OPEC and World Crude Oil Markets from 1973 to 1994: Cartel, Oligopoly, or Competitive?

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This study investigates the existence of a dominant producer in the world crude oil market for the period 1973 to 1994. Contrary to the literature, the results show that neither OPEC nor the OPEC core can be characterized as a dominant producer. Using statistical tests, we also investigate whether OPEC, the OPEC core, or Saudi Arabia fit the competitive model or the Cournot model. The statistical results reject all models except the dominant firm model for Saudi Arabia. New user cost estimates are introduced and included in the models. An alternative explanation of high OPEC profits in the 1973-82 period is also developed as part of a statistical test of the effect of the US oil price regulation on world oil demand and supply. An estimate of the wealth transfer from price regulation is also calculated.

I. INTRODUCTION

Many models were introduced in the past 25 years to explain OPEC behavior. While most of these studies deal with OPEC as a profit-maximizing cartel that seeks monopoly profits by influencing prices and production, others argue that the world crude oil market is competitive and that oil price increases can be explained by factors other than cartelization. Some statistical studies were introduced to examine these models but these studies have been confined exclusively to the single-equation path broken by Griffin (1985) and followed by

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Before turning to the statistical tests, Section II summarizes the cartel and non-cartel models in the literature. Section III shows the development of the basic models to be tested. Section IV summarizes the data used, and Section V demonstrates the statistical tests results. Section VI evaluates the effect of US oil price regulation as an alternative explanation for OPEC profit. Section VII summarizes the conclusions.

It is important to remind the reader that a dominant producer could be a single producer or group of producers forming a cartel. A cartel requires collusion among members and dominance in the market. Therefore, in order for OPEC to be a profit-maximizing cartel, researchers have to prove its dominance in the market in addition to collusion among members.

II. LITERATURE REVIEW

An overview of the many oil market models developed over the past twenty years shows that these models divide easily into cartel and non-cartel models.² Turning first to non-cartel models, these include the target revenue model of Teece (1982), the property rights model of Johany (1979),³ and the competitive model of McAvoy (1982) and Verleger (1987) all of which were tested and rejected by Griffin (1985), Jones (1990), and Dahl and Yücel (1991). Variants of these models were tested again and rejected by Alhajji (1995). Variants of the target revenue model were tested by Alhajji and Huettner (2000b) and they concluded that only centrally planned and isolated economies follow this model. Political models were introduced by Moran (1980 and 1982) but none have been statistically tested.

Turning to the cartel model literature, one finds numerous models used mainly to predict the direction of future oil prices. In general, OPEC has been described as a monopoly, an oligopoly, and a cartel. The only model statistically tested is the single-equation OPEC cartel model accepted by Griffin (1985) and Jones (1990) and partially accepted by Dahl and Yücel (1991). Since one variant

¹. Rauscher (1989) introduced a dominant firm, multi-equation, simulation model. No statistical tests were performed.
². For a detailed literature review see Cremer and Isfahani (1991), Isfahani (1995), and Mabro (1996).
³. These two models will not be tested in this study. However, these models have been tested and rejected by Griffin (1985).
of all the cartel models is the dominant firm model, the lack of any statistical testing of the dominant firm/competitive fringe model is surprising.

The dominant firm model is widely used in economic literature to explain OPEC behavior. The dominant firm has control over world oil prices but not its competitors’ output. There are many versions of this model: OPEC as the dominant firm in the world oil market, Saudi Arabia as a dominant firm in the world oil market, and the OPEC core countries as a dominant firm in the world oil market. The latter model includes two versions: two-part cartel (saver/spender) introduced by Pindyck and Hnyilicza (1976), Tourk (1977) and Aperjis (1982), and three-part cartel (the core/price maximizers/quantity maximizers) introduced first by Eckbo (1976) and later by Houthakker (1979) and Noreng (1978). Griffin and Steele (1986) use a similar model but assume monopoly behavior on the part of the OPEC core countries. These single-equation models were statistically tested and rejected by Alhajji (1995).

The dominant firm model considers OPEC a cartel and assumes that OPEC members have unified goals and collectively set the price of oil. Non-OPEC oil producers are the competitive fringe which includes Mexico, the North Sea area, United States, China, Russia, India, Argentina, and Egypt. The demand for OPEC’s oil is “residual” demand. OPEC sets the price where the marginal revenue equals marginal cost and the competitive fringe will supply up to where P = MC; afterwards, OPEC will supply the rest. Although similar simple dominant firm models were introduced in many studies, none were tested statistically and predictions differ from one to another.

The competitive model has been introduced by many economists in different single-equation versions. Some of these versions assume that, since the market is competitive, there is no need to model OPEC behavior. Verleger (1987) argues that the oil crisis occurred because of problems on the demand side. Others such as McAvoys (1982) explain world oil price behavior by a competitive model. Even Adelman (1982b), the proponent of the cartel model, argues that the excess demand in 1979 caused the crises at that time.

Overall, the above studies indicate that a plethora of models were developed, that few models were tested statistically, and that fundamental disagreement exists among economists about the structure of the world crude oil market. The above literature review indicates a clear need to develop and test


5. This model was introduced by Pindyck (1976), Cremer and Wietzman (1976), Eckbo (1976), Ben-Shaher (1976), Blitzer (1975), Salant (1976), Tourk (1977), Adelman (1978), Ezzati (1976) & (1978) and Aperjis (1982).

6. Many simulation models were introduced to predict prices. See Gately (1984), for example.
several variants of the dominant firm-competitive fringe model. Nearly all of the statistical studies followed the path breaking study of Griffin (1985) in its single-equation approach and results. A review of these studies indicates six potential weaknesses that justified retesting their results: use of single equation models; use of the official price figures; exclusion of production costs from all models; exclusion of demand from the model; limited sample sizes for some tests due to the use of quarterly data for OPEC and annual data for non-OPEC members; and use of results not corrected for autocorrelation.7

Based on this literature review, three other facts are clear: considerable non-OPEC production has existed since 1973 until the present; OPEC has attempted to set production quotas only since 1983 and has never agreed on price; and OPEC has no mechanism for punishing cartel members for deviation from any OPEC agreement. These three facts indicate that no model of OPEC as a cartel or monopoly is plausible and suggest that empirical evidence is likely to support this conjecture.8

III. BASIC MODELS

In this section, three models are developed: the dominant firm model, the Cournot model and the competitive model. Although our multi-equation models (static and dynamic) have certain limitations, they are a major improvement over those in the literature. In fact, most of the econometric models developed in the literature are single equation static models. The few dynamic models introduced in the literature suffer from severe multicollinearity and other methodological problems. A multi-equation model will demonstrate the behavior of demand and supply while a single-equation model cannot. The flawed nature of the single-equation models used in the literature is demonstrated by the fact that when they are applied to non-OPEC data they actually show that Non-OPEC producers fit the cartel hypotheses better than OPEC producers do (Dahl and Yücel, 1991; and Alhajji, 1995). This result indicates that the single-equation models are not appropriate for modeling OPEC behavior and, at best, test for parallel behavior.

Since most of the models currently in the literature are static, and dynamic models do not produce efficient, unbiased estimates, our initial modeling will follow the bulk of the literature by introducing static models. However, our static models could be classified as dynamic models by allowing for price expectations if one assumes that the expected future price equals today's price. Further research is encouraged to formulate better dynamic

7. Detailed criticism of the statistical tests are available from the author upon request.
8. For more information see Alhajji and Huetmner (2000a), "OPEC and other Commodity Cartels: A Comparison."
models. Since the initial static models suffered from severe first order autocorrelation, we implemented two solutions. The first was to correct the static model using generalized least squares. The second solution was to introduce dynamic models. The autocorrelation is eliminated in both static and dynamic models but multicollinearity and bias toward the lagged variable remain a problem in some dynamic models.9

a - Definition of Variables:

\[
\begin{align*}
D_w &= \text{world demand for crude oil, thousands of barrels a day (b/d),} \\
P &= \text{real price of crude oil ($),} \\
G &= \text{OECD's GDP ($),} \\
d &= \text{dummy variable. It equals 1 for the period of US oil price regulation, 0 otherwise} \\
\varepsilon &= \text{Error term,} \\
S_{no} &= \text{non-OPEC supply (thousands b/d),} \\
D_o &= \text{residual demand for OPEC (thousands b/d),} \\
S_o &= \text{OPEC supply (thousands b/d),} \\
U_{no} &= \text{per barrel user cost for non-OPEC ($),} \\
U_o &= \text{per barrel user cost and increased security cost for OPEC ($),} \\
M_o &= \text{OPEC's market share in the international oil market (%),} \\
M_{no} &= \text{Non-OPEC's market share in the international oil market (%),} \\
\beta_s &= \text{price elasticity of world demand,} \\
\delta_s &= \text{price elasticity of non-OPEC supply,} \\
\alpha_s &= \text{price elasticity of OPEC supply,} \\
E_o &= \text{price elasticity of demand for OPEC's oil,} \\
P^* &= \text{long term expected price.}
\end{align*}
\]

b - Static Models

The Dominant Firm Model:

We test three variants of the dominant firm model:

a. OPEC as the dominant firm in the world oil market.

b. Saudi Arabia as the dominant firm in the world oil market.

c. The OPEC core countries as the dominant firm in the world oil market.10

9. We made many attempts to correct for multicollinearity by differencing and use of instrumental variables; none of these attempts was successful so we decided to leave the models unchanged.

10. The core countries include Saudi Arabia, Kuwait, UAE, and Qatar.
The demand for the dominant firm is the residual demand, the difference between the total demand in the market and the supply of the competitive fringe. In the case of the world oil market, the dominant firm is OPEC, Saudi Arabia, or the OPEC core countries. For the purpose of simplicity, we are going to use OPEC as an example. The demand for OPEC oil ($D_o$) is the difference between the world demand ($D_w$) and the oil supplies by non-OPEC producers ($S_{no}$). The world demand is a function of the price of oil ($P$), GDP ($G$), and a US oil price control dummy variable ($d$):\(^{11}\)

$$D_w = D(P, G, d)$$  \hspace{1cm} (1)

Non-OPEC supply is a function of price ($P$), user cost ($U_{no}$) and the exogenous US oil price control dummy variable ($d$)

$$S_{no} = S(P, U_{no}, d)$$  \hspace{1cm} (2)

Then the residual demand for OPEC oil is

$$D_o = D_w(P, G, d) - S_{no}(P, U_{no}, d)$$  \hspace{1cm} (3)

According to this model, OPEC will set the price, non-OPEC members will produce up to $P = MC$ at that price and OPEC will supply the rest. OPEC will maximize its profit by setting the price where the marginal revenue equals marginal cost.

Following the bulk of the literature,\(^ {12}\) equations (1) and (2) can be rewritten in logarithmic terms:\(^ {13}\)

$$\ln D_w = \beta_0 - \beta_1 \ln P + \beta_2 \ln G + \beta_3 d + \epsilon_w$$  \hspace{1cm} (5)

$$\ln S_{no} = \delta_0 + \delta_1 \ln P - \delta_2 \ln U_{no} - \delta_3 d + \epsilon_{no}$$ \hspace{1cm} (5)

$$D_o = D_w - S_{no} \quad \text{Equilibrium Condition}$$  \hspace{1cm} (6)

\(^{11}\) Dummy variable = 1 for the 1973-1981 period of US oil price control, = 0 otherwise.

\(^{12}\) See for example, Griffin (1985), Jones (1990), Dahl and Yücel (1992), and Alhajji (1995).

\(^{13}\) Some of the IO literature uses price on the left side of these equations in an inverse demand relationship. See, for example, Bresnahan (1992) and Porter (1983).
The specification of the model in equations (4), (5), and (6) assumes that the US oil price regulation dummy variable is an exogenous variable. The Hausman specification test was used to confirm that this dummy variable is exogenous in both supply and demand in all of the models tested. Note that the effect of US oil price regulation has never been statistically tested in the literature. A positive coefficient is expected for this dummy variable in the demand equation (4). A negative coefficient is expected in any supply equation that includes US producers (Eq 5).

The dummy variable form used assumes that the impact of US oil price regulation was relatively uniform over the 1973-1980 period of price regulation. Figure 1 shows the refiner’s acquisition cost of US domestic and imported oil from 1968 to 1995. The gap between these two prices is relatively stable during the period of US price regulation (1973 to 1981). Indeed the gap is caused by US price regulation and disappears rapidly once regulation is removed in January 1981. The uniform dummy variable used in this study is consistent with the empirical evidence of Figure 1. In fact a simple regression of the refiners’ acquisition cost difference between imported and domestic oil in Figure 1 on the dummy variable of this model yields a t-ratio for the dummy variable of 7.59 and an R² for the regression of 69%. The regulatory dummy variable of this model is highly correlated with the 1968 to 1994 price difference of Figure 1.

The profit maximization condition for the OPEC dominant firm variant of the model is:

\[
P = \frac{U_o \beta_1}{M_o + \beta_1}
\]

(7)

Rearranging and setting \( M_o = 1 \), \( \beta_1 = E_o \), the profit maximization condition becomes the usual monopoly condition of:

\[
P = \left[ \frac{U_o}{1 + \frac{1}{E_o}} \right] \quad \text{Where } E_o < -1
\]

(8)

Since substantial non-OPEC production exists, the elasticity of demand for OPEC’s oil \( E_o \) is

14. Griffin and Steele (1986) predict a positive impact on US demand and a negative impact on US oil production and even note (page 285) that US price controls could be renamed the “OPEC Assistance Act.” All other published studies predict similar signs for the coefficients. These studies include Gordon (1990), Pindyck and Rubinfeld (1995), and Tietenberg (1992). Basically, US demand would increase because all US barrels consumed are subsidized including the marginal barrel.

15. The difference between the two prices could be used instead of the dummy variable. Further research is needed to investigate the superiority of this approach.

16. Derivation of the profit maximization condition is available from the authors upon request.
A negative price coefficient is expected for the demand model of equation (4). The GDP coefficient for all of these demand equations is also expected to have a positive coefficient. Many studies have documented a positive relationship between demand for energy and GDP including Griffin and Steele (1986), Gordon (1990), Hamilton (1985) and Hwang and Gum (1990).

User cost \((U)\) is best measured by the price of replacing the oil stock, but data are not available. An attempt was made by Pakravan (1984) to estimate the user cost for oil. He concluded that the user cost is very small relative to the price of oil. This conclusion is questionable since his study covers the 1960s and early 1970s when OPEC countries did not control the oil reserves.\(^{17}\) The user cost could be much higher if Pakravan used the finding and production cost instead of production cost alone. Adelman and Shahi (1989) measured the development cost and suggested many methods to estimate the user cost and contend that “the price [of oil] has no relation to scarcity, present or future. Long-term marginal cost, even with an excessive allowance for resource rent or user cost, remains a small fraction of the price.” Appendix A explains the

\(^{17}\) His estimates suffer from other problems, such as applying US drilling data to the Middle East.
method of estimating user cost used in this study. The dominant firm models are estimated using a user cost, which includes the increased security cost for OPEC countries.

Since the cost of extraction and the user cost will increase over time while the resource is being depleted, a negative user cost coefficient is expected in equation (5). In other words, higher costs would reduce supply. This negative coefficient is predicted in all studies including: Hotelling (1931), Adelman (1993), Cave and Salant (1995), Dahl and Yücel (1992), and Gilbert (1978).

The dominant firm model should not be rejected if the coefficients in equations (4) and (5) are statistically significant, have the signs shown, and the profit maximization condition of equation (7) is met. The profit maximization condition requires that the elasticity of demand for the dominant producer to be less than −1, and within the boundaries of equation (7). The profit maximizing condition is not met if the dominant producer (OPEC in our example) operates on the inelastic segment of its demand curve (-1 < \( E_o \) < 0). A profit maximizing dominant producer operates on the elastic part of its demand curve (\( E_o < -1 \)).

The Competitive Model

The production of OPEC (\( S_o \)) is a function of price (\( P \)), user cost (\( U_o \)), and the exogenous US oil price control dummy variable (\( d \)):\(^{18}\)

\[
S_o = S(P, U_o, d) \tag{10}
\]

The competitive models of this study are also estimated using a user cost, which includes the increased security cost for OPEC countries.\(^{19}\) We expect the usual positive relationship between production and price for the supply curves in the competitive model. Also, we expect a negative relationship between user cost and production. The model to be estimated for the OPEC and non-OPEC supplier variant of this model is:

\[
\ln D_w = \beta_0 - \beta_1 \ln P + \beta_2 \ln G + \beta_3 d + \varepsilon_w \tag{11}
\]

\[
\ln S_{no} = \delta_0 - \delta_1 \ln P + \delta_2 \ln U_{no} - \delta_3 d + \varepsilon_{no} \tag{12}
\]

\(^{18}\) Dummy variable = 1 for the period of US oil price control and = 0 otherwise.

\(^{19}\) Griffin (1985) and Jones (1990) estimated the model with price only.
\[
\ln S_o = \alpha_0 + \alpha_1 \ln P - \alpha_2 \ln U_o + \alpha_3 d + \varepsilon_o \quad (13)
\]

\[
D_w = S_{no} + S_o \quad \text{Equilibrium Condition} \quad (14)
\]

The competitive model should not be rejected if the coefficients in equations (11), (12) and (13) are statistically significant and have the signs shown in these equations.

The Cournot Model

OPEC will determine the output, which maximizes its profit, based on rival non-OPEC output in the previous period. In the same manner, non-OPEC producers will determine the output which maximizes their profit. Both groups determine their output simultaneously and both are faced with the same elasticity of world demand. In this model we have two equations: the demand equation and the profit maximization condition. World demand is

\[
\ln D_w = \beta_1 - \beta_2 \ln P + \beta_3 \ln G + \beta_4 d + \varepsilon_w \quad (15)
\]

Cost and market shares play a crucial role in the Cournot model since the profit maximization condition for the OPEC and non-OPEC variant of the model is\(^{20}\)

\[
\beta_2 = \frac{U_{no}M_o - U_o M_{no}}{U_o - U_{no}} \quad (16)
\]

The Cournot model should not be rejected if the coefficients in equation (15) are statistically significant, have the signs shown in the equation, and the profit maximization condition of equation (16) is met. The profit maximization condition is tested by calculating an upper and lower bound for the profit maximizing \(\beta_2\) and observing whether the calculated \(\beta_2\) in equation (16) falls in this range.\(^{21}\)

---

20. Griffin (1985) and Jones (1990) estimated the model with price only.

21. Actual user costs and market shares are plugged into equation (16) to yield a calculated \(\beta_2\). The upper and lower limits of the range for this calculated \(\beta_2\) are determined by taking the \(\beta_2\) estimated in equation (15) plus or minus twice its standard error.
c - Dynamic Models

Most of the econometric tests developed in the literature are single equation static models that generally suffer from severe first order autocorrelation indicating a specification error due to exclusion of important variables. Specifically, the assumption that actual demand and supply adjust immediately to the desired demand and supply, results in the exclusion of the short run dynamics. Lagged adjustments are required especially since the demand for oil and the supply for oil are known to exhibit such an adjustment. To specify the short run dynamics through which the actual demand and supply adjust to the desired demand and supply, we use the partial adjustment process where the current price \( P_t \) is replaced by the long term expected price \( P_t^* \):

\[
\ln P_t^* - \ln P_{t-1}^* = \lambda (\ln P_{t-1} - \ln P_{t-1}^*)
\]

(17)

Where \( \lambda \) is the speed of the adjustment and \( 0 < \lambda < 1 \). After a series of substitutions and rearrangements the dynamic models to be estimated are as follows:

The Dominant Firm Model

\[
\ln D_{wt} = \beta_0 - \beta_1 \ln P_t + \beta_2 \ln G_t + \beta_3 d_t + \beta_4 \ln D_{wt-1} + \varepsilon_{wt}
\]

Where \( \beta_4 = (1 - \lambda) \)

(18)

\[
\ln S_{not} = \delta_0 + \delta_1 \ln P_t - \delta_2 \ln U_{not} - \delta_3 d_t + \delta_4 \ln S_{not-1} + \varepsilon_{not}
\]

Where \( \delta_4 = (1 - \lambda) \)

(19)

The Competitive Model

\[
\ln D_{wt} = \beta_0 - \beta_1 \ln P_t + \beta_2 \ln G_t + \beta_3 d_t + \beta_4 \ln D_{wt-1} + \varepsilon_{wt}
\]

Where \( \beta_4 = (1 - \lambda) \)

(20)

\[
\ln S_{not} = \delta_0 + \delta_1 \ln P_t - \delta_2 \ln U_{not} - \delta_3 d_t + \delta_4 \ln S_{not-1} + \varepsilon_{not}
\]

Where \( \delta_4 = (1 - \lambda) \)

(21)
\[ \ln S_{ot} = \alpha_0 + \alpha_1 \ln P_r - \alpha_2 \ln U_{ot} + \alpha_3 d_t + \alpha_4 \ln S_{ot-1} + \varepsilon_{ot} \] 

Where \( \alpha_4 = (1 - \lambda) \) \hspace{1cm} (22)

\[ \ln D_{ot} = \beta_0 + \beta_1 \ln P_r + \beta_2 \ln G_r + \beta_3 d_t + \beta_4 \ln D_{wt-1} + \varepsilon_{ot} \] 

Where \( \beta_4 = (1 - \lambda) \) \hspace{1cm} (23)

IV. DATA AND SECURITY COST

Details of the data sources used and the adjustments made are provided in Appendix A. The balance of this section will focus on the use of the security cost of a barrel of oil as a component of user cost.

Economists and politicians alike, agree that political factors influence the world oil market. In fact, Moran (1980 and 1982) explained the behavior of the oil market by the influence of political factors. However, econometric models with political parameters are non-existent in the literature. This study incorporates military expenditures in some of its modeling as a first step to introduce political instability into modeling the world oil market. Further research is required to investigate the connection between political instability, military expenditures, and the world oil market. When oil companies owned and controlled the reserves in the host countries, they included the security costs in the cost of production. These include fencing, bodyguards, patrol cars and airplanes. After the transfer of ownership to the host governments, security costs are not accounted for because security became the job of a different agency such as the defense ministry. In addition, the basic thrust of our assumption is that the level of military expenditures is a function of the perceived threat to security both through time and across OPEC members. For example, Saudi Arabia has never been colonized, but after the discovery of oil, it became a target for other countries. Therefore, we can assume that security costs increased above normal levels and this increase must be included in production costs. Note that we do not include domestic security expenditures in the cost. Between 1973 and 1994, military costs for Saudi Arabia have ranged from 10% to 90% of the revenue per barrel and currently are about 40% of revenue per barrel.

Venezuela is an OPEC country under low risk of invasion by neighboring countries—or any country given US foreign policy regarding South America since Teddy Roosevelt's presidency. Venezuela’s military expenditures
per barrel are, not surprisingly, among the lowest in OPEC. Subtraction of Venezuela’s military expenditures per barrel from that of other OPEC countries yields an estimate of the increase needed to meet increased security needs. Military expenditure data were obtained from World Military Expenditure and Arms Transfers.

### Table 1. Summary of Expected Results for the Three Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Variable</th>
<th>Dominant Firm Model</th>
<th>Competitive Model</th>
<th>Cournot Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Equation</td>
<td>In Price</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>In GDP</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Dummy</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Lag In $D_w$</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Non-OPEC Supply Equation</td>
<td>In Price</td>
<td>+</td>
<td>+</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>In Cost</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Dummy</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Lag In $S_o$</td>
<td>+</td>
<td>+</td>
<td>N/A</td>
</tr>
<tr>
<td>OPEC Supply Equation</td>
<td>In Price</td>
<td>N/A</td>
<td>+</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>In Cost</td>
<td>N/A</td>
<td>-</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Dummy</td>
<td>N/A</td>
<td>+</td>
<td>N/A</td>
</tr>
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<td></td>
<td>Lag In $S_o$</td>
<td>N/A</td>
<td>+</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Profit Maximization Condition**

$$P = \frac{U_o}{1 + \frac{1}{E_o}}$$

$$P = U$$

$$\beta_2 = \frac{U_m M_o - U_m M_{no}}{U_o - U_{no}}$$

Note: N/A denotes not applicable.
V. RESULTS

1. The Dominant Firm Model

The results of the static and dynamic models are not consistent with OPEC as the dominant producer. Only Saudi Arabia's behavior is consistent with the model as shown below. Note also that for each of the models tested, the exogenous variables are GDP, user costs, and the US price regulation dummy variable. Only price and quantities are endogenous. In addition, statistical tests confirmed that both the price and quantity time series are stationary.22

a. OPEC

The model was rejected for OPEC. OPEC is not a dominant producer in the world crude oil market as has been claimed by many in the literature. Table 2 shows the results of two-stage generalized least squares regressions for the static dominant firm model. The covariances estimated using three-stage least squares regression results were small and not close to statistical significance. Using three-stage least squares regressions did not change the results in any equation in this study. Hence, the two-stage least square results are used throughout.

All the expected results from the demand equation and non-OPEC production equation are met: The price coefficient in the demand equation ($\beta$) is negative and significant and the GDP coefficient is positive and significant. The dummy variable is positive and significant. This indicates that world oil demand increased because of the lower oil prices generated by the subsidy effect of the US oil price controls.

Non-OPEC producers exhibited competitive behavior because the price coefficient is positive and significant. The user cost coefficient was negative and significant as expected from a competitive producer. The most interesting result, however, is the dummy variable, which is negative and significant. As many economists have suspected for a long time, price control suppressed US oil production.

22. We used the Augmented Dickey-Fuller method to test for stationarity. Details of this test and other statistical tests are available from the authors upon request.
Table 2. Two Stage Generalized Least Squares Results for the Dominant Firm Model

<table>
<thead>
<tr>
<th></th>
<th>ln Price</th>
<th>ln GDP</th>
<th>ln Cost</th>
<th>Dummy</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPEC</td>
<td>-0.251*</td>
<td>0.148*</td>
<td>0.156*</td>
<td>0.37*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.290*</td>
<td>-0.165*</td>
<td>-0.190*</td>
<td>0.45*</td>
<td></td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>ln $D_w$</td>
<td>0.091</td>
<td>0.171*</td>
<td>0.38*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.212</td>
<td>-0.150*</td>
<td>-0.057*</td>
<td>0.14*</td>
<td></td>
</tr>
<tr>
<td>OPEC Core</td>
<td>ln $D_w$</td>
<td>0.093</td>
<td>0.165*</td>
<td>0.39*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.042</td>
<td>-0.101*</td>
<td>0.087</td>
<td>0.26*</td>
<td></td>
</tr>
</tbody>
</table>

* Significant at 1%. ** Significant at 5%. The GDP in the Saudi and OPEC Core equations is significant at 10%. All results are corrected for serial autocorrelation. We used the Hildreth-Lu procedure, which produces a more efficient estimate than Cochran-Orcutt Method. For more details, see Appendix 2 available from the authors upon request. As explained in the text, the use of two-stage least squares are reported in Tables 1, 2 and 3. According to the Variance Inflation Factor (VIF) measure, none of the equations had any serious multicollinearity problem (we also used other measures to test for multicollinearity). Also, all of the error terms passed a normality test and a test of randomness.

The profit maximization condition was not met for OPEC in any quarter of the sample (88 quarters) because the elasticity of demand for OPEC's oil is larger than -1 and neither equations (7) or (8) are met. This result means that OPEC has been operating on the inelastic segment of its demand curve between 1973 and 1994.\(^{23}\) In order for OPEC to be a dominant producer, and subsequently a cartel, the elasticity of demand for OPEC's oil must be less than -1. Elasticity was computed according to Equation (10). Results show that the elasticity of demand for OPEC ranges from -0.1644 in the first quarter of 1983 (the lowest) to -0.2209 (the highest) in third quarter of 1973 but never less than -1. This conclusion is important and indicates that OPEC is not a profit-maximizing cartel because it is not operating on the elastic part of its demand curve. When this elasticity is plugged into Equation (7), the profit maximization condition is rejected because prices are negative for the whole period.

\(^{23}\) Some economists believe that OPEC is not maximizing profit but emphasizes social or political factors and therefore, our results are not applicable. Since the literature does not support this claim, it is merely an unsupported conclusion and the profit maximization condition is a reasonable assumption.
The results of the dynamic model confirmed the results of the static model as shown in Table 2. The table presents the short-run and the long-run price and income elasticities. The short-run and the long-run elasticities of demand are lower than that of the static model and all are higher than -1. Multicollinearity is present in some of the dynamic models but is not a serious problem in the demand equations.

b. Saudi Arabia

The dominant firm model cannot be rejected for Saudi Arabia as demonstrated in Table 2. All of the expected results from the demand equation and the supply of the rest of the world equation are met.24 The profit maximization condition is met in all but one quarter because the elasticity of demand is less than −1.25 Elasticity of demand for Saudi Arabia ranges from the low of −1.7468 in the fourth quarter of 1980 to the high of −5.6513 in the third quarter of 1985. As mentioned earlier, a monopolist or dominant producer, must operate on the elastic part of the demand curve. The previous result suggests that Saudi Arabia acts as a dominant producer in the world oil market. This result is also confirmed by the dynamic model as shown in Table 3. This result is consistent with Adelman’s statement, “The Saudis are the chief of the price makers.” (Adelman, 1985, page 17). It is also consistent with the models and the ideas of Mabro (1975), Tourk (1977), Gilbert (1978), Erickson (1980), Plaut (1981), and Singer (1983). It is consistent with the statement, “Saudi Arabia is unique in its ability to swing production over a wide range and thereby affect the world price.” (Rowen and Weyant, 1981). However, this result contradicts Griffin’s result.26

The $R^2$ values in the static models may seem small to some analysts. However, they are higher than all of the other studies after correction for autocorrelation. The $R^2$ values of the dynamic models are high and consistent with those in the literature.

24. Notice that the dummy coefficient in the supply of others equation in Table 2 is negative and significant as expected but is much smaller than that in the non-OPEC supply equation above it because the supply of others in the Saudi model includes both non-Saudi OPEC and non-OPEC production. As we will see later, US oil price control has a positive impact on OPEC production, particularly that of Saudi Arabia.

25. The model was rejected in the fourth quarter of 1985 when Saudi Arabia increased its production suddenly from 2.7 mb/d in the third quarter to 4.3 mb/d in the fourth quarter. This made the Saudi market share larger than the dominant firm market share.

26. Griffin (1985) concluded that Saudi Arabia does not fit the dominant firm model because the correlation between the output of Saudi Arabia and the output of other OPEC members is positive.
Table 3. Two Stage Least Squares Results for the Dynamic Dominant Firm Model

<table>
<thead>
<tr>
<th></th>
<th>Short Run In Price</th>
<th>Long Run In Price</th>
<th>Short Run In GDP</th>
<th>Long Run In GDP</th>
<th>In Cost</th>
<th>Dummy</th>
<th>Lag lnD and Lag InS</th>
<th>R²</th>
<th>Elasticity of Demand for the Dominant Producer</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPEC</td>
<td>ln D_a</td>
<td>-0.03**</td>
<td>0.123</td>
<td>0.12*</td>
<td>0.491</td>
<td>0.1**</td>
<td>0.756*</td>
<td>0.84*</td>
<td>Inelastic</td>
</tr>
<tr>
<td></td>
<td>ln S_m</td>
<td>0.01</td>
<td>1</td>
<td></td>
<td></td>
<td>0.002</td>
<td>-0.01</td>
<td>0.99*</td>
<td></td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>ln D_a</td>
<td>-0.032**</td>
<td>0.135</td>
<td>0.13**</td>
<td>0.548</td>
<td>0.08**</td>
<td>0.763*</td>
<td>0.85**</td>
<td>Elastic</td>
</tr>
<tr>
<td></td>
<td>ln S Others</td>
<td>-0.03</td>
<td>0.188</td>
<td></td>
<td></td>
<td>0.013</td>
<td>-0.01</td>
<td>0.841*</td>
<td></td>
</tr>
<tr>
<td>OPEC Core Countries</td>
<td>ln D_a</td>
<td>-0.03**</td>
<td>0.122</td>
<td>0.13**</td>
<td>0.783</td>
<td>0.08</td>
<td>0.755*</td>
<td>0.85*</td>
<td>Inelastic/Elastic</td>
</tr>
<tr>
<td></td>
<td>ln S Others</td>
<td>-0.02</td>
<td>0.120</td>
<td></td>
<td></td>
<td>0.01</td>
<td>-0.2**</td>
<td>0.834*</td>
<td></td>
</tr>
</tbody>
</table>

* Significant at 1%  ** Significant at 5%
Moran (1982) argues in favor of political models. He concludes (without statistical testing) that Saudi Arabia is the dominant firm in the international oil market and controls prices in order to maximize and achieve political goals. The inclusion of defense expenditures in the user cost of Saudi Arabia is consistent with his emphasis on political factors.

The US oil price control dummy variable shows that world oil demand was increased due to price control but non-Saudi production declined leaving only Saudi Arabia to benefit from the output increase needed.

c. The Core

The core consists of Saudi Arabia, Kuwait, UAE, and Qatar. The core behavior is not consistent with the dominant firm model. All the expected results from the demand equation and the supply of the rest of the world equation are met as shown in Tables 2 and 3. While the elasticity condition in equation (10) is met in the static model for the whole period, and for most of the period using dynamic models, the profit maximization condition in equations (8) or (9) is not met. This result is supported by the fact that between 1971 and 1980, the years of the claimed success of the cartel, the correlation coefficient between the production of Saudi Arabia and that of Kuwait and Qatar was negative and significant (-0.727). When the UAE is included, the coefficient became positive but not significant (0.156). One of the reasons for the elastic demand for the core is the inclusion of Saudi Arabia which meets 70% of the demand for the core’s oil. When Saudi Arabia is not included, the demand becomes inelastic. However, looking at the models without the profit maximization condition, the Saudi results are superior to that of the core as indicated in Tables 2 and 3.

2. The Competitive Model

Table 4 shows the competitive model results. The results of this study are not consistent with any of the three variants of the competitive model. The competitive model was rejected for OPEC, Saudi Arabia, and the core because the sign of the price coefficients in their respective supply equations are negative and significant. Also, the user cost variable for OPEC and for Saudi Arabia is positive and significant contrary to economic theory. Table 5 reports the results of the dynamic competitive model.
Table 4. Two Stage Generalized Least Squares Results for the Static Competitive Model

<table>
<thead>
<tr>
<th></th>
<th>ln Price</th>
<th>ln GDP</th>
<th>ln Cost</th>
<th>Dummy</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPEC</td>
<td>ln (D_w)</td>
<td>-0.406*</td>
<td>0.109**</td>
<td>0.162*</td>
<td>0.42*</td>
</tr>
<tr>
<td></td>
<td>ln (S_w)</td>
<td>0.099</td>
<td>-0.121*</td>
<td>-0.094*</td>
<td>0.29*</td>
</tr>
<tr>
<td></td>
<td>ln (S_o)</td>
<td>-0.213**</td>
<td>0.045*</td>
<td>0.163*</td>
<td>0.79*</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>ln (D_w)</td>
<td>-0.243*</td>
<td>0.076</td>
<td>-0.119*</td>
<td>0.23*</td>
</tr>
<tr>
<td></td>
<td>ln S. others</td>
<td>0.008</td>
<td>-0.127*</td>
<td>0.035</td>
<td>0.14*</td>
</tr>
<tr>
<td></td>
<td>ln S. SA</td>
<td>-0.063*</td>
<td>0.006**</td>
<td>0.064*</td>
<td>0.83*</td>
</tr>
<tr>
<td>OPEC Core</td>
<td>ln (D_w)</td>
<td>-0.415*</td>
<td>0.085</td>
<td>-0.160*</td>
<td>0.44*</td>
</tr>
<tr>
<td></td>
<td>ln S. others</td>
<td>0.201*</td>
<td>0.127</td>
<td>-0.071*</td>
<td>0.49*</td>
</tr>
<tr>
<td></td>
<td>ln S. Core</td>
<td>-1.34*</td>
<td>-0.071*</td>
<td>0.407*</td>
<td>0.26*</td>
</tr>
</tbody>
</table>

* Significant at 1%, ** Significant at 5%. All results are corrected for serial autocorrelation. According to the Variance Inflation Factor (VIF) measure, none of the equations had any serious multicollinearity problem (we also used other measures to test for multicollinearity). In addition, all of the error terms passed a normality test and a test of randomness.

3. The Cournot Model

This model was rejected for all three variants of the model (OPEC, Saudi Arabia and the core) because the price elasticity of demand is lower than that required by the Cournot model profit maximization condition. Tables 6 and 7 summarize the results for the static and dynamic demand equation for OPEC, Saudi Arabia, and the core countries.

VI. ALTERNATIVE EXPLANATIONS FOR OPEC PROFIT

The market power of Saudi Arabia, associated with oil price controls in the US, enabled OPEC in general and Saudi Arabia in particular to generate extra profits. Regression results of various models show that US oil price control suppressed US production, increased the world demand for oil, and raised Saudi Arabia’s output. This enabled OPEC members, mainly Saudi Arabia, to transfer wealth from the consuming countries to the producing countries. A rough estimate of OPEC economic rent shows that OPEC was able to generate profit in excess of user cost only during the period of price control. The economic rent vanished immediately after US oil price deregulation in January 1981. OPEC’s highest economic rent was obtained just a month before deregulation and declined sharply by the end of 1981.
Table 5. Two Stage Least Squares Results for the Competitive Dynamic Model

<table>
<thead>
<tr>
<th></th>
<th>Short Run</th>
<th>Long Run</th>
<th>Short Run</th>
<th>Long Run</th>
<th>ln Cost</th>
<th>Dummy</th>
<th>Lag lnD &amp; Lag lnS</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ln $D_w$</td>
<td>ln Price</td>
<td>ln $S_m$</td>
<td>ln GDP</td>
<td>0.12**</td>
<td>0.461</td>
<td>0.1**</td>
<td>0.74**</td>
</tr>
<tr>
<td></td>
<td>ln $S_m$</td>
<td>0.01</td>
<td>1</td>
<td></td>
<td>0.004</td>
<td>0.01</td>
<td>0.99*</td>
<td>0.99*</td>
</tr>
<tr>
<td></td>
<td>ln $S_w$</td>
<td>-0.03</td>
<td>0.105</td>
<td></td>
<td>0.098**</td>
<td>0.072**</td>
<td>0.716*</td>
<td>0.92*</td>
</tr>
</tbody>
</table>

|                | ln $D_w$  | ln Price | ln S others | ln GDP | 0.09 | 0.391 | 0.08 | 0.77* | 0.85* |
| Saudi Arabia   | ln S others | -0.03 | 0.196 | 0.01 | -0.01 | 0.847* | 0.85* |
|                | ln S SA   | -0.19*  | 1.40      | 0.17* | 0.865* | 0.86* |

|                | ln $D_w$  | ln Price | ln $S_m$  | ln GDP   | 0.01 | 0.347 | 0.08 | 0.770* | 0.84* |
|                | ln S others | -0.02 | 0.154 | 0.01 | -0.01 | 0.870* | 0.86* |
| OPEC Core      | ln S Core | -0.035* | 0.12      | 0.06* | 0.706* | 0.93* |

Table 6. Two Stage Generalized Least Squares Results for the Cournot Static Model

<table>
<thead>
<tr>
<th>ln $D_w$</th>
<th>ln Price</th>
<th>ln GDP</th>
<th>Dummy</th>
<th>R²</th>
<th>Profit Max Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.028**</td>
<td>0.195*</td>
<td>0.148*</td>
<td>0.23*</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Two Stage Least Squares Results for the Cournot Dynamic Model

<table>
<thead>
<tr>
<th>ln $D_w$</th>
<th>Short Run ln Price</th>
<th>Long Run ln Price</th>
<th>Short Run ln GDP</th>
<th>Long Run ln GDP</th>
<th>Dummy</th>
<th>Lag ln $D_w$</th>
<th>R²</th>
<th>Profit Max Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03*</td>
<td>0.120</td>
<td>0.05**</td>
<td>0.2</td>
<td>0.08**</td>
<td>0.751*</td>
<td>0.85</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

* Significant at 1%  ** Significant at 5%
The US Congress instituted regulation of US oil prices from the wellhead through refining and marketing in early 1970s. US consumers were to benefit from the lower price allowed for domestically produced “old” oil. 27 Unfortunately, the US regulations failed to recognize that international oil is sold under contracts between major producing countries and major oil companies and in spot markets. Spot market prices and volume increased dramatically after the start of the 1973 oil embargo, while contract prices remained lower and drifted up slowly as OPEC gained confidence that the market would support higher prices. During the era of price control, the US regulations did not account for this two tier international price for crude oil and did not foresee that high cost spot market oil was imported and sold to the American consumer while the lower cost contract oil was imported into Europe until prices equalized. 28 If the oil companies had not switched the oil in this way, any person could make money by buying cheap oil products in the US (where the weighted average price of upper and lower tier oil was low) and shipping those products to Europe. OPEC countries (particularly Saudi Arabia) realized this and they gradually shifted these extra profits to themselves by canceling their long-term contracts with major oil companies and selling more oil in the high priced spot market.

The US loss is estimated from the dummy variable in the demand equation in the dominant firm model for Saudi Arabia to be around $490 billion between 1973 and 1982. This US producer loss went to Saudi Arabia which increased its output to replace US output lost because of price controls. As a result, it is difficult to conclude that OPEC was able to transfer wealth due to cartel power.

This study estimates Saudi Arabia’s extra revenues from price control in the US to be $508 billion (current dollars) between 1973 and 1982. 29 Of this $508 billion, Saudi Arabia’s additional economic rent for that period is estimated to be $300 billion. The average economic rent at its maximum did not exceed $30 billion a year. It is evident that the transfer of wealth did not happen as a

27. See Griffin & Steele (1986), Energy Economics and Policy for a discussion of the US price controls and entitlement program of this era. Refining and marketing profit margins were controlled along with wellhead prices in the belief that this would ensure that the lower wellhead prices benefited US consumers.

28. For example, the 1979-1980 run-up in oil prices increased Texaco’s 1979-1980 foreign profit ratio by a multiple of 2.2 over 1977-1978 while its US profit rates multiple increased only 1.4. For Exxon, the same comparison yielded a foreign multiple of 4.7 versus the US multiple of only 3.4 (Exxon and Texaco Annual Reports).

29. Revenue estimation was obtained directly from the model and shows the upward shift in demand as a result of the US price control. It also shows the inward shift in the supply of the others. The difference between demand and supply is supplied only by Saudi Arabia. Total revenues are obtained by multiplying the supply by the average price in that year. Economic rent was calculated by subtracting total cost from total revenue.
result of OPEC's power. Wealth transfer is not a complete transfer of wealth since OPEC countries have to buy most of their consumer items from the US and other developed countries. 30 Because user costs are often excluded or underestimated, prior studies have overestimated OPEC profit. 31

VI. CONCLUSION

As mentioned at the start of this paper, no model of OPEC as a cartel is plausible for three reasons: non-OPEC production is the majority of the world output; OPEC has attempted to set production quotas only since 1983 and has never agreed on price; and OPEC has no mechanism for punishing cartel members for deviation from any OPEC agreement. A punishment mechanism is one classic characteristic of all cartels and OPEC's lack of one is a serious oversight for those who assign OPEC cartel status. 32 The result of this study establishes a fourth reason for rejecting OPEC as a cartel since the dominant firm model did not fit OPEC. While we did not test collusion behavior among OPEC members, this model is highly implausible because OPEC has not acquired the level of market dominance to achieve cartel results since its market share exceeded the 50% level in only two quarters.

The extreme reliance of prior modeling, both nested and unnested, on single-equation models to test cartel and other non-competitive models is highly suspect since our tests of a wide range of single equation models show that these models fit non-OPEC producers better than OPEC members. At best, single equation models test for parallel behavior and this may even be questioned since the modelers rarely identified the supply/demand assumptions necessary for the single equation model to be valid.

This study is the first to use a multi-equation model to test dominant firm, Cournot and competitive models for the world crude oil market. Neither OPEC, nor the core fit the dominant firm model. Only Saudi Arabia is found to act as a dominant producer. This study suggests that the world oil market is not competitive since the competitive model is rejected and it is dominated by Saudi Arabia not OPEC or the core. There is no statistical support for Cournot or competitive models.

30. For detailed information, see Alhajji (1992) "Inflation and Oil Prices in the United States."
31. See, for example, Pindyck (1978), "Gains to Producers from the Cartelization of Exhaustible Resources."
32. All other cartels have a punishment mechanism such as the diamond and the coffee cartels. For more information, see Alhajji and Huettner (2000a), "OPEC and Other Commodity Cartels, A Comparison."
Seven other factors support acceptance of Saudi Arabia as the dominant producer:

1. Non-OPEC suppliers produce at capacity in nearly all quarters (once an allowance for normal equipment downtime is made).

2. OPEC producers, excluding Saudi Arabia, do not voluntarily reduce capacity unless forced to do so by market conditions or wars.

3. Saudi Arabia is the only country to voluntarily reduce capacity and production. For example, in the 1982-85 period, Saudi Arabia mothballed over 3 million b/d of production capacity. In 1996 and again in 1999, Saudi Arabia volunteered the largest production cut among OPEC and other producing countries.

4. Saudi Arabia's output is negatively correlated with that of the rest of OPEC. The correlation coefficient between Saudi output and that of other OPEC members between 1973 and 1981 is -0.428. 33

5. The $R^2$ in this model is much higher than any other model in the literature particularly when corrected for autocorrelation.

6. Saudi Arabia was the only country among OPEC members, which was not assigned a quota when OPEC implemented the quota system in 1983. It was decided during that meeting that Saudi Arabia will be the “swing producer” to stabilize the world oil market. 34

7. Saudi Arabia operates on the elastic part of its demand curve while OPEC operates on the inelastic segment of its demand curve.

One interesting feature of acceptance of the dominant firm model for Saudi Arabia of all the multiple equation models we tested, is that it has the highest estimated short run world demand elasticity, -0.49. This short run elasticity of demand is also higher than that estimated in single equation models. Short run demand elasticity may be higher than prior estimates in the literature. However, the elasticities obtained from the dynamic models are consistent with that in the literature.

33. The correlation for the 1982 to 1994 period is positive ($r = 0.582$). This result does not conflict with our results since the dominant firm and the competitive fringe can both have increasing output when world demand is increasing.

34. For more details, see Petroleum Intelligence Weekly, March 20, 1983 and Yergin (1992).
This study is the first to statistically test for the effect of US oil price control on world oil supply and demand. Additionally, statistical testing confirmed that the price control dummy variable was an exogenous variable in both the demand equation and the competitive fringe supply equation and in all of the models tested. The dominant firm model results for Saudi Arabia in Table 2 demonstrate clearly that world demand increased due to the subsidy provided by US oil producers. US production declined and nearly all the output increase needed to offset the decline and meet the increased world demand was provided by Saudi Arabia, which earned about $508 billion (current dollars) in extra revenues from 1973 to 1982. US regulators failed to recognize the two tier world price for oil (spot versus contract) and did not anticipate that international oil companies would send the high priced spot oil to the US and ship the lower priced contract oil to Europe and other countries. The end result is certainly one of the major regulatory blunders in US history.

Over the past year, press reports have created the belief that several OPEC members along with other oil producing countries (Mexico, Norway, Russia, and Oman) have each curtailed production to support oil prices after OPEC's meeting March 23, 1999. Closer examination, however, revealed that only Saudi Arabia has cut production. The other countries have not cut production voluntarily; they simply have been unable to produce even their allocated quota for a variety of technical reasons. These results suggest that the model is still applicable today, and Saudi Arabia continues to play a dominant firm role in supplying the world with residual demand.

Finally, the results of this study suggest that a combination of models may be needed to describe the world oil market. If Saudi Arabia acts as a dominant firm, the behavior of the balance of OPEC should be the focus of future research. Recently, Alhajji and Huettner (2000b) have argued that Iran, Libya, and Nigeria follow variants of the Target Revenue model. They also found that variants of the target revenue model fit non-OPEC countries that own and control production of their oil resources, that are price takers, and that are centrally planned (i.e., Mexico, former USSR, China, Egypt, and India). Many non-OPEC countries where the oil is privately owned and produced (i.e., US and Canada) or publicly owned but privately produced (i.e., UK, Norway, and

35. For example, Venezuela and Nigeria are producing below their new OPEC quota. Venezuela is producing 50,000 b/d below its quota because of technical difficulties (Bloomberg, April 28, 1999). Nigeria is producing less than its quota because of political unrest (Bloomberg, July 23, 1999 and CNN, September 26, 1999). Mexico is producing 30,000 b/d less than the pledged cuts (Bloomberg, June 24, 1999). Similarly, the oil production of Norway and Russia declined by more than the pledged cuts because of a variety of technical problems. In fact, maintenance of the North Sea oil took much longer than expected and Phillips had to close the Ekofisk field, which produced 30,000 b/d (Bloomberg, Oct. 22, 1999). Also, See Abraham (2000), "If OPEC members are cheating, why have oil prices been rising?"
Australia) are known to be price takers and behave competitively. Alhajji (1997) found that other OPEC members behave competitively in order to maximize the purchasing power of their exported oil. While beyond the scope of this paper, a multi-model description of the world oil market would appear to be the next step.

APPENDIX A

DATA

We use quarterly data between 1973 and 1994. Data for production, prices, OECD oil consumption, and stocks are taken from the *Monthly Energy Review*. Production and finding cost data for the non-OPEC group is assumed to be the US’s cost since the US has the highest cost and is the marginal producer. Data for the US cost are combined from the *Oil and Gas Journal* and the *Department of Energy*. The user and increased security costs for OPEC were calculated as follows:

\[ C_{it} = \mu_{it} + \rho_{it} + [\alpha_{it} + 0.03(\alpha_{it})] \]  \hspace{1cm} (A-1)

\[ \mu = \] The security cost of a barrel of oil (per barrel increase in military expenditure per day for each OPEC country relative to Venezuela).

\[ \rho = \] Royalties = 0.17 times \( p \), where \( p \) is the real price in period \( t \).

\[ \alpha = \] Extraction cost: we assume that the cost is 50 cents in 1970 and that it increases by 3% a year. The security cost of a barrel of oil has been discussed above in the main text.

Royalties are payments to the owner of the resource. Royalties were paid to the owners of oil since the birth of the industry and are paid currently throughout the world. It ranges from 12% to over 50% of total revenues. In fact, the first success of OPEC after its establishment in 1960 was expensing royalties (Abdalla, 1979). After reviewing many contracts, we decided to use 17%, which is most common and currently paid by the oil companies in Venezuela.

36. This assumption was used by Hylilicza and Pindyck (1976). Note that this 3% increase is in nominal terms. Hence, the real price effect is smaller. Our final cost estimates, like others in the literature, increase then decrease. Adelman (1992) shows the US cost rises and then decreases over a long period of time.
GDP data for the OECD countries\textsuperscript{37} were obtained from the OECD publications, \textit{Oil and Gas Information} and \textit{Main Economic Indicators}. The US oil price control dummy variable used in each equation tests for the effect of the US oil price control on crude oil demand and supply can be used to estimate any wealth transfer to OPEC countries. (See Section VI for details).

We use the real price of Saudi light crude, which is the Saudi FOB price deflated by the purchasing power of Saudi Arabia.\textsuperscript{38} Note that the results of this study are improved by, but do not depend on the purchasing power prices used. Purchasing power prices for OPEC and for the Core producer countries are used for their respective supply functions when testing for the dominant firm; Cournot or the competitive models.

We use FOB prices instead of official prices.\textsuperscript{39} These supply prices are deflated by the purchasing power of the producer country instead of the GDP deflators of the US.\textsuperscript{40}

None of the studies mentioned above use demand in the model. For this reason, we estimate our own demand by adding addition to stocks in OECD countries to OECD oil consumption.\textsuperscript{41} The price used in the demand equation is the purchasing power price for Saudi Arabia used in the Saudi supply equation. The official price was tested in the supply and demand equations and

\textsuperscript{37} We could not find reliable data for the world GDP. However, we use the OECD GDP as a proxy since it represents about 75\% of the world GDP and OECD countries are energy intensive unlike the rest of the world. The GDP of the OECD was used by other studies such as Pindyck (1978) and Green (1988).

\textsuperscript{38} Alhajji (1995) used currencies and export prices of more than 50 countries that export to Saudi Arabia. These exports represented over 90\% of the total imports of Saudi Arabia.

\textsuperscript{39} All studies but Kandel (1993) and Loderer (1985) use official prices. Kandel uses spot prices. Neither official prices nor spot prices reflect the market conditions for the following reasons: First, official prices are guideline prices but not the actual prices. OPEC members offer price cuts to their customers. FOB prices are the actual prices at which oil is sold. Second, spot prices cannot be used because only part of the oil in the international oil market is sold in the spot market. In addition, spot markets are highly influenced by the policy and regulation of the government where the spot market is located.

\textsuperscript{40} It does not make sense to deflate oil prices by the GDP deflators of the US. A dollar of oil revenue in Saudi Arabia has a different value from a dollar of oil revenue in Venezuela because the trading partners are different and each buys different amounts of goods and services. For further discussion see Alhajji (1995) and Alhajji (1997).

\textsuperscript{41} On the supply side, we use the supply of market economies. Note that consumption is defined by the Department of Energy to include decrease in stocks (both crude and finished products) hence only additions to stocks must be added to consumption.
it yielded similar results. The R²'s were clearly improved, however, by use of the Saudi purchasing power price.⁴²

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⁴². We were unable to find a product price for all OECD demand nor the data to construct one. Also, theory does not require that the end-user rely solely on end-user prices to make demand decisions. For example, the end-user could use the Saudi official price to form price expectations and guide overall demand strategy. Given the high correlation between the Saudi official price and the Saudi purchasing power price (ρ = 0.828), our model is consistent with this view yet retains the simplicity of one market clearing price for supply and demand.
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