TESTING ALTERNATIVE THEORIES OF THE OIL MARKET

I. Introduction

After more than two decades since the first oil shock there is still no consensus among economists about the nature of the world oil market and what role the Organization of Petroleum Exporting Countries (OPEC) has played in this market. Existing explanations of oil market structure cover a wide range that runs from competitive to collusive. One of the reasons for the continuing coexistence of these divergent views is the lack of empirical studies testing the validity of alternative theories of the oil market. The lack of good quality data and the difficulty of distinguishing between the testable implications of the alternatives might explain economists' reluctance to carry out an empirical analysis. However, in the absence of the evidence these studies could provide, it is difficult to convincingly argue for, or against, any of the alternative explanations of oil producer behavior.

Before the pioneering work of Griffin (1985), the standard practice was to carry out a simulation analysis, mainly used to predict future price movements, in which the models were treated as maintained hypotheses without being tested.[1] Griffin tests the market sharing cartel hypothesis along with three competitive models (target revenue, property rights and supply shock models) for the 1971:1-1983:3 period, using different equations for each model. He concludes that the cartel theory does the best job of fitting the data based on the evidence favoring partial market sharing on the part of OPEC. He rejects models based on competitive behavior. Jones (1990) extends Griffin's study through 1988:4 to test the consistency of falling real oil prices in the 1980s with OPEC's market sharing behavior. He concludes that these price reductions are the result of output adjustments by OPEC and that the members share the market. Salehi-Isfahani (1987) challenges Griffin's test of the target revenue model on the basis that the equation is misspecified. Using the same data, a slightly modified equation to incorporate expectations and a two stage estimation technique to take care of simultaneity, he shows that competitive theory fits the data as well as the cartel theory. Dahl and Yücel (1991) also use different equations for different models. They reject any competitive behavior on the part of OPEC and, surprisingly, also on the part of non-OPEC countries. Additionally, cointegration tests do not provide them any evidence for coordination as a strict cartel. Overall, they conclude that a loose coordination or duopoly model would best represent the behavior of OPEC.

The evidence from Kandel's (1990) tests supports cooperative behavior, but is not consistent with the competitive view's implications. His estimates show that total OPEC production has significant explanatory power for members' individual production levels but not for those of non-OPEC producers. Output and market share time series are positively correlated within OPEC and non-OPEC subsamples, whereas the correlation across the subsamples is negative. Polasky (1992) tests the predictions of the oligopoly model described in the same work using oil industry data. Using a panel data set of 73 countries for the 1970-89 period and the fixed effects estimation technique, Polasky finds that the implications of the theory are consistent with the data.

As compared to previously cited studies that used cross-country data, Loderer (1985) and Lowinger et al. (1986) carry out their analysis on the aggregate level, treating OPEC as a cohesive whole. Loderer follows the 'event study' methodology in testing whether OPEC's policy decisions affected market prices, which should be the case if OPEC were a cartel. There is evidence of market impact for only the 1981-83 period. Lowinger et al. incorporate non-OPEC producers' behavior into their model. They consider three different roles for non-OPEC producers: de facto members of OPEC, independent price takers, or exogenous producers. They develop a two-equation system based on a two-period model in which they treat OPEC as a wealth maximizing organization that owns a renewable resource.[2] They estimate this

[1] For a critical survey of these studies, see Fischer, et al. (1975) and Cremer and Salehi-Isfahani (1991).

[2] They argue that since theirs is a short-run model estimated with quarterly data, the renewability of oil should be an acceptable assumption.

system using simultaneous equations techniques. They conclude that OPEC's impact on prices is only evident after 1979, with no meaningful effect in the 1974-79 period. They also conclude that OPEC does not change prices in response to the expansion of non-OPEC production.

In this essay, a single equation that explains oil production as a function of the price of crude oil, the amount of proven oil reserves and the cost per barrel is estimated. The whole spectrum of market structure theories - competitive, oligopolistic and collusive - is tested based on their implications on the output response of an oil producer to changes in the price of oil, the level of reserves and the cost of production. Although rather indispensable to exhaustible resources theorists, reserves were not included in an empirical study prior to Polasky's work (1992). Polasky was also the first to test oligopoly behavior on the part of oil producers. However, Polasky's approach is directed towards evaluating the consistency of the theory with the data and not towards testing it against the alternatives. The data set used in this essay contains all thirteen OPEC members as well as twelve non-OPEC producers for the 1965-92 period. Non-OPEC countries include large producers such as the U.S. and Canada with a large number of firms sharing production (also two of the few countries without a national oil ministry), a cartel sympathizer with high potential such as Mexico, and small to medium producers from Africa, Asia, Europe and South America. The sample period covers all the major events of the oil market. Some of these events are expected to fundamentally alter market structure, which might change the way a country responds to movements in the price of oil. This is incorporated into the analysis in the form of dummy variables, both as shift factors and interacted with the coefficient of oil price. Finally a systems estimation technique, seemingly unrelated regressions (SUR), is used to take cross-equation correlations into account. The estimation results indicate that oil producer behavior is best represented as oligopolistic and that some large producers have the power of influencing the market for oil.

The essay is organized as follows: Section II provides a critical survey of the methodology employed in previous empirical studies. The theoretical background and the testable implications of the oil market theories are discussed in Section III. In Section IV the data and the equation to be estimated are introduced. Some critical aspects of the estimation as well as the empirical results are also discussed in this Section. Section V concludes the essay.

II. A Critical Survey of the Empirical Literature on the Oil Market

The handful of studies mentioned in the introduction constitute the empirical component of the oil market literature. While their results are most certainly useful, one should be cautious in interpreting the results, because they suffer from various econometric problems. Most of these studies excluded Ecuador and Gabon (in case of Dahl and Yücel, also Qatar) because of data inadequacies. Also the data were truncated for some of the countries, especially for non-OPEC countries. Although these are presumably unimportant members of the organization, they might have close relations (political, historical, geographical, or other) to more powerful members which joint estimation will pick up. Second, as pointed out by Salehi-Isfahani (1987) and Kandel (1990), Griffin's estimates have a serial correlation problem. Griffin corrects for serial correlation, but instead of reporting these results he prefers to say that the conclusions are not affected. Although the magnitude of the estimates might not be changed much, correction of positive serial correlation will, in general, increase their standard errors which in turn might render the estimates statistically insignificant. Third, the market for oil is not a smooth one; the energy crisis marked the 1970s and affected economies all around the world. This might have caused a structural change in the way the oil exporters behave, yet most studies did not incorporate that into their estimates.[3]

A more serious issue is that some of the most influential members of OPEC are Arab countries from the Middle East sharing similar political and geological problems. Their economies are based on the

[3] Polasky (1992) used dummy variables in his estimation for the following periods: 1970-72, 1973-78, 1979-81, 1982-85, and 1986-89.

revenues from exporting the most important energy source to the rest of the world, including industrialized countries. Cross-country correlations are implied and should be taken into account when a production equation is estimated for these countries. In other words, a joint estimation technique should be preferred to single equation estimation. Except for Dahl and Yücel who used seemingly unrelated regressions (SUR), this issue has been neglected.

Another problem comes from the estimation of a reduced form equation, essentially derived from a supply-demand relation, in which production of a country is explained as a function of the price of oil, cost of production, and/or some other variables depending on the model being tested, the analyst's implementation of that model and data availability. In this framework, all explanatory variables that are common to both supply and demand behavior are potentially endogenous in the estimated supply equation. In order to conduct inference without loss of relevant information, the exogeneity of these variables must be established. Except for Dahl and Yücel, this issue has been ignored and the exogeneity test used by Dahl and Yücel is not appropriate. This issue is discussed further in Section IV-C.

Finally, it is possible to simultaneously accept two competing hypotheses under the testing procedure common to most of these studies, because they use non-nested equations, i.e., different sets of right-hand variables for different models. For example, Griffin estimates an equation in which oil production of a country is expressed as a function of the price of oil and total OPEC production in order to test the market sharing hypothesis (equation (5), page 955), and another equation in which the explanatory variables are the price of oil and the capital investment of the producer country to test the target revenue model (equation (9), page 956). Both equations have a common explanatory variable (the price of oil) in addition to unique ones (total OPEC production in the first and the capital investment in the second). This is a case of non-nested hypothesis testing. Pesaran and Deaton (1978) introduce a technique that allows one to test a regression model against a non-nested alternative hypothesis. Davidson and MacKinnon (1981) provide several conceptually much simpler ways of properly carrying out these tests involving the joint estimation and testing of two models and an auxiliary regression. Clearly, independent testing based on two different regressions is not conclusive. Similar problems exist in other studies as well. For example, Dahl and Yücel rejected both strong and weak versions of the target revenue model in the specific equation used in testing that model (equation (6), page 120), but it is hard to reject the weak version in the equation they treated as the "preferred specification" (equation (9), page 125).[4]

III. Discussion of Alternative Theories and Their Testable Implications

The unexpected four-fold increase in crude oil prices in December 1973, following the October war in the Middle East, has been widely attributed to the activities of OPEC operating as a cartel. Prices are accepted to be substantially higher than if they had been solely determined by market conditions and OPEC is accused of curbing production in order to raise prices. The time series graphs of the price (Figure 1) and the production of crude oil (Figure 2) indicate that OPEC might have some power in determining the price of crude oil, as each significant increase in the price is matched with a considerable decline in OPEC production. This is most apparent for the second shock of the 1979-82 period where rising prices coincide with falling production by OPEC and rising production by the rest of the world. Over the years, especially after 1973-4, OPEC production declined while their reserves increased (Figures 2 and 3). In 1973, OPEC countries were responsible for 56% of total world production while they owned almost 70% of total world reserves. By 1992, the percentage of world reserves owned by the members of OPEC increased to 78%, while the production share of the organization reached 40% after a historical low of 30% during the mid-1980s (Figure 4). It appears that they have the power to influence

[4] However, their null and alternative hypotheses for both strong and weak versions of the target revenue model seem to be switched, which might explain the inconsistency of their results.

market conditions and the decrease in their share of production along with the increase in their share of reserves is consistent with price-setting behavior.

However, as argued by the proponents of competitive behavior, OPEC did not show the characteristics of a textbook cartel until the early 1980s: no production nor profit sharing, and no policing devices to detect and punish possible cheaters. Yet they enjoyed high prices in the 1970s through 1986. The 1970s, though, were turbulent years, including Arab-Israeli war and the accompanying oil embargo to the western world by Arab exporters in 1973-74, the revolution in Iran and the beginning of the war between Iran and Iraq. These events shook the oil market and had significant effects on the economies of oil importing countries. The transfer of property rights from multinational oil companies to host governments that took place mostly in the 1973-4 period provided another vital change in the market. Perhaps most important of all, the rapid industrialization of the world in the 1960s increased the demand for crude oil. The cost of alternative energy sources was very high which provided an opportunity for large producers to charge much higher prices for crude oil than their cost of extracting it. In short, OPEC did not really have to act as a cartel in those years; the economic and political conditions provided the organization with a chance to enjoy monopoly profits. This was only natural for a group of producers that owned 70% of world's total oil reserves (Figure 4) and that had excess capacity (OPEC depletes 1% - 2% of its reserves annually as compared to 4% - 7% by the rest of the world - see Figure 5).

On the other hand, Adelman (1980), who still believed in OPEC's power to control supply and therefore the price of oil, admitted OPEC's failure in setting production levels while calling the organization 'the clumsy cartel.' In 1985 Adelman preferred to call OPEC 'Saudi Arabia and its partners.' In his own words (page 17): "The Saudis are the chief of the price makers, the cartel of the OPEC nations - not OPEC itself, which is of no importance." Adelman (1990) claimed that the shock in 1990 was created, like the others, by the deliberate actions of the cartel: Saudi Arabia and some other big producers seized the opportunity and refused to increase their production to fully compensate for the loss of production after Iraq's invasion of Kuwait.

The competitive view of the oil market was first expressed by Cremer and Salehi-Isfahani (1980, 1989) and Teece (1982). Both argued that there has never been an excess supply in the oil market; instead, the supply curve is backward bending. This perverse supply response is explained by the limited absorptive capacities of oil exporting countries, especially those in the Middle East. These countries produce only enough to meet a target revenue for internal investment purposes and therefore a large increase in the price of oil may lower their production. According to this view, the high prices in 1973-1974 and again in 1979-1980 constitute competitive equilibria which would eventually have occurred without OPEC. Although both studies are usually referred to as the target revenue model, Salehi-Isfahani (1987) points out that there are substantial differences between the two approaches. In the model of Cremer and Salehi-Isfahani, both consumption and investment are endogenously determined whereas in the target revenue model of Teece, investment and expenditure are fixed. Also, while the former distinguishes between price changes that are expected to be temporary and those that are expected to persist, the latter treats the supply response to all price increases to be negative.

In another competitive approach MacAvoy (1982), arguing against the cartel theory, explains the price increases by supply disruptions: the 1973-1974 oil embargo to the United States by the Arab countries reduced the world supply of oil and caused prices to rise; the 1979 Iran Revolution and the beginning of the Iran-Iraq war in 1980 reduced OPEC's supply and raised prices. In 1990, a similar pattern was observed following the invasion of Kuwait by Iraq. However, as Adelman repeatedly argued, Saudi Arabia alone had the capacity to compensate for a majority of the production loss, especially in the events of 1979-80, yet they preferred not to increase their production, and thus let the price rise. Also, the theory does not provide an explanation for the crash in prices in 1986.

Mead (1979) and Johany (1980) argue that higher prices are caused by the transfer of property rights from foreign oil companies with high discount rates to the host government with a lower discount rate.

According to the Hotelling principle, the price of an exhaustible resource (net of extraction cost) should rise at the rate of interest. The effective discount rate of oil companies producing in Persian Gulf countries was higher, because the companies were uncertain about their production rights. The companies responded to that uncertainty by shifting their production from the future to the present, which in turn lowered prices. When the transfer of property rights actually occurred the production went back to normal levels and prices rose. However, Adelman (1986a) argues that discount rates are actually higher in oil exporting countries of the Persian Gulf than in private companies. Also, the empirical support for the Hotelling principle is not unanimous. Miller and Upton (1985a) show the validity of a reinterpretation of it, which they call the Hotelling Valuation Principle for prices of oil and gas and then contradict their results in Miller and Upton (1985b), while Halvorsen and Smith (1991) fail to find support for the principle at all. The inadequacy of the Hotelling principle for the oil market is repeatedly underlined by Adelman (1990, 1993) who strongly challenged studies like Miller and Upton (1985a) that supported the principle. Moreover, the transfer of property rights took place in the 1973-74 period and the second oil shock of the 1979-80 period or the crash in 1986 cannot be explained by this exchange.

As the previous discussion suggests, the supply shock model of MacAvoy and the property rights model of Mead and Johany are not as credible as they first appeared to be in the literature. These models are empirically tested and rejected more than once. More importantly, neither model can explain the developments, such as the crash in 1986, that took place in the oil market after the first two shocks in the 1970s. As for the target revenue model, for which empirical support is ambiguous, one needs information on investment behavior of producer countries in addition to the oil price in order to test that model. Unfortunately, good quality data on investment are not available for most of the OPEC countries for any reasonable period. Therefore in this essay a more traditional description of competition is tested rather than any of these variants.

'Oil'igopoly theory models the market for exhaustible resources as an oligopoly (Loury, 1986; Polasky, 1992a). In this model, nonrenewable resource producers chose the level of production in order to maximize the present discounted value of profits, $\Pi_i(q_i, Q_{\sim i}) = \int_{t=0}^{T} e^{-\delta t}\left[P(Q_t) - c\right] q_{it}\,dt$ subject to the following feasibility constraint: $\int_0^{\infty} q_{it}\,dt \le S_{i0}$, where δ is the discount rate, c is the constant marginal extraction cost, S_{i0} is the ith producer’s initial stock of reserves, q_i is its production (choice variable) and $Q_{\sim i}$ is total production by the rest of the industry. $P(Q_t)$ is a downward sloping market inverse demand function with a price elasticity decreasing in quantity. The revenue function, $P(Q_t)Q_t$, is assumed to be concave in quantity. There is a Nash equilibrium in open-loop strategies and the equilibrium conditions provide, among others, the following result: countries with larger reserves produce a smaller percentage of their reserves at any time compared to countries with smaller reserves (Polasky, 1992: Proposition 2, page 220). Empirically, this implies a reserves elasticity between 0 and 1 for every oil producing country. Alternatively, if the oil market is competitive, the reserves elasticity should be one, since there is no gain for an individual producer in extracting a greater percentage of its reserves than its competitors. This would only cause the extraction cost to rise and for a constant market price this means less average profit. After all, under competition the order of production is determined by differences in extraction costs rather than by the percentage of reserves produced. On the other hand, as MacAvoy (1982) put it "if the organization were to have cartel effects, then OPEC countries would respond similarly to reserve and price changes" (page 18). Then, one would expect similar reserves elasticities of supply for each OPEC member if OPEC were an effective cartel; but, according to the 'oil'igopoly theory this cross-country equality is not necessary.

Polasky who extended Loury's analysis to the cases where extraction costs differ among producers, i.e., c_i instead of c, and where cost is a function of cumulative extraction has shown that extraction cost and production have a negative relationship in the 'oil'igopoly model (Polasky, 1992: Proposition 3, page 221). Similarly, in a competitive world, one would expect cost to have a negative coefficient. As mentioned earlier, under competition firms are expected to produce cheaper oil before they start developing more expensive fields. On the other hand, most of the OPEC members have the capacity to increase the production at any time with extremely low extraction costs ($0.50 to $1.00 for Persian Gulf countries) and, as cartel members, these countries aim to raise prices by curbing their output. Therefore the extraction cost is not expected to play a role in their production decision.

Standard practice has been to reject competitive behavior when the price elasticity is negative, i.e., when the supply curve is downward sloping. The negative relationship between price and quantity, however, is compatible with the production cutting behavior of a monopolist. As discussed earlier, OPEC is often accused of curbing its production in order to raise prices. On numerous occasions, Adelman supported this view as he characterized the organization, or some subset of core members led by Saudi Arabia, as a price-setting cartel. In 1980, he argued that "...the richer they get, the easier it becomes to be good cartelists and restrain output. The more they change, the less they produce: a backward-bending curve" (page 46). This behavior prevails because when the price is higher the countries are financially better off and it is easier for them to cut production in order to maintain the high price.[5] This production-cutting/price-setting behavior is tested in this study and therefore a negative relationship between production and price is treated as supportive of collusion. In the disaggregate approach of this essay, one can see which members engage in production cutting behavior in order to raise prices. A priori, one would expect this to be the case at least for ‘good cartelists’ such as Saudi Arabia, Kuwait and the U.A.E. if not for every member. Following the standard practice, positive price elasticities uphold competitive behavior.

IV. Empirical Analysis

A. Data

The data on estimated proven reserves (in 1,000 bbl) and actual yearly average oil production (in 1,000 b/d) for 13 OPEC and 12 non-OPEC countries are taken from the *Oil and Gas Journal*'s yearly Worldwide Report issues. The Oil and Gas Journal Energy Database is the source for the West Texas Intermediate (WTI) crude oil price (in U.S. dollars per barrel) and the real values are obtained using the Producer Price Index (1982=100) for the U.S. reported in the *Basic Petroleum Databook* published by the American Petroleum Institute.[6] The cost variable is calculated using a slightly modified version of the algorithm introduced by Adelman and Shahi (1989). This algorithm is described in the appendix. The data are annual from 1965 to 1992.

B. Model Specification and Tests

Production in the oil industry is assumed to be adequately represented by a Cobb-Douglas function:[7]

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[5] For further discussion, see Adelman (1982).

[6] Despite the common belief, WTI is highly correlated with price series from the Middle East such as S.A. Light, Dubai Fateh or Mideast Light (somewhat a mixture of the first two). The sample correlation coefficient is around .98 in all cases. Moreover, the publications such as *Basic Petroleum Data Book* of API, *British Petroleum Statistical Review of World Energy* and *OPEC Annual Statistical Bulletin* have different values for the same series from the Middle East although they all cite *Platt's Oilgram Price Report* as their source. Given these inconsistencies and high correlation WTI is preferred over others.

[7] This function is chosen to be compatible with the rest of the literature. Hence one might be able to make comparisons between the results of this paper and the results of other studies.

$$Q_{it} = a_i P_t^{\beta_{1i}} R_{it}^{\beta_{2i}} C_{it}^{\beta_{3i}} e^{\varepsilon_{it}}, \tag{1}$$

where Q_{it} is oil production, R_{it} is estimated proven reserves, C_{it} is the cost per barrel of production of country i at time t, and P_t is the crude oil price at time t. ε_{it} is an i.i.d. error term for the ith producer at time t. a_i , β_{1i}, β_{2i} and β_{3i} are country-specific parameters. The equation to be estimated is obtained by taking natural logarithms of equation (1):

$$q_{it} = \alpha_i + \beta_{1i} p_t + \beta_{2i} r_{it} + \beta_{3i} c_{it} + \varepsilon_{it}, \tag{2}$$

where $\alpha_i = \ln a_i$ and lower case letters stand for natural logarithms.

The equation will also include dummy variables to account for the major events of the sample period that are expected to cause structural changes in the production behavior of oil exporting countries. Four dummy variables are created, one for each of the following time periods: 1973-78, 1979-1982, 1986-1989 and 1990-92. The first one is the period of high and stable prices following the initial shock. The second price shock is represented by the 1979-82 period. 1986 was the year prices fell considerably and low prices persisted through 1989. In 1990 another sharp increase in prices, though much milder than the previous two, occurred. Dummy variables interacting with the coefficient of price are also considered, because the effects of these events might not be only on the level of production but also on the way oil producers respond to changes in the price of oil.[8]

The discussion of the alternative theories in the previous section implies the following restrictions on the three slope coefficients of equation (2): a positive and significant estimate for β_1 along with a β_2 estimate not significantly different than one and a significantly negative estimate for β_3 favors competitive behavior. If the estimate for β_2 is significantly less than one and greater than zero along with a significantly negative estimate for β_3, oligopoly behavior will be supported, with no restriction on the sign or magnitude of β_1. A significantly negative estimate of β_1, a β_2 estimate less than one and an insignificant estimate for β_3 are treated as supporting collusive behavior. The following table summarizes these evaluations:

	β_1	β_2	β_3
Competition	(+)	1	(-)
Oligopoly	(+/-)	(0, 1)	(-)
Collusion	(-)	<1	0

However, these restrictions might not always lead to clear-cut support for one of the alternatives, as they are not mutually exclusive. Fortunately, following MacAvoy's characterization, cross-equation restrictions on the estimates of β_1 and β_2 can be imposed: these estimates should not differ significantly across OPEC members as one would expect these countries to respond similarly to changes in the oil price and the level of reserves, possibly following guidelines set by the cartel.

C. Estimation

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[8] The coefficients of reserves and cost variables are not considered to be time-varying. The results of Polasky (1992a) indicate that the elasticity of production with respect to reserves is not sensitive to these time periods. Also there are no theoretical grounds for us to expect these events to have an effect on the way the producers respond to changes in the cost of production.

Although individual OLS estimations for the thirteen OPEC members of equation (2) provide consistent estimates, these estimates are not efficient. First of all, these countries are all members of an organization which makes decisions about the price of oil and production policies. Moreover, their economies are based on the revenues from exporting oil. Finally and perhaps most important of all, seven OPEC members are Arab nations from the same region of the world and share similar political and geological problems. Hence the disturbances of the individual equations are most likely to include factors that are common to all, or some, of the countries. It is then expected that joint estimation of these equations by using the seemingly unrelated regressions (SUR) technique will be more efficient.

The estimation of production (or supply) equations is not free of problems. In a market the equilibrium quantity and price are determined simultaneously within a demand-supply framework. Therefore both price and quantity are endogenous in this two-equation system. In order to efficiently estimate these equations one must utilize simultaneous equations techniques (see Lowinger et al.), or if one works with a single equation, as it is the case for the most of this literature, the exogeneity of price should be established. In the previous empirical studies, except for Dahl and Yücel, this issue has not been considered. The exogeneity test Dahl and Yücel used is that suggested by Sims (1972) which is based on the lack of Granger-causality. However, Engle et al. (1983) and Engle and Hendry (1993) have shown that lack of Granger-causality is neither necessary nor sufficient for weak exogeneity and although necessary, not sufficient for strong exogeneity. For 'efficient estimation' they show that one only needs weak exogeneity.[9] In this study I will use an instrumental variable based test procedure described in Engle and Hendry.[10] The test involves regressing price on a set of instruments Z_t:[11]

$$p_t = Z_t{}'\gamma + \eta_t, \tag{3}$$

and testing the significance of $\hat{\eta}_t$ in the original supply equation (equation (2) in our case). The t-statistic is a simple form of the test. If $\hat{\eta}_t$ is not significant, p_t is considered to be exogenous in equation (2); otherwise, p_t is replaced by the fitted values from equation (3).[12]

D. Results

The results of SUR estimation are reported in Tables 1 and 2, for OPEC and non-OPEC countries respectively.[13] Although none of the alternative explanations can be said to be fully supported, there is greater support for the 'oil'igopoly theory than for the others. The fit of the equations is fairly good and all three slope estimates are jointly significant in both the system of OPEC members and the system of non-OPEC countries (see Table 3).

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[9] Here 'efficient estimation' means conducting inference without loss of relevant information (See Engle et al. (1983), footnote 3 in page 278).

[10] Tests proposed by Wu (1973) and Hausman (1978) are established to be optimal by Engle (1982) who showed them to be Lagrange Multiplier (LM) tests. These tests and the test carried out in this paper, which is essentially an LM-test, are asymptotically equivalent.

[11] The instruments used in this study are p_{t-1}, q_{t-1}, r_t, r_{t-1}, c_t, c_{t-1} and dummy variables, for the four time periods described in the text, interacting with reserves and cost variables.

[12] A more straightforward method that would produce consistent and efficient estimates is 3SLS. This method would require the use of instruments (listed in footnote 11) in each equation during joint estimation. However, with only 28 observations for each country this is not feasible. Using fitted values of p_t from equation (3) is second best to 3SLS, but it has the advantage of saving degrees of freedom.

[13] For countries p_t is concluded to be endogenous, fitted values from equation (3) is used instead. Also correction for first order serial correlation is carried out when necessary.

For the system of OPEC producers (Table 1), there are seven significant β_1 estimates, four of them positive. As one might suspect from the coexistence of both negative and positive price elasticities, the equality of β_1 estimates across OPEC members is rejected ($\chi^2(13) = 80.16$). Nine β_2 estimates are significant at the five percent level (one negative and eight positive) and three of them are not significantly different than one. Again, the equality of β_2 estimates across OPEC members is rejected ($\chi^2(13) = 71.35$). Also, nine β_3 estimates are significantly negative at the five percent level. These results are not compatible with collusive behavior.

On the other hand, only Iraq, Nigeria and Qatar show strong signs of competitive behavior: positive price elasticities (except for Iraq whose price elasticity estimate is not significant), reserves elasticities not significantly different from one and significantly negative coefficients for the cost of production (only at the ten percent level for Qatar). Ecuador and Gabon have significantly positive price elasticities. Neither of the other two coefficients are significant for Gabon, but the reserves elasticity is positive and the cost elasticity is negative for Ecuador. All countries that have either positive price elasticities or reserves elasticities not significantly different than one (but not both) are small insignificant members of OPEC except for Iraq. However Iraq is known to be a rebel in the organization and was involved in wars with two different members during the sample period. Thus it is not surprising for Iraq to have a different behavior than other big producers of the organization.

Negative cost elasticities along with positive reserves elasticities significantly less than one favor oligopoly behavior. Both negative and positive price elasticities are compatible with the theory. Except for equations of Algeria, Indonesia and Saudi Arabia, all β_2 and β_3 estimates have expected signs. The coefficients of cost for Iran, reserves elasticity for Kuwait and both for Gabon are not significant. The only unexpected results are that three of the reserves elasticities are not significantly different from one (Iraq, Nigeria and Qatar).

Overall, there is no absolute support for any of the three alternatives. However, the evidence against competition and collusion is stronger than that against oligopoly. The existence of negative price elasticities along with reserves elasticities significantly less than one indicates that one cannot characterize the behavior of oil producers as competitive. On the other hand, neither price nor reserves elasticities are equal across OPEC members. These results do not favor MacAvoy's characterization of a cartel. A less restrictive cartel specification, which does not impose cross-equation equality of price and reserves elasticities, cannot be supported either: there are positive price elasticities that are inconsistent with price-setting behavior and cost per barrel has a significant effect on the production decisions of OPEC countries. Surprisingly, even the lowest-cost producers (where the average cost per barrel is between $0.50 and $1.00) such as Saudi Arabia and Kuwait have significantly negative cost elasticities. Under the light of this evidence, 'oil'igopoly theory is chosen as the best representation of the production behavior of OPEC members as compared to its alternatives.

A priori there is no rationale, similar to the one we had for OPEC members, to jointly estimate the system of non-OPEC countries. However, the joint estimation improves the precision of the estimates hence implying the existence of cross-country correlations; therefore, the joint estimation results are reported (Table 2).[14] The basic conclusions do not differ much, although equation (2) is weaker than it was for the system of OPEC countries both in terms of R^2 and significance of coefficients. There are nine significant price elasticities and only two of them are positive. Reserves do not seem to explain non-OPEC countries' production decisions; Australia, Canada, India, Mexico and the U.S. have significant reserves elasticities (at 10% for Canada and the U.S.). Canada has the only negative estimate among them. Also, seven β_3 estimates are significant (one positive and six negative). Surprisingly,

[14] In any event, if there is no cross-country correlation SUR results will be identical to OLS results.

non-OPEC countries seem to be less competitive than OPEC members; there are more negative price elasticities, and all reserves elasticities are less than unity. Again, 'oil'igopoly theory illustrates the oil producer behavior better than the alternatives.

In addition to the inferior performance of equation (2) for non-OPEC countries, another notable difference between the two groups is the overall significance of dummy variables, both intercept and slope, in the system of OPEC members as compared to the system of non-OPEC countries. All eight dummies are jointly significant in OPEC equations while the intercept and slope (interactive with the coefficient of the price) dummies for the 1979-82 and 1986-89 periods are not jointly significant in non-OPEC equations (see Table 3). The crash in 1986 has sometimes been defined as a result of output maximization of non-OPEC producers and once the price fell they followed the same policy to keep revenues high. However, there is no such explanation for the insignificance of dummies covering the 1979-82 period, which includes the second major oil shock.

Throughout the OPEC literature, different cartel core specifications have been brought to life. Moran (1978) called it a "core of balancers" which consisted of Saudi Arabia, the U.A.E., Kuwait, Libya, Iran and Iraq. Pindyck's (1978) "saver countries" included all but Iran and Iraq of the above list. The most conventional cartel core is the trio of Saudi Arabia, the U.A.E. and Kuwait. It is said that the cartel core, almost always led by Saudis, influences the market for crude oil and that OPEC is of no importance as an organization. To check the validity of these claims, the testing procedure is carried out for the different core classifications. In addition to the three listed above, two different specifications are also considered: original OPEC (Saudi Arabia, Kuwait, Iran, Iraq and Venezuela) and the Organization of Arab Petroleum Exporting Countries (OAPEC) consisting of Arab members of OPEC.

The results are almost identical (both in terms of magnitude and significance of coefficient estimates) to the ones obtained considering all 13 members (see Table 1) except for the following: Iraq's reserves elasticity is significantly different than one in the original OPEC specification and the U.A.E. does not have a significant estimate for β_2 in any of four specifications in which it was included (i.e., except for original OPEC). However, the cost of production is the only variable that is jointly significant in all specifications of the core. The price of crude oil is not jointly significant in three core classifications: core of balancers, saver countries and conventional. Somewhat surprisingly, in original OPEC and conventional definitions of the core the level of reserves is not jointly significant either. The cost of production is the only jointly significant variable when the conventional definition of the core is considered. One can reject the equality of price and reserves elasticities across countries in specifications they are jointly significant. Taken together, evidence still favors oligopolistic behavior on the part of OPEC members.

There is one notable distinction when the significance of dummy variables is considered. With the two smallest core specifications (saver countries and conventional), only the dummy variables for the 1990-92 period are significant. Those two groups include Kuwait, the recipient of Iraq's atrocities. It seems none of the other shocks to the oil market surprised those particular countries (Saudi Arabia, the U.A.E., Kuwait and to some extent Libya). One of the possible explanations of this situation is that they were aware of what would happen, or carrying the argument further they staged those events.

VI. Conclusion

It is admittedly difficult to test empirically the validity of alternative theories of the oil market, yet one needs empirical evidence to support or refute any of the alternative theories in a persuasive manner. On the other hand, one has to be cautious while carrying out the empirical analysis and avoid the econometric problems that might lead to deceptive conclusions. This essay emphasizes the importance of modelling and the use of appropriate econometric techniques in testing alternative theories of the world oil market. Using a single equation in which the oil production of an exporter is a function of the price of crude oil, the level of proven reserves, and the cost per barrel of production, different theories of the oil market (emphasizing monopoly, competitive and oligopoly behavior) are tested. The tests are based on the implications of the theories on the production behavior of the oil exporting countries in response to changes in the price of oil, the level of reserves and the cost of production.

The behavior of oil exporting countries is probably best represented as oligopolistic although some degree of effective coordination among few larger producers cannot be discarded. Empirical results of this essay indicate that the market for crude oil is not competitive and that there is no coordination among all of the OPEC's members while trio of Saudi Arabia, Kuwait and the U.A.E. (most conventional definition of a cartel core) might have some market power.

In 1979-80, Saudi Arabia along with a couple of other large producers, and not OPEC, were able to push prices up by refusing to increase their production when the war between Iran and Iraq broke out. However, in 1986 the price of oil plummeted after Saudi Arabia quit its role of swing producer and increased its production by almost 3 million barrels a day. Saudis continued to surprise the world when they utilized their extra capacity to compensate for the loss of production when Iraq invaded Kuwait in 1990. This action brought the price, which jumped to the $35-$40 range right after the invasion, back to the $15-$20 range which was established after 1986. Although much lower than the average price of the 1970s or the early 1980s, this price is still significantly higher than the price that would prevail under competition - which is around $5 for Persian Gulf producers and $8 for the U.S. according to Adelman (1986b). As a recent article in *The Economist* (June 18, 1994) suggests, “OPEC has, it seems, learnt that expensive oil stimulates conservation, alternatives and non-OPEC supplies.” Although it might be misplaced to credit the organization as such, Saudi Arabia and perhaps a few other large reserves producers have apparently realized that the decline in the demand for oil and the increase in the non-OPEC supplies would hurt their economy in the long-run much more than a decrease in the price of oil would in the short-run. It is also interesting to note that non-OPEC output ceased to increase in the second half of the 1980s. Since 1986, Saudi Arabia has been urging Mexico along with the U.K. and Norway (two major North Sea producers) to coordinate in order to keep prices high. Considering all the outside evidence and the empirical results of this essay, oil producer behavior is best represented as oligopolistic with some effective coordination among larger producers, especially after 1986. The reserve size is clearly an important variable for oil exporters in making their production decisions. The strength of 'oil'igopoly theory might lie in recognizing this fact.

Appendix

I followed the methodology of Adelman and Shahi (1989) in order to calculate the cost per barrel of production. However, I used the percentage of offshore production in adjusting the average cost per well for offshore production (see rows 3b through 3c.4 in Table 1 and corresponding explanations, pages 3 and 4, in Adelman and Shahi). If θ is the percentage of offshore production, the average cost per well (row 3a) is calculated as follows: [θ*(average cost per foot in an offshore well) + (1-θ)*(average cost per foot in an onshore well)]*(average depth).

Since the algorithm used to calculate the cost data includes five variables (the number of oil wells drilled, the number of total wells drilled, total footage drilled, oil production and percentage of offshore production), any missing data in any one of these variables prevents the calculation of cost data. This is not a major problem for most of the countries (except for Iran and Iraq for whom the 1980s meant a lot of missing data) since there are at most a few years missing for some countries. However in a joint estimation any year for any country without data for any of the variables causes the loss of the information for that year from the whole data set.[15] Since there are countries with cost data missing for different years, that would mean losing a considerable amount of information, not to mention lost degrees of freedom rendering inference on the estimates virtually impossible. Fortunately, using time series properties of the series one can solve this problem. In that direction, I estimated autoregressive models with different number of lags for each of the series. Also the correlation between the number of oil wells and the number of total wells as well as the correlation between total footage and the number of total wells is considered. A time trend is included whenever it is significant. The specification with the highest adjusted R^2 is chosen to estimate the missing values. In most of the cases, the fit was better than .90.

Since there are five variables in the algorithm affecting the final cost estimate in different directions and for any year usually only one variable is missing, these calculations are not expected to induce any measurement error. Also, most of the series are highly correlated with the ones reported in Adelman and Shahi (except for Egypt, India and Mexico the correlation is .50 or more).

Average cost per foot figures are taken from Basic Petroleum Databook published by American Petroleum Institute (Section III, Tables 9 and 10). The number of oil wells drilled, the number of total wells drilled and total footage drilled are taken from the annual International Outlook issues of *World Oil* from 1960 to 1992. The oil production and the percentage of offshore production is taken from *Oil and Gas Journal*'s yearly Worldwide Report issues. The percentage of offshore production is calculated from the individual country tables by taking the ratio of production from offshore wells to total production.

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[15] SUR does not necessarily require a balanced data set. However, with only 28 observations for each country and a missing data problem, the variance-covariance matrix of the system is not informative. Each off-diagonal element of this matrix is the inner product of residuals from two different equations of the system. As an extreme example, consider two countries, one with data for only first 14 years and the other with data for only last 14 years of the sample, then this inner product will be undefined. The problem in our data set is not that severe. Nevertheless, using a balanced data (with missing values replaced by estimates from time series techniques described in the text) promises to be more effective than using the variance-covariance matrix for the unbalanced data.

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Table 1- Joint estimation of equation (2) for OPEC producers.

Standard errors are given in parentheses. 'I' stands for intercept and 'S' stands for slope dummy respectively.

SUR results

Country	R^2	p_t	r_{it}	c_{it}	1973-78 I	1973-78 S	1979-82 I	1979-82 S	1986-89 I	1986-89 S	1990-92 I	1990-92 S
Algeria	0.797	-0.449[a]	-0.429[a]	-0.217[a]	a	a	b	b	-	-	-	-
		(0.119)	(0.042)	(0.068)								
Ecuador	0.980	1.185[a]	0.224[a]	-0.665[a]	-	-	-	-	a	a	-	-
		(0.137)	(0.023)	(0.036)								
Gabon	0.375	0.403[a]	0.163	-0.095	-	-	-	-	-	-	-	-
		(0.199)	(0.112)	(0.067)								
Indonesia	0.238	0.082	-0.084	-0.007	-	-	-	-	-	-	-	-
		(0.115)	(0.065)	(0.033)								
Iran	0.907	-0.344[a]	0.513[a]	-0.071	a	a	a	a	a	a	-	-
		(0.108)	(0.098)	(0.049)								
Iraq	0.818	-0.231	0.764[a,c]	-0.254[a]	-	-	-	-	-	-	a	a
		(0.160)	(0.224)	(0.064)								
Kuwait	0.820	-0.079	0.133	-0.404[a]	-	-	-	-	-	-	a	a
		(0.183)	(0.478)	(0.074)								
Libya	0.917	-0.103	0.698[a]	-0.403[a]	a	b	-	-	-	-	a	a
		(0.077)	(0.038)	(0.051)								
Nigeria	0.878	0.556[a]	1.030[a,c]	-0.728[a]	-	-	-	-	-	-	-	-
		(0.195)	(0.091)	(0.102)								
Qatar	0.617	0.286[a]	0.868[a,c]	-0.116[b]	-	b	-	-	-	-	-	-
		(0.121)	(0.147)	(0.065)								
S.A.	0.757	0.104	-0.147[b]	-0.407[a]	-	-	-	-	-	-	a	b
		(0.118)	(0.077)	(0.045)								
U.A.E.	0.634	-0.026	0.123[a]	-0.233[a]	-	a	-	-	a	a	-	-
		(0.116)	(0.058)	(0.032)								
Venezuela	0.982	-0.606[a]	0.090[a]	-0.067[a]	a	a	a	a	a	a	a	a
		(0.021)	(0.034)	(0.013)								

[a] Significant at the five percent level.

[b] Significant at the ten percent level.

[c] The hypothesis that β_{2i} is equal to one cannot be rejected at the five percent level.

Table 2- Joint estimation of equation (2) for non-OPEC producers.

Standard errors are given in parentheses. 'I' stands for intercept and 'S' stands for slope dummy respectively.

SUR results

Country	R^2	p_t	r_{it}	c_{it}	1973-78 I	1973-78 S	1979-82 I	1979-82 S	1986-89 I	1986-89 S	1990-92 I	1990-92 S
Angola	0.298	-0.933[b]	0.134	-0.359[a]	-	-	-	-	-	-	-	-
		(0.552)	(0.133)	(0.057)								
Argentina	0.368	-0.176[a]	-0.002	-0.160[a]	-	-	a	a	-	-	-	-
		(0.065)	(0.035)	(0.040)								
Australia	0.897	1.426[a]	0.748[a]	0.132	a	a	-	-	-	-	-	-
		(0.239)	(0.081)	(0.229)								
Bolivia	0.364	0.066	0.204	-0.223[b]	-	-	-	-	-	-	-	-
		(0.224)	(0.171)	(0.126)								
Brazil	0.884	-0.463[a]	0.025	0.696[a]	-	b	-	-	-	-	-	-
		(0.164)	(0.052)	(0.086)								
Canada	0.797	-0.079	-0.105[b]	-0.238[a]	a	a	-	-	-	-	a	a
		(0.062)	(0.062)	(0.035)								
Colombia	0.985	-0.211[a]	-0.034	-0.110[a]	-	-	-	-	-	-	a	-
		(0.058)	(0.042)	(0.036)								
Egypt	0.325	-0.685[a]	0.046	-0.106[a]	-	-	a	a	-	-	-	-
		(0.283)	(0.064)	(0.053)								
India	0.535	-0.504[a]	0.090[a]	-0.040[b]	a	a	a	a	-	-	a	a
		(0.132)	(0.043)	(0.023)								
Mexico	0.548	0.161	0.148[a]	0.049	-	-	-	-	-	-	-	-
		(0.113)	(0.021)	(0.077)								
United Kingdom	0.988	4.475[a]	-0.007	-0.864[a]	a	b	-	-	b	-	b	-
		(0.431)	(0.040)	(0.113)								
United States	0.504	-0.099[a]	0.132[b]	-0.026	b	-	-	-	-	-	a	b
		(0.035)	(0.073)	(0.030)								

[a, b, c] See Table 1.

Table 3- Likelihood ratio test results for joint significance tests.[a]

Null Hypothesis	OPEC $\chi^2(13)$	Non-OPEC $\chi^2(12)$
β_{1i} = 0 for all i	80.09	28.33
β_{2i} = 0 for all i	52.59	33.55
β_{3i} = 0 for all i	88.59	50.32
1973-78 intercept dummies = 0 for all i	43.41	22.58
1979-82 intercept dummies = 0 for all i	32.76	16.84
1986-89 intercept dummies = 0 for all i	22.73	9.40
1990-92 intercept dummies = 0 for all i	37.13	36.69
1973-78 interactive (with price) dummies = 0 for all i	39.79	21.17
1979-82 interactive (with price) dummies = 0 for all i	35.86	15.90
1986-89 interactive (with price) dummies = 0 for all i	21.83	11.56
1990-92 interactive (with price) dummies = 0 for all i	36.35	36.39

[a] The critical values for $\chi^2(13)$ are 22.36, 24.74 and 27.69 for 5%, 2.5% and 1% level of significance respectively. The critical values for $\chi^2(12)$ are 21.03, 23.34 and 26.22 for 5%, 2.5% and 1% level of significance respectively.