other Western countries by affecting the oil market and causing oil prices to increase? Do quota cuts, which OPEC members adopt in their meetings, reflect such a goal, or is it just a tool that used to maximize profit? These and other important questions will be addressed in this paper.

III. Residual Demand for Oil and the Cost Function for OPEC

In order to proceed empirically, we need to determine the residual demand function that OPEC faces, and estimate the cost function for OPEC's oil development and production. In this paper, it is assumed that OPEC's behavior follows the dominant firm model in the world oil

[4] A good example can be tariffs used by politicians to gain political support even though certain local industries may be harmed.

market. The dominant firm model is used widely in economics (Salant (1976), Cremer and Weitzman (1976) and Pindyck (1978)). The model assumes that OPEC countries set the price of oil and the non-OPEC countries are the competitive fringe (assumed to be price takers). The demand for OPEC's oil is the "residual demand". By residual demand function we mean the relationship between OPEC's price and quantity, taking into account the competitive supply response of all non-OPEC countries to an OPEC-set price.[5]

OECD countries, as a group, account for most imports of OPEC's oil. Table 1 summarizes the total exports of OPEC countries to the entire world and to OECD countries from 1960-2007. It shows that yearly exports to OECD countries average 72.2% of total OPEC exports.

Table 1

III.1 the Model of Residual Demand

. The approach used here to model the crude oil residual demand facing OPEC is to specify the major buyers or importers from OPEC, which are the OECD countries. Thus, the model splits the buyers from OPEC into two groups: OECD and non-OECD countries. It is important to emphasize that, in modeling the demand for OPEC producers' exports of crude oil, the research is modeling their net demand. Clearly, there are competing non-OPEC supplies of crude, but these will be assumed to be a function only of the prices set by the OPEC producers. When these non-OPEC supplies are subtracted from the gross demands, which is assumed to be a function of OPEC prices and other exogenous variables, this results in a residual demand for OPEC's crude that is a function only of OPEC prices and the exogenous variables. Dahl (1994) reviews studies that estimate the demand for oil. Following the standard convention in these studies, the residual demand for oil can be represented by the following function:

$$q_t = f\,(P_t , Y_t^O , Y_t^N , N_t^O , N_t^N , q_{t-1}) \qquad (1)$$

Where, q_t is OPEC's exports of crude oil (1000b/day), P_t is real spot OPEC reference basket prices (base=2005), Y_t^O is OECD's real GDP (in millions, base=2005), Y_t^N is Non-OECD's real GDP (in millions, base=2005), N_t^O is OECD population (in thousands), N_t^N is Non-OECD population (in thousands), and q_{t-1} is lagged OPEC's exports of crude oil (1000b/day)

[5] The quantities here are OPEC's exports which are assumed to be the same as the quantities that OPEC produce.

The model here incorporates the demand of all countries, OECD and non-OECD. But because the research focuses on the relation between OPEC and OECD countries, the covariates are divided into OECD variables and non-OECD variables. This will help to see the differences in demand between the two groups. And also, will be seen later, non-OECD countries have a stable - if not constant - demand for oil over time, which suggests that the fluctuation in demand for oil is mostly related to factors associated with OECD countries. When applying optimal control theory, it is more convenient to use a linear demand curve. Many studies have adopted this form (e.g. Herfindahl (1967), Salant (1976), Cremer and Weitzman (1976), and Pindyck (1978)). Following this approach, the dynamic linear demand model then can be expressed as follows:

$$q_t = \beta_0 + \beta_1 P_t + \beta_2 Y_t^O + \beta_3 Y_t^N + \beta_4 N_t^O + \beta_5 N_t^N + \beta_6 q_{t-1} + \varepsilon_t \quad (2)$$

Where ε_t is an error term.

To avoid identification problem, we also incorporate a linear supply function. The supply function can be identified by the following equation:

$$q_t = \alpha_0 + \alpha_1 P_t + \alpha_2 R_t + \alpha_3 t + v_t \quad (3)$$

Where q_t is OPEC's exports of crude oil (1000b/day), P_t is real spot OPEC reference basket prices (base=2005), R_t is OPEC's reserves, t is time index that is used to detrend the data and vt is an error term. Estimating demand function will be done using two-stage least-squares (**2SLS**).

III.1.1 Data

The data used in this section are taken from different sources. OPEC oil production, reserves and exports are the levels reported by OPEC in its Annual Statistical Bulletin for different years (1989-2007). OPEC's Annual Statistical Bulletin provides data about world energy markets. It contains statistical data regarding the oil and gas activities of OPEC's member countries (Algeria, Angola, Ecuador, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates and Venezuela), as well as the global petroleum industry in general. It also provides comprehensive and detailed data on upstream and downstream activities, and the global flows of oil and gas, in addition to basic financial data about some of the world's largest oil and gas companies. Crude oil production and exports for OPEC Members from 1970 – 2007 are in 1,000 b/day. The oil prices used are also coming from the same bulletins. It is the spot OPEC reference basket prices of crude oil, in nominal and real terms, from 1970–2007 (in U.S. dollars per barrel). OPEC's spot price from 1970 to 1981 was the Arab Light official price. As of 1982, OPEC's spot reference basket price is the arithmetic average of seven selected oil crudes: Saharan Blend (Algeria); Minas (Indonesia); Bonny Light (Nigeria); Arab Light (Saudi Arabia); Dubai (United Arab Emirates), Tia Juana Light (Venezuela), and Isthmus (Mexico), although Mexico is not a Member of OPEC.[6] The bulletins also report the quantities of OPEC's oil exports to all OECD and non-OECD countries from 1970 – 2007 (in 1,000 barrel per day).

Data about the OECD's real GDP and population come from OECD dot Stat (http://stats.oecd.org/ WBOS/ index.aspx), which enables users to search for and extract data from across OECD's many databases included in this source. OECD's real GDP is reported in millions of U.S. dollars, where the base year is 2000. The OECD population is reported in thousands. Data regarding the non-OECD's real GDP and population come from the World Bank, which enables users to search for and extract data from across many databases included in this source. Non-OECD's real GDP is reported in millions of U.S. dollars, where the base year is 2005 and the population is reported in thousands. For adjustment purposes, the Consumer Price Index (CPI) from the Bureau of Labor Statistics will be used, and is based upon a 1982-1984 base of 100. The series reflects monthly and yearly data from 1949-2007.

Table 2 reports the mean, standard deviation, maximum and minimum values of the variables. From the data we can graph the time path of OPEC's oil exports, quantities imported by OECD countries, quantities imported by non-OECD countries, and the real spot OPEC prices. Figures 2 and 3 report the time path of these movements.

Table 2

Figures 2 and 3

Figure 2 shows that imports by OECD countries did dropped from 1979 to 1985, but since then there has been an upward trend in imports from OPEC. As for non-OECD countries, we see a stable pattern in their imports from OPEC. Figure 3 shows that real spot OPEC prices

[6] OPEC Annual Statistical Bulletin 1999

increased between 1970-1974, and then again between 1978 -1981. But for the period 1981-2000 there was a downward trend in real prices. After that, there was an upward trend in the real prices until 2007. These trends in OPEC's prices also go along with the trends in the world oil prices, in Figure 1, which reflect major events like Arab oil embargo, Iranian Revolution, and Iraq-Iran War.

III.1.2. Results

In this section, the linear residual demand model is estimated and Table 3 reports the results. The regression coefficients have the expected signs. The estimate of the price coefficient is negative, indicating that the residual demand slopes downward (price and quantity demanded are inversely related). The coefficient is (- 74.02) and significant. The estimates of the income coefficient for both OECD and non-OECD countries provide a reasonable picture of the income effect on the demand for oil. Both coefficients have a positive sign, although the coefficient for non-OECD countries is not significant, but it is highly significant for OECD countries. The estimate of the population coefficient for OECD countries is consistent with the economic theory and intuition (positive and highly significant). The increase in population over the years in OECD countries has generated higher rates of oil consumption. The estimate of the lagged demand coefficient is positive and highly significant. This indicates that the current demand is positively related to the last year's demand and perhaps reflecting peoples' habits over time. With habit formation, current quantity depends not only on covariates like price, income, and population, but also on a "habit stock" formed by a lagged quantity (see, for example, Pollak (1970), and Abel (1990)). For a given level of current quantity, a habit formation causes consumers to adjust slowly to shocks in prices, income or population.

Table 3

From table 3, the estimated residual demand function is:

$$q_t = -74.02\ P_t + 0.002\ Y_t^O + 0.0000048\ Y_t^N + 0.029\ N_t^O - 0.016\ N_t^N + 0.83\ q_{t-1} \quad (4)$$

The inverse demand function becomes:

$$P_t = -0.014\ q_t + 0.000027\ Y_t^O + 0.000000065\ Y_t^N + 0.00039\ N_t^O - 0.00022\ N_t^N + 0.0112\ q_{t-1} \quad (5)$$

III.2. the Cost Function

The objective of this section is to estimate the cost function for OPEC's oil development and production. During the 1970s, the neoclassical cost function gained renewed popularity as a tool for estimating the structure of production. This surge of popularity is attributed to the wide - spread application of duality theory to economic analysis and the concomitant development of flexible functional forms.

III.2.1. the Model of the Cost Function

The cost function is one of the most useful concepts in economics. It is used conceptually in a variety of settings and is convenient in measuring many important economic concepts like efficiency; technical change; input substitution; economies of scale and more. Since the development of the translogarithmic function by Christensen, Jorgenson and Lau (1973), it has been used in production functions, cost functions and profit functions. The translog function has become an integral tool for analyzing the structure of many firms and industries in terms of production, cost and profits.

Consider the following cost function that attributes cost variation to a quantity effect and a time index that reflects the technology changes over time:

$$C_t = f\ (q_t\ ,\ t) \qquad (6)$$

where (C_t) is the total cost, (q_t) is the output level, and (t) is a time index employed to measure technical change. Both the cost function and the production function in (5) are assumed to satisfy standard regularity conditions. Estimating Hotelling rents requires estimates of marginal costs. But as Adelman and Shahi (1989) noted, reliable, well-documented cost data are difficult to obtain for oil-exporting countries, and OPEC is no exception. For the sake of simplicity and for ease in computation of model solutions with optimal control theory, the estimated cost function is assumed to be quadratic.

$$C_t = \alpha_0 + \alpha_1\, q_t + \alpha_2\, q_t^2 + \alpha_3 t + \varepsilon_t \qquad (7)$$

III.2.2. Data

The econometric model is estimated with annual data on the oil development-operating cost estimates from 1955-85. The estimates used are from Adelman and Shahi (1989). They estimate adjusted development and operating cost ($/barrel) on an annual basis over the period

1955-1985 for 41 oil-producing countries including OPEC member countries, using U.S. drilling costs (in U.S. dollars per barrel) and publicly available data on drilling under particular assumptions. The estimates for each country vary from year to year, substantially in some cases. They attribute these annual variations to reservoir depletion and to innovation in technology. Smith (2005) also points out other sources of variation, like random fluctuations in drilling results, factor prices, and classification errors that affect the cost estimation process directly or indirectly. The cost estimates of Adelman and Shahi are then used to calculate the cost function for OPEC according to the production weights of its members. The major data problem was missing information. This issue was handled by estimating for every country the cost over the years 1955-1985 and then predicting the missing data[7]. OPEC oil production levels are reported in its Annual Statistical Bulletin for different years (1999-2007). Table 4 reports the mean, standard deviation, maximum and minimum values of the variables used in this study.

Table 4

III.2.3. Results

Table 5 reports the estimation results for the cost function model. The estimated coefficients have the expected signs and are consistent with the literature. MC is positive ($\partial C/\partial q > 0$), and increasing ($\partial^2 C/\partial q^2 > 0$). The results show that the oil development-operating cost increases as production (extraction) increases. This could be attributed to the fact that extraction reduces the oil reserves and exploration may not keep pace with the reduction in reserves. This is also noted from the coefficient on the time index, which is positive and significantly different from zero. The positive time trend may also reflect the impact of reserve depletion.

Table 5

Table 5 also reports the Durbin-Watson d-statistic (2.135), which shows no evidence of autocorrelation in the residuals, since the (d_L) = 1.143 and (d_U) = 1.652 for the 26 observations with the three explanatory variables. The estimates now can be used to write the cost function for OPEC as follows:

$$C_t = 11929.32 - 1.22\, q_t + 0.00003\, q_t^2 + 578.74\, t \quad (8)$$

[7] Others who have used this approach include Kim and Curry (1977), and Little (1992).

The residual demand curve, that OPEC faces in the market, and the cost function of oil production, that OPEC follows, have been estimated for the available data. The next chapter will use optimal control theory to represent the process that OPEC follows to decide on oil extraction levels that maximize its objective function.

IV. Optimal Control Model

Hotelling (1931) pioneered the theory of exhaustible resources. He demonstrated that, with competitive markets and constant marginal extraction costs, the price of the resource minus marginal cost should rise at the rate of discount. The work of Hotelling was extended to apply to the cartel model (Salant, 1976; Pindyck, 1979; Porter, 1983; Green and Porter, 1984). In this part we discuss the mathematical model used to explore how OPEC members choose oil extraction levels to attain their goals. We also solve for the optimal time path of extracted quantities of oil, using the residual demand that OPEC faces and a previously derived OPEC cost function. This part also reports the simulation results of the model solution.

IV.1. Mathematical Model of OPEC

There is a rich literature on the process of oil price determination, but the question of whether OPEC is a cartel or not remains hotly debated. Economists have devoted much attention to this issue, since it reflects different arguments regarding OPEC's role in determining oil prices. Some economists have assumed OPEC as a monopolist and others use models that regard OPEC as a dominant firm.[8] As mentioned before, OPEC is assumed to act as a dominant firm, and non-OPEC countries are regarded as fringe firms. The main concern here is to explore the objective function for OPEC, and how OPEC determines the time path of production. This section of the chapter applies optimal control theory to study the dynamics of oil prices and therefore the time path of quantities extracted. OPEC includes Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela. Following the approach suggested by Wirl (2008), these countries can be divided into allies and adversaries, in terms of their relations with the West. Countries like Indonesia, Kuwait, Nigeria, Qatar, Saudi Arabia, and United Arab Emirates are seen as allies to the European countries and the U.S. Countries like Iran, Algeria and Venezuela are considered to be anti-West (until 2003, Iraq and Libya considered to be in this group).

[8] A good review of this literature can be found in Alhajji & Huettner (2000).

Following Wirl (2008), the hypothesis in this research is that OPEC countries do not pursue strict profit maximization. Indeed, they also seek political support among their people. These countries realize that the Wes depends on OPEC's oil; this gives them some power of influence. The people of these countries frequently express anti-Western sentiments.[9] For this reason, OPEC countries in need of popular domestic support may take production decisions to gain such support. The statements and interviews that we read and watch for Ahmadi Nejad of Iran and Chavez of Venezuela are good examples of these policies. Even countries considered to be allies must still secure the support of their people, some of whom also have anti-Western sentiments. Such countries (allies) may adopt a moderate anti-Western policy.

With the political consideration in mind, OPEC countries will be assumed to maximize the net present value of benefits, where benefits are derived from oil profits as well as political support, based on the degree to which the west is harmed. OPEC countries maximize the net present value of benefits. Benefits have two parts: current profits from oil, π_t , and political support among citizens of the country, S_t. Political support is a function of the adverse effect on the West of higher oil prices, so S_t is the harm function.[10] This harm function depends on the quantity of oil extracted and supplied to the market, and on an indicator, α_t , that measures the desire of OPEC to harm the West.

The harm function can be written as: $S_t = f\,(q_t;\, \alpha_t)$ (9)

where political support increases when output is reduced ($\partial S_t/\partial q_t < 0$), and when the desire to harm is strong ($\partial S_t/\partial \alpha_t > 0$). This harm function applies even for those countries who consider themselves U.S. allies in the region such as the Saudi's or the Kuwaiti's, since decision makers in OPEC do care about their peoples' support. It should be noted that the harm function in this research differs from Wirl's work, where his harm function is based on the deviation of the current demand from the long run demand. Furthermore, Wirl's model is an infinite time horizon model that does not assume a finite stock of nonrenewable resource. Also this work solves and uses simulation methods to test the model, which Wirl does not.

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[9] They disagree primarily with the American and European policy toward the Arab-Israeli conflict.

[10] Citizens of the Middle East and some Latin Americans believe that the US policy is targeting them, and that it ignores the good aspects of their countries. This is why most of them consider themselves to be "Anti West".

The above harm function is incorporated in the model, which is then calibrated to determine the value of $\alpha_{t,}$. This is done by solving the optimization problem, simulating extraction quantities based on different values of $\alpha_{t,}$, and then comparing the simulated quantities to the actual extracted quantities to find the value of $\alpha_{t,}$ that best aligns the two time paths. Based on these theoretical notions, the objective function for OPEC can be written as:

$$\text{Max} \ {}_0\int^T e^{-rt} \{P_t (q_t)\, q_t - C_t (q_t) + f (q_t; \alpha_t)\}.dt \tag{10}$$

subject to:

$$\dot{X} = \partial x / \partial t = -q_t \tag{11}$$

$$X_0 = \underline{X} \tag{12}$$

$$\text{T is free} \tag{13}$$

where; (11) is the equation of motion, (12) is the initial stock of oil, and (13) states that the terminal time T will be determined endogenously. To solve this model, the Hamiltonian function becomes:

$$H_t = e^{-rt} (P_t (q_t)\, q_t - C_t (q_t) + f (q_t; \alpha_t)) - \lambda_t q_t \tag{14}$$

This Hamiltonian can be solved and the resulting optimization conditions can be interpreted. Also, because the residual demand function that OPEC faces is derived as well and the cost function of OPEC is specified, one can numerically solve the model.

IV.2. The Mathematical Harm Function

The general form of the harm function is: $S_t = f\ (q_t;\ \alpha_t)$. OPEC is able to harm the western countries and the U.S. by cutting production and raising the price. Recall that OPEC has direct control over quantity not price, as the latter is determined in the market.

Pure profit maximization would normally require OPEC to set an output level where MR> 0 (assuming MC > 0). If the residual demand is linear, a further cut in output to raise the market price and harm the West would reduce profits. But this may occur if OPEC countries derive greater domestic political support by harming the West. The political support (S_t) will increase as (q_t) is cut or if the desire to harm (α_t) is stronger. This means:

$$\partial S_t / \partial q_t < 0, \tag{15}$$

$$\partial S_t / \partial \alpha_t > 0, \tag{16}$$

Using these notions, a simple form of the harm function with appropriate properties is:

$S_t = \alpha_t / (1 + q_t)$ (17)

Equation (17) implies that the harm decreases when OPEC increases quantities (one in the denominator avoids the case of infinity when quantity is zero). Also the harm increases with a higher desire to harm, α_t. If OPEC has no desire to harm anyone, then α_t = zero and the harm function vanishes, meaning that OPEC just maximizes profits like any other producer in any market with no other considerations in mind.

IV.3. The Solution for the Mathematical Model of OPEC

With the estimated residual demand, estimated cost function and the assumed harm function, now we can proceed to solve the model representing OPEC's behavior.

a) The residual demand is:

$$P_t = -0.014\ q_t + 0.000027\ Y_t^O + 0.000000065\ Y_t^N + 0.00039\ N_t^O - 0.00022\ N_t^N + 0.0112\ q_{t-1} \quad (18)$$

By using the average values, from the data used in the estimation, for the variables: Y_t^O, Y_t^N, N_t^O, N_t^N, q_{t-1}, we can write the residual demand as a relation between P_t and q_t. Therefore, the residual demand becomes:

$$P_t = 389.62 - 0.014\ q_t \quad (19)$$

b) The cost function is:

$$C_t = 11929.32 - 1.22\ q_t + 0.00003\ q_t^2 + 578.74\ t \quad (20)$$

c) The harm function is:

$$S_t = \alpha_t / (1 + q_t) \quad (21)$$

These functions now are used to write the objective function of OPEC.

$$\text{Max: } {}_0\int^T e^{-rt} \{(389.62 - 0.014\ q_t)\ q_t - (11929.32 - 1.22\ q_t + 0.00003\ q_t^2 + 578.74\ t) + \alpha_t / (1+q_t)\}.dt \quad (22)$$

Subject to:

$$\dot{X} = \partial x / \partial t = -q_t \quad (23)$$

$$X_0 = 400{,}686, \text{ as of 1970 (in million barrels)} \quad (24)$$

$$T \text{ is free} \quad (25)$$

This gives the following Hamiltonian:

$$H_t = e^{-rt} \{(389.62 - 0.014\ q_t)\ q_t - (11929.32 - 1.22\ q_t + 0.00003\ q_t^2 + 578.74\ t) + \alpha_t / (1 + q_t)\} - \lambda_t\ q_t \quad (26)$$

The necessary conditions for the solution to this problem are:

$\partial H_t / \partial q_t = 0 \rightarrow e^{-rt}\{(389.62 - 0.028\, q_t) + 1.22 - 0.00006\, q_t - \alpha_t / (1 + q_t)^2\} = \lambda_t$ (27)

$\partial H_t / \partial X_t = - \partial \lambda_t / \partial t = 0$ (28)

where, ${}_0\int^T q_t = 400{,}686$ (29)

Differentiating equation (27) with respect to (t) gives:

$- r\, e^{-rt}\ \{(389.62 - 0.028\, q_t) + 1.22 - 0.00006\, q_t - \alpha_t / (1 + q_t)^2\} + e^{-rt}\ \{(- 0.028\, \partial q_t/\partial t - 0.00006\, \partial q_t/\partial t + 2\ (\alpha_t / (1 + q_t)^3)\ \partial q_t/\partial t - (\partial \alpha_t/\partial t\ / (1 + q_t)^2)\} = 0$

This gives:

$\partial q_t/\partial t = - \{[r\ (390.84 - 0.02806\, q_t - \alpha t / (1 + q_t)^2)] - (\partial \alpha_t/\partial t / (1 + q_t)^2\} / \{0.02806 - (2\alpha_t / (1+q_t)^3)\}$ (30)

Equation (30) shows the time path of quantity. This path shows that as αt increases (more desire to harm) the quantity will decrease.

Also (T) is free, which means that H (T) = 0:

$e^{-rt}\{(389.62 - 0.014\, q_T)\, q_T - (11929.32 - 1.22\, q_T + 0.00003\, q_T^2 + 578.74\, T) + \alpha_T /(1+ q_T)\} = \lambda_T\, q_T$ (31)

Since, $\lambda_T = e^{-rt}\{(389.62 - 0.028\, q_T) + 1.22 - 0.00006\, q_T - \alpha_T / (1 + q_T)^2\}$ (32)

Substituting (32) into (31) and simplifying gives:

$e^{-rt}\{(389.62 - 0.014\, q_T)\, q_T - (11929.32 - 1.22\, q_T + 0.00003\, q_T^2 + 578.74\, T) + \alpha_T /(1+ q_T)\} = e^{-rt}\{(389.62 - 0.028\, q_T) + 1.22 - 0.00006\, q_T - \alpha_T / (1 + q_T)^2\} q_T$ (33)

In time T, α_T should be zero, since in last period OPEC does not consider any more harming the west, instead it will concentrate on just getting the maximum profit at that period. This means equation (33) will become:

$390.84\, q_T - 0.01403\, q_T^2 - 11929.32 - 578.74\, T = 390.84\, q_T - 0.02806\, q_T^2$ (34)

Simplifying equation (34):

$q_T = (\ 850272.27 + 41250.18\ T)^{0.5}$ (35)

Equation (35) indicates that OPEC will end-up with quantities not extracted in the last period (T). This means the harming function is forcing OPEC not to extract all reserves.

To proceed further, we use Microsoft Excel to solve the model numerically over 150 years and perform sensitivity analysis. For the sensitivity analysis, the discount rate is varied between 5%, 10% and 15% while the harm indicator, α_t, goes from zero (no harm) to a very high value. The solution shows that a very high harm indicator value is consistent with OPEC's behavior as compared to no harm policy ($\alpha_t = 0$), in which the net present value does increase.

When α_t is zero or low, the oil extraction stops very early depending on the discount rate used (optimal terminal time varies between 13 – 20 years). But with a very high α_t the time path extends to 140-147 years.[11] When comparing the actual extracted quantities to the simulated ones, the results show that with high harm indicators, α_t, the simulated quantities are closer to the actual ones (e.g. for α_t = 1E+20 the simulated quantities do not exceed the actual extracted quantities when the discount rate r is 10%).

With a high harm indicator values, OPEC also harms itself financially. The extent of this financial sacrifice to inflict damage on the West may be calculated by comparing the net present value of OPEC profits when α_t is high with the net present value of OPEC profits when $\alpha_t = 0$. Tables 6 and 7 report the net present value of losses that OPEC suffers with relatively high values for α_t, using discount rates of 5% and 10%. The losses range from about 10% to 20% for this variation in discount rates. The result suggests that OPEC appears to be accepting considerable monetary set-backs to appease its citizens by harming the West.

Under the assumption that our model is otherwise reliable, these outcomes can provide some evidence that OPEC members do consider harming the western countries as part of their goal when deciding on the extracted levels of oil. This means that OPEC members take into account the support of their people, and this affects their decisions about oil extraction. These results can explain, in part, some of the oil cuts taken by OPEC when world economy is in recession and such cuts could make the recovery harder and even cause financial losses to OPEC.

V. Conclusions

Two oil price shocks changed the pattern of cheap oil. The first was the Arab embargo on oil exports in 1973, in which oil prices rose five fold. In 1978, the second was the fall of Shah Iran.

[11] The results and tables are available upon request from the authors.

Prices soared to $80-$100 a barrel in today's prices. In 1960, OPEC was established and since then it has been a considerable political and economical force in the oil market. Two thirds of the world's oil reserves belong to OPEC members. When we look at the oil prices over the past years, one could argue that OPEC is responsible for most of the price increases due to their production cuts and market power. This paper provides a general framework to examine the role of OPEC in affecting oil prices through the extracted quantities. A mathematical model is developed to explore the objective function of OPEC, which includes economic and political considerations. The idea is that OPEC members consider both the political support of their citizens and profits when determining oil extraction rates. This support is represented by a "harm function" which was added to the objective function of OPEC. The solution of the model lends some support for inclusion of this harm function, through which OPEC benefits from the cuts in production aimed at harming the western countries. For this harm function to be meaningful empirically, OPEC members should have a high harm indicator, α_t . With high harm indicator values, OPEC harms itself financially. The results suggest that OPEC appears to be accepting considerable monetary setbacks to appease its citizens' taste for harming the West. At different discount rates, the monetary losses range from about 10-20%. Solving the mathematical model required estimation of the residual demand that OPEC faces plus the cost function that applies to OPEC production. This paper reports the results of these estimations.

Figure 1:

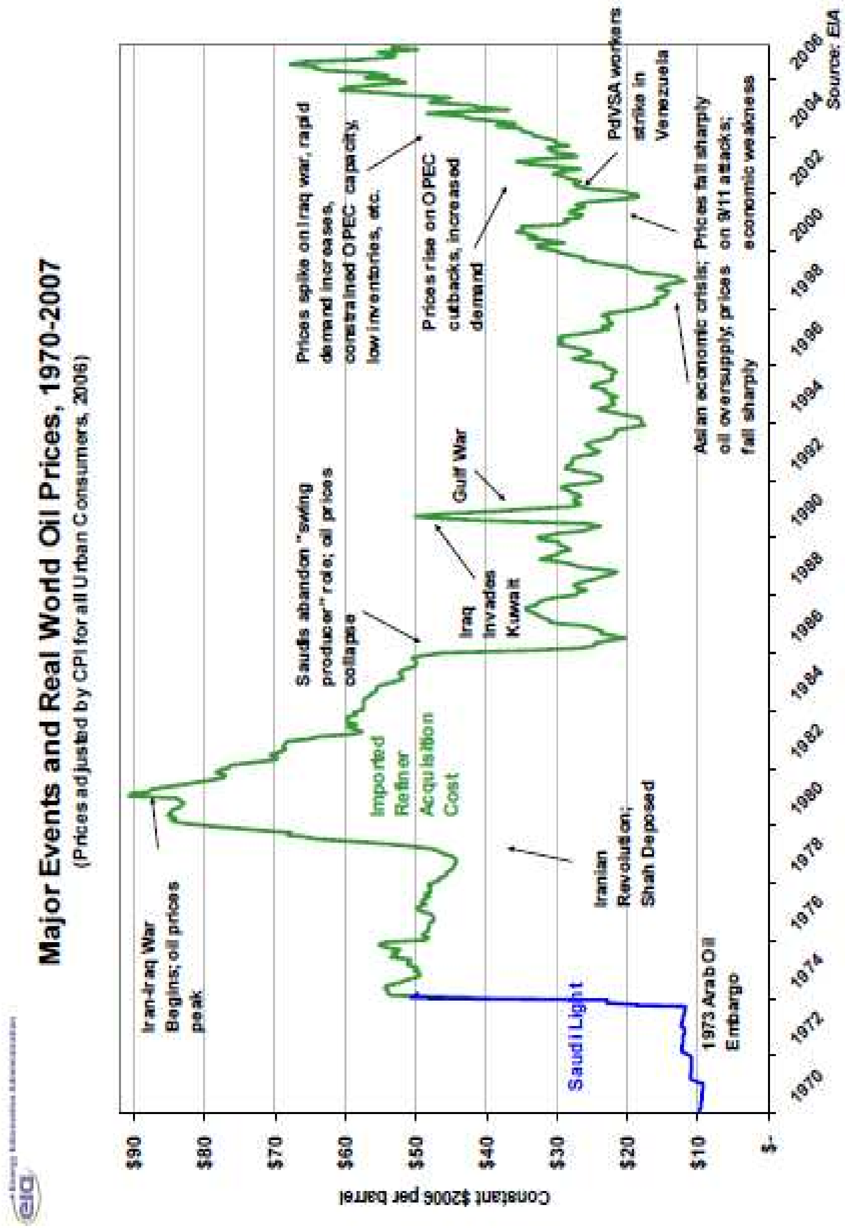
Major Events and Real World Oil Prices, 1970-2007
(Prices adjusted by CPI for all Urban Consumers, 2006)
Constant $2006 per barrel
Iran-Iraq War Begins; oil prices peak
Iranian Revolution; Shah Deposed
1973 Arab Oil Embargo
Saudi Light
Imported Refiner Acquisition Cost
Saudis abandon "swing producer" role; oil prices collapse
Iraq invades Kuwait
Gulf War
Asian economic crisis; oil oversupply; prices fall sharply
Prices rise on OPEC cutbacks, increased demand
Prices fall sharply on 9/11 attacks; economic weakness
PdVSA workers strike in Venezuela
Prices spike on Iraq war, rapid demand increases, constrained OPEC capacity, low inventories, etc.
Source: EIA

TABLE 1: OPEC Crude Oil Exports by Region, 1960-2007
(Thousand Barrels per Day)

Year	Total World	OECD	OECD %
1960	6731.6	4848.5	72.03%
1961	7392.8	5492.6	74.30%
1962	8338.5	6222.7	74.63%
1963	9239.9	6793.7	73.53%
1964	10603.2	7855.9	74.09%
1965	11744.9	8931.7	76.05%
1966	13477.4	9893.6	73.41%
1967	14172.7	10636.1	75.05%
1968	16001.3	12408.3	77.55%
1969	18025	13792.6	76.52%
1970	20225.3	15861.9	78.43%
1971	22031.1	17166.6	77.92%
1972	24042.6	18936.5	78.76%
1973	27381.2	21109.4	77.09%
1974	27063.5	20610	76.15%
1975	23854.5	17631.4	73.91%
1976	27237.8	19914.9	73.11%
1977	27446.9	20061.4	73.09%
1978	25903.9	19735.8	76.19%
1979	26597.5	19771.5	74.34%
1980	23050.9	17099	74.18%
1981	18777.2	13490	71.84%
1982	14514.6	10195.7	70.24%
1983	12739.4	8996.6	70.62%
1984	12213.5	8932.8	73.14%

Continue on next page

TABLE 1(continued): OPEC Crude Oil Exports by Region, 1960-2007
(Thousand Barrels per Day)

Year	Total World	OECD	OECD %
1985	11126.2	8281.2	74.43%
1986	13132.3	9868.6	75.15%
1987	12200.9	9388.3	76.95%
1988	13477.8	10071.1	74.72%
1989	15364.3	11581.9	75.38%
1990	16536.1	12474.4	75.44%
1991	17434.3	12844.7	73.67%
1992	18136.8	12558.9	69.25%
1993	18594.2	13060.8	70.24%
1994	18769	13099.1	69.79%
1995	18939.6	12866.2	67.93%
1996	19237.2	12823.7	66.66%
1997	20191.9	13786	68.27%
1998	21559.6	14789.7	68.60%
1999	20380.9	13447.2	65.98%
2000	21527.1	14000.3	65.04%
2001	20490.5	12877.9	62.85%
2002	18845.1	12677.8	67.27%
2003	20228.4	12510.5	61.85%
2004	22903.9	14765.5	64.47%
2005	23690.3	16620.3	70.16%
2006	23866.8	16769.6	70.26%
2007	24352.2	16363.2	67.19%

* Source: OPEC Statistical Annual Books (1999-2007)

TABLE 2:

Descriptive Statistics of the Residual Demand Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
q_t	38	20106.98	4708.57	11126.2	27446.9
q_t^O	38	14395.8	3607.99	8281.2	21109.4
q_t^N	38	5711.18	1544.14	2812.6	8138.4
P_t	38	34.56	17.03	8.41	69.85
Y_t^O	38	2.48e+07	5975574	1.52e+07	3.65e+07
Y_t^N	38	3453974	3191413	433788.4	9745614
N_t^O	38	1033839	91772.45	874335	1180281
N_t^N	38	3706881	690260.4	2570466	4824109
q_{t-1}	38	19940.48	4666.07	11126.2	27446.9
t	38	19.5	11.11	1	38
R_t	38	665746.5	192102.3	400686	939016

For the table:
q_t: OPEC's exports of crude oil (1000b/day)
q_t^O: OECD's imports of crude oil (1000b/day)
q_t^N: Non-OECD's imports of crude oil (1000b/day)
P_t: Real spot OPEC reference basket prices (base=2005)
Y_t^O: OECD's real GDP (in millions, base=2005)
Y_t^N: Non-OECD's real GDP (in millions, base=2005)
N_t^O: OECD's population (in thousands)
N_t^N: Non-OECD's population (in thousands)
q_{t-1}: lagged OPEC's exports of crude oil (1000b/day)
t: Time index used to detrend the data

Figure 2: The Time Path of OPEC's Exports, OECD's Imports, and Non-OECD's Imports

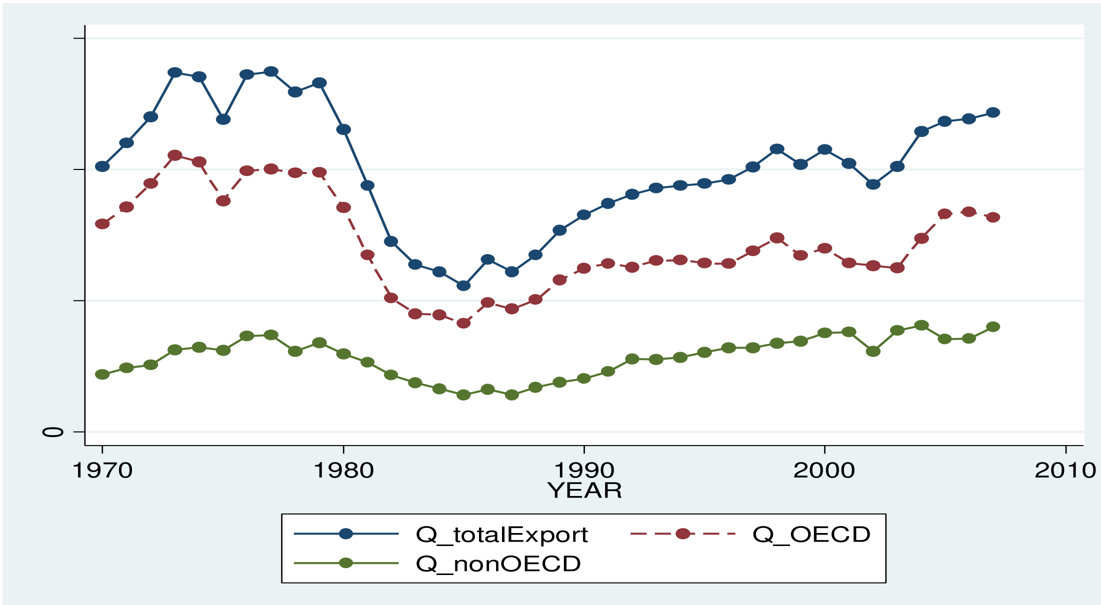

Figure 3: The Time Path of OPEC's Real Spot Price

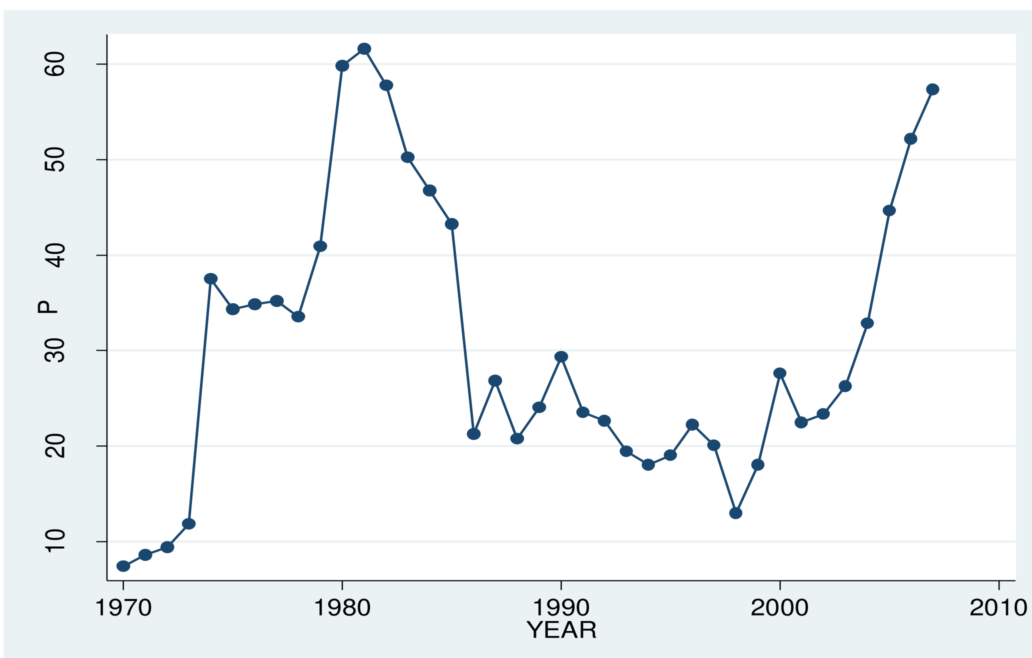

TABLE 3: The Estimation Results of the Residual Demand Using Instrumental variables (2SLS) regression

Variable	coefficient	Robust Std. Err.	t - values
P_t	- 74.02***	8.527	- 8.68
Y_t^O	0.002***	0.0004	4.69
Y_t^N	0.0000048	0.0004	0.01
N_t^O	0.029***	0.0065	4.48
N_t^N	- 0.0162***	0.002	- 7.97
q_{t-1}	0.83***	0.05	16.56
Constant	Dropped		
Number of Observations	38		
Adj. R- squared	0.932		

-The dependent variable is OPEC's exports of crude oil (1000b/day). The table reports the coefficients of the 2 SLS regression of OPEC's exports of crude oil (1000b/day) on real spot OPEC reference basket prices (base=2005), OECD's real GDP (in millions, base=2005), non-OECD's real GDP (in millions, base=2005), OECD's population (in thousands), non-OECD's population (in thousands), lagged OPEC's exports of crude oil (1000b/day) with a constant.
-Robust standard errors and t-values are reported in the table.
*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.

TABLE 4: Descriptive Statistics of the Cost Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
C_t	26	10530.36	5198.079	3265.167	20482.72
q_t	26	20916.55	7535.012	8682.601	31209.1
q_t^2	26	4.92e+08	3.17e+08	7.54e+07	9.74e+08
t	26	13.5	7.648529	1	26

C_t: OPEC's cost of oil production
q_t: OPEC's crude oil production (1000b/day)
t: time index

TABLE 5: The Estimation Results of OPEC's Cost Function

Variable	coefficient	Robust Std. Err.	t - values
q_t	- 1.22***	0.429	- 2.84
q_t^2	0.00003***	0.00001	3.11
t	578.74***	55.926	10.35
Constant	11929.32***	3952.509	3.02
R- squared	0.83		
Number of Observations	26		
Durbin-Watson d-statistic	2.135		

-The dependent variable is OPEC's crude oil total cost. The table reports the coefficients of the regression of OPEC's crude oil total cost on OPEC's output level, square value of OPEC's output level, a time index employed to measure technical change, with a constant.
-Robust standard errors and t-values are reported in the table.
*** Significant at the 1% level.

TABLE 6: Monetary Losses when r = 5%

Harm Indicator(α)	NPV(including Harm Function)	NPV(Harm Function)	NPV(excluding Harm Function)	Monetary loss
α =1e+16	5.44302e+14	3.77038e+12	5.40531e+14	1.23005e+14
α =1e+18	9.18641e+14	3.77099e+14	5.41541e+14	1.21995e+14
α =1e+19	4.35278e+15	3.78891e+15	5.63872e+14	9.96639e+13

NPV (**α = 0**) = 6.63536E+14
Monetary loss = NPV (**α = 0**) - NPV (excluding Harm function)

TABLE 7: Monetary Losses when r = 10%

Harm indicator(α)	NPV(including Harm Function)	NPV(Harm Function)	NPV(excluding Harm Function)	Monetary loss
α =1e+16	4.71288e+14	5.14e+10	4.71236e+14	4.81588e+13
α =1e+18	4.77006e+14	5.16361e+12	4.71842e+14	4.75531e+13
α =1e+19	5.41647e+14	5.92447e+13	4.82403e+14	3.69924e+13

NPV (**α = 0**) = 5.19395E+14
Monetary loss = NPV (**α = 0**) - NPV (excluding Harm function)

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