# Dynamic Modelling and Testing of OPEC Behaviour

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## ABSTRACT

Although conventional wisdom suggests that OPEC is a cartel, many studies since 1973 have focused on other underlying forces to explain and forecast OPEC behaviour. Economic theory suggests that natural resource producers should dynamically optimize, and a variety of studies have relied on dynamic optimization. Hence, we build a model consistent with dynamic optimization and jointly test dynamic optimization with other hypotheses prevalent in the literature. We use econometric analysis of quarterly data from 1971:1 to 1986:4.

We find that individual OPEC countries behave in quite dissimilar ways, suggesting that a cartel hypothesis is not appropriate. Under our specification, there was no evidence of dynamic optimization or a strong target revenue model. Some evidence indicated that Iran, Libya, Saudi Arabia, and the United Arab Emirates (UAE) may include a form of target revenue in their goals. Iraqi behaviour was most consistent with a static competitive market structure. While a static non-competitive market structure was not rejected for Algeria, capacity constraints are more likely to have dictated Algerian policy. A static non-competitive market structure was not rejected for Nigeria, Saudi Arabia, Kuwait, and Venezuela. Given the divergent behaviour of OPEC countries, we conclude that OPEC, rather than being a weak cartel, consists of a non-competitive core of swing producers, each swinging to its own rhythm.

# 1 INTRODUCTION

The market structure of the Organization of Petroleum Exporting Countries (OPEC) has been debated since 1973, when large price increases catapulted the organization into public attention. The debate continued as prices rose still higher in 1978 and 1979 but subsided when they fell closer to historical levels in 1986. Conventional wisdom suggests that OPEC is a cartel, albeit perhaps a weakly functioning one, groping toward an optimal level of revenue.

The cartel argument, however, is not universally accepted.[1] Various arguments have been used to explain OPEC behaviour. Because simulations of OPEC as a cartel failed to predict the high oil prices of the 1980s, modellers have explained continuing high prices with political arguments, changing OPEC behaviour, or changing perceptions of OPEC. Competitive arguments suggest that market forces led to high prices and then to lower prices. Property rights arguments suggest that high prices resulted from shifting property rights from the multinational oil companies with a higher discount rate to OPEC countries with a lower discount rate. A competitive target revenue model, which yields backward-bending supply curves once target revenue has been attained, suggests that higher prices lead to lower OPEC output.

Economic theory based on Hotelling suggests that owners of a natural resource should dynamically optimize if they want to maximize the value of their resource. Many studies have been devoted to analysis of OPEC under dynamic optimization. For example, Nordhaus (1973) has dynamically optimized world oil markets assuming competitive suppliers that minimize costs in a competitive world subject to constraints. Kalymon (1975) maximized OPEC's total discounted revenues from foreign and domestic sales plus domestic consumer surplus with OPEC as a monopolist and for several coalitions within OPEC. Cremer and Weitzman (1976) maximized OPEC's core countries' discounted present profits assuming present world demand minus

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[1] For more complete surveys of the literature see Fischer et al. (1975), Hammoudeh (1979), Gately (1984), and Dahl and Yücel (1988).

supply by the competitive fringe, given cumulative cost functions and capacity constraints. Hnyilicza and Pindyck (1976) divided OPEC into a block of savers with a low discount rate and a block of spenders with a high discount rate. Their dynamically optimal bargaining solutions, solved for fixed and variable shares, are Nash equilibria. Pindyck (1978) treated OPEC as a cartel which maximizes the discounted present value of profits while explicitly recognizing adjustment lags in demand.

More recently, Roumasset et al. (1983) used a competitive dynamic simulation model arguing that the oil-price variation before 1983 can be explained by changing perceptions of alternative reserves and the price of backstop production. Salant (1982) dynamically optimized assuming a multicommodity Nash Cournot model. Nesbitt and Choi (1988) dynamically simulated a US tariff over a sixty-year time horizon using seven supply and five demand regions. They divided OPEC into a core cartel and a competitive fringe. In their simulation, oil resources are a function of future additions to proved reserves and backstop fuels are $60 per barrel. Yücel and Dahl (1989) considered a US tariff, domestic subsidy to oil producers, and a gasoline tax in a dynamic optimization model assuming OPEC is a dominant firm.

Griffin (1985) was the first analyst to systematically test OPEC market structure across competing hypotheses. Using quarterly data from 1971 to 1982, he estimated four simple static econometric models that represent four competing theories of OPEC behaviour - a cartel model, a competitive model, a target revenue model, and a property rights model - and concluded in favour of a market-sharing cartel model for OPEC. Salehi-Isfahani (1987), using Griffin's data and model, allowed for expectations with a lagged price and concluded in favour of a target revenue model.

Neither Griffin nor Salehi-Isfahani considered the implications of dynamic optimization on their tests, and both tested their hypotheses one at a time. We build upon their framework and extend their work by explicitly considering a dynamic model and the implications that dynamic behaviour would have on the competing hypotheses. Providing a strong theoretical base allows us to test directly rather than assume whether static or dynamic behaviour is more appropriate. We increase the power of our tests by building a model in which all hypotheses are nested in one equation, rather than testing each hypothesis separately as in previous studies. We use this more general model to first test whether a static or a dynamic model better characterizes each OPEC country. Using the results of these tests, we test the earlier hypotheses: whether property rights models with lower discount rates for OPEC than for the multinational oil companies explain OPEC behaviour, whether evidence suggests non-competitive behaviour, and whether target revenue appears to be any OPEC country's primary goal. We also test formally across the various OPEC countries to determine if they have the same economic goals and lags in behaviour.

Data limitations precluded Griffin and Salehi-Isfahani from including cost in their model. Recently released cost information allows us to include this important variable for a more complete model specification. Econometric advances include testing for serial correlation and correcting for it where appropriate, testing for simultaneity using a Sims' test, estimating using two-stage seemingly unrelated regressions where appropriate, and paying somewhat more attention to creating quarterly from annual data. We, of course, include more recent data than the original studies, which allows estimation over periods of dramatic price increases as well as more recent price decreases.

## 2 MODEL

For a producer of a non-renewable resource, economic theory suggests a dynamic optimization model. Because assuming such Hotelling type behaviour does not preclude static behaviour, hypothesizing such a model allows us to test both static and dynamic behaviour within a single framework. We start with producers maximizing the present value of profits from exports over a finite time period.

$$\text{Max} \int_0^T [f(Y,q)q - C_1(R)q - C_2(w)]e^{-rt}\, dt \qquad (1)$$

subject to

$$\dot{R} = G(X,w) - q$$
$$\dot{X} = G(X,w)$$

where f is the demand function, Y is income, q is output, $C_1$ the cost of production, R the level of reserves, $C_2$ the cost of exploration, w the level of exploratory effort, X the sum of all discoveries to date, and G the discoveries function. We cannot obtain an explicit expression for q but one can see from the above objective function and constraints that an implicit function of q would be

$$F(q,\ p,\ Y,\ R,\ w,\ r,\ C_1, C_2) = 0, \qquad (2)$$

which we approximate with the following model. The quantity of oil exported is calculated to be a function of the demand for oil, the costs of extraction and exploration, the interest rate, and the level of reserves equal to initial reserves plus new discoveries minus extraction. Demand for OPEC oil is world demand minus non-OPEC supply. In our model, price and income will represent the world demand function. Because non-OPEC supply depends heavily on price, price and income may represent a reduced form for OPEC demand. We will also add non-OPEC production directly, along with price and income to test whether non-OPEC production adds any information to the estimation. The number of wells drilled represents exploration. The intercept picks up the effect of the initial level of reserves.

Exploration, development, and lifting costs are entered directly. Because the inclusion of extra variables does not bias parameter estimates, we also include investment in fixed-capital formation to test the target revenue hypothesis. Our model is:

$$\text{Ln QOIL} = \alpha_o + \alpha_p \text{ Ln POIL} + \alpha_q \text{ Ln Qw} + \alpha_w \text{ Ln WELLS} + \alpha_r \text{ r} + \alpha_y \text{ Ln GDP} + \alpha_I \text{ Ln Inv} + \alpha_c \text{ Ln COST} \qquad (3)$$

Where QOIL = oil exported.

POIL = current and/or lagged real prices of oil.

Qw = current and/or lagged non-OPEC, free world oil production.

WELLS = current and/or lagged wells drilled.

r = current and/or lagged interest rate.

GDP = current and/or lagged indices of gross domestic product of buyers of OPEC oil.

Inv = current and/or lagged investment in gross fixed capital used as the target revenue.

COST = a five-year running average of extraction and exploration costs per barrel.

We will begin with current values of all variables but will also conduct an array of lag testing to determine what sorts of lags might best capture OPEC behaviour. Interest rates, already in percentage form, are entered directly. We enter all other variables as logs and hence their coefficients are elasticities.

## 3 DATA AND ESTIMATION TECHNIQUE

Our model is estimated on quarterly data for 1971:1 to 1986:4 for the countries where all data are available - Algeria, Indonesia, Kuwait, Nigeria, Saudi Arabia, and Venezuela; 1971:1 to 1985:4 for Iran; 1971:1 to 1982:4 for Iraq and Libya; and 1972:1 to 1986:4 for United Arab Emirates. The analysis omits Gabon, Qatar, and Ecuador because too many data are missing. The price of oil in dollars, supplied by Griffin, is updated by the OPEC Annual Statistical Bulletin and the US Department of Energy Monthly Energy Review. While Griffin used OPEC production data, we use export data because domestic pricing and consumption, which are isolated from world markets in many of these countries, may be responding to political goals. We acquire export data by adjusting Griffin's data through 1982 and using more recent data from the Oil and Gas Journal. Counts of wells drilled are not available on a quarterly basis but are created by interpolations using quarterly exploration data on rig counts. The proxy for the interest rate facing OPEC is the real rate of return on US treasury bills, and the proxy for GDP for buyers of OPEC crude oil is an International Monetary Fund (IMF) index of real GDP for the industrial world. Investment numbers, only available on an annual basis from the IMF, are converted into quarterly data by interpolations based on a one-year lag on oil revenues. We use a one-year lag because regressions experimenting with annual lags up to three years suggest that a one-year lag provides the best fit. Oil price in US dollars is deflated by the US GDP deflator, base year 1982. Investment is converted to U. S. dollars by the exchange rate and then deflated by the US fixed investment deflator base year 1982. Cost is taken from Adelman and Shahi (1989). Given the random variation in costs that occurs from year to year, for each year we take a moving average of the previous five years' costs and interpolate to make the data quarterly.

We estimate and test using seemingly unrelated regressions unless otherwise specified. Given the difficulty in programming with differing sample sizes, we estimate on four sample sizes 1971:1-1986:4, 1971:1-1985:4, 1972:1-1986:4, and 1971:1-1982:4. We include all countries with sufficient data in each of the runs.

We conducted tests on the longest sample available for the country. In the initial estimates, the Durbin-Watson statistic suggested that first order serial correlation was a problem for all countries except Iraq, which would lead to biased and inconsistent estimates of the variance covariance matrix. To obtain consistent estimates, we adjusted the data by a rho, which was estimated using a Hildreth-Lu search procedure for each equation. We conducted a Sims' (1972) exogeneity test on each equation because some of the OPEC exporters have significant market shares, and if their exports influence the price of oil, oil-price endogeneity will bias estimates. The Sims'(1972) tests rejected the hypothesis that the price of oil was exogenous for Iran, Kuwait, the UAE, and Venezuela.[2] For these countries, we substituted an instrumental variable for the price of oil by regressing the price of oil on lags of the other variables.

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[2] This test was conducted by including a future lag on price in the equation. The null hypothesis is rejected for each country where the coefficient on the future lag is significantly different from zero.

## 4 HYPOTHESIS TESTING

Table 1 shows a wide variation in reserves, production, costs, and absorption capacity for OPEC economies. Despite these differences, if OPEC is strictly a cartel with some sort of market sharing scheme, or if countries have similar market structures, we might expect similar estimated coefficients across countries. Our first three hypotheses formally test this conjecture for OPEC and for two cores of producers using equation 1 and current values of all variables.

Table 1: Variables Representing OPEC's Production Capacity, Absorptive Capacity and Export Variance.

| | *Reserves mb* | *R/P yr* | *Number of Wells* | *Oil Production 1000 b/d* | *Oil Production /well* | *Pop. (1000)* | *1987 $ Per Cap. GDP* | *Oil Exports 1000 b/d Avg.* | *Oil Exports 1000 b/d Range* |
|---|---|---|---|---|---|---|---|---|---|
| Algeria | 8500 | 35.94 | 840 | 648 | 771.4 | 21720 | 2566 | 631 | 958 |
| Ecuador | 1615 | 28.18 | 922 | 157 | 170.3 | 9650 | 1153 | - | - |
| Indonesia | 8400 | 19.40 | 577 | 1186 | 205.4 | 166940 | 451 | 959 | 799 |
| Iran | 92850 | 108.62 | 361 | 2342 | 6487.5 | 44210 | 3362 | 3113 | 5355 |
| Iraq | 100000 | 130.71 | 615 | 2096 | 3408.1 | 11120 | 1225 | 1618 | 3036 |
| Kuwait | 91920 | 229.78 | 363 | 1096 | 3019.2 | 1790 | 9556 | 1538 | 2702 |
| Libya | 21000 | 56.41 | 661 | 1020 | 1543.1 | 3600 | 5514 | 1587 | 2574 |
| Nigeria | 15980 | 35.34 | 125 | 1239 | 988.8 | 98520 | 374 | 1593 | 1719 |
| Qatar | 3150 | 30.39 | 174 | 284 | 1632.1 | 330 | 15000 | 420 | 388 |
| Saudi A | 166980 | 112.85 | 588 | 4054 | 6894.5 | 11540 | 6446 | 6347 | 7769 |
| UAE | 96605 | 194.47 | 680 | 1361 | 2001.4 | 1380 | 1545 | 1450 | 1351 |
| Venezuela | 56300 | 96.89 | 979 | 1592 | 162.5 | 17320 | 2808 | 1402 | 1809 |
| Data year | 1987 | 1987 | 1986 | 1987 | 1987 | 1987 | 1986 | 1986 | 1986 |

Data Definitions: mb = millions of barrels, R/P = reserve to production ratio (in years), b/d = barrels per day, yr = years.

Sources: Oil and Gas Journal
Opec Annual Statistical Bulletin,
International Financial Statistics

Hypothesis 1: All OPEC countries share a similar market structure and have similar coefficients. Let i and j represent all OPEC countries, then

$$
\begin{aligned}
H_o:\ & \alpha_{pi} = \alpha_{pj} \quad \text{for all } i \neq j \\
& \alpha_{wi} = \alpha_{wj} \\
& \alpha_{qi} = \alpha_{qj} \\
& \alpha_{ri} = \alpha_{rj} \\
& \alpha_{yi} = \alpha_{yj} \\
& \alpha_{Ii} = \alpha_{Ij} \\
& \alpha_{ci} = \alpha_{cj}
\end{aligned}
$$

$$
\begin{aligned}
H_1:\ & \alpha_{pi} \neq \alpha_{pj} \quad \text{for all } i \neq j \\
& \alpha_{wi} \neq \alpha_{wj} \\
& \alpha_{qi} \neq \alpha_{qj} \\
& \alpha_{ri} \neq \alpha_{rj} \\
& \alpha_{yi} \neq \alpha_{yj} \\
& \alpha_{Ii} \neq \alpha_{Ij} \\
& \alpha_{ci} \neq \alpha_{cj}
\end{aligned}
$$

Hypothesis 2: Same as 1 but let i and j = Iran, Iraq, Kuwait, Saudi Arabia, and UAE.

Hypothesis 3: Same as 1 but let i and j = Iran, Iraq, Kuwait, Saudi Arabia, UAE, and Venezuela.

We test these three hypotheses using Chi Square tests. Table 2 displays the significance levels of these tests and all subsequent hypotheses tests. Degrees of freedom and test statistics vary, so we report significance levels rather than the test statistic for economy and clarity of exposition. Because all testing is done at the 5 per cent significance level, any significance level less than 5 per cent results in a rejection of the null hypothesis.

| Table 2: Significance Levels for all Hypothesis Tests (in percentages) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Alg* | *Ind* | *Irn* | *Irq* | *Kuw* | *Lib* | *Nig* | *Sau* | *UAE* | *Ven* | *Null Hypothesis* |
| **H1** | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | All OPEC Same |
| **H2** | - | - | 0 | 1 | 0 | - | - | 0 | 0 | - | (5) MidEast Same |
| **H3** | - | - | 0 | 0 | 0 | - | - | 0 | 0 | 0 | Core (6) Same |
| **H4** | 99 | 100 | 21 | 99 | 100 | 88 | 100 | 94 | 100 | 94 | NonDynamic |
| **H5** | 0 | 26 | 47 | 37 | 15 | 40 | 58 | 71 | 24 | 64 | No Property rights |
| **H6** | 100 | 88 | 100 | 1 | 8 | 100 | 17 | 100 | 100 | 100 | OPEC Non-Competitive |
| **H7** | 2 | 21 | 19 | 3 | 0 | 6 | 0 | 0 | 89 | 0 | OPEC Non-Monopoly |
| **H8** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Strong Target Rev |
| **H9** | 0 | 1 | 46 | 0 | 0 | 16 | 0 | 26 | 0 | 0 | Weak Target Rev |

Any hypothesis that all countries or a core of countries are similar is strongly rejected using current values of all variables. Before completing our hypothesis testing, we investigate whether current values or some lag structure better explain these countries' behaviour. To do so we run separate regressions with lags from zero to 20 for each variable except cost. The lag length is chosen that minimizes the Schwarz (1978) Criterion = (RSS + K log(T) $\sigma^2$ )/T, where RSS is the regression sum of squares, K is the number of regressors, $\sigma$ is the estimated standard error of the regression and T is the number of observations. Cost is not included in the testing because it is a five-year running average with lags built into it. Table 3 contains the lag length chosen for each of the variables using this procedure.

Table 3: Lag Lengths Chosen by the Schwarz Criteria.

| | *Poil* | *r* | *Wells* | *GDP* | *Inv* | *Qw* |
|---|---|---|---|---|---|---|
| Algeria | 1 | 0 | 20 | 1 | 0 | 0 |
| Indonesia | 1 | 0 | 0 | 1 | 0 | 0 |
| Iran | 3 | 0 | 0 | 0 | 8 | 16 |
| Iraq | 8 | 9 | 0 | 0 | 9 | 8 |
| Kuwait | 0 | 0 | 0 | 17 | 0 | 0 |
| Libya | 0 | 0 | 0 | 0 | 0 | 8 |
| Nigeria | 1 | 0 | 0 | 4 | 0 | 3 |
| Saudi Arabia | 0 | 0 | 20 | 0 | 0 | 20 |
| UAE | 0 | 0 | 0 | 4 | 0 | 0 |
| Venezuela | 3 | 12 | 8 | 12 | 4 | 0 |

The lag testing most often suggests that the current value fits better than a distributed lag of the variable. Where lags are appropriate, they vary considerably across countries but are generally eight quarters or less. To further investigate lags in behaviour, the lags resulting from the above testing are included in each equation, and the model is re-estimated to determine whether lags added any information. Only those lags whose sum is significantly different from zero are retained in the model. The only lags that added information and were retained in the final estimation results are those on income for Kuwait and the interest rate for Iraq.

Finally, we estimate the coefficient on non-OPEC free-world production to determine if it added information to the model. Only for Nigeria and Iraq is the coefficient significantly different from zero, leading to its inclusion in our preferred results. Table 4 provides these results, which are used for all subsequent hypothesis testing. The first row of numbers next to the sample years are the estimated coefficients, while the second row of numbers are the *t* statistics.

Table 4: Econometric Estimates of OPEC Exports

| | *C* | *Poil* | *Wells* | *r* | *Y* | *Inv* | *Cost* | *QW* | *rho* | *DW* | *R2* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Algeria** | | | | | | | | | | | |
| 1971 1986 | 2.85 | -0.27 | 0.33 | -0.02 | -1.62 | 0.62 | -0.74 | - | 0.78 | 1.89 | 0.74 |
| t stat | 4.06 | -3.38 | 7.48 | -2.33 | -2.39 | 12.79 | -1.66 | | 8.00 | | |
| **Indonesia** | | | | | | | | | | | |
| 1971 1986 | 3.28 | -0.07 | 0.11 | -0.02 | -0.48 | 0.20 | -0.18 | - | 0.61 | 2.29 | 0.36 |
| t stat | 5.21 | -1.17 | 3.70 | -2.79 | -1.28 | 3.67 | -2.09 | | 5.65 | | |
| **Iran** | | | | | | | | | | | |
| 1971 1985 | -1.18 | -0.49 | 0.11 | 0.01 | 1.79 | 0.59 | -2.42 | - | 0.68 | 1.82 | 0.80 |
| t stat | -0.54 | -4.37 | 1.05 | 0.82 | 1.31 | 11.55 | -3.39 | | 5.84 | | |
| **Iraq** | | | | | | | | | | | |
| 1973 1982 | -21.06 | 0.40 | -0.54 | -0.35 | -3.77 | 0.70 | -0.20 | 2.54 | - | 1.72 | 0.94 |
| t stat | -5.15 | 2.80 | -7.70 | -14.28 | -2.40 | 17.49 | -0.87 | 3.97 | | | |
| **Kuwait** | | | | | | | | | | | |
| 1975 1986 | 13.56 | 0.09 | 0.01 | -0.04 | -4.84 | 0.55 | 0.25 | - | 0.45 | 1.88 | 0.93 |
| t stat | 14.39 | 1.43 | 0.31 | -4.39 | -13.90 | 14.88 | 3.16 | | 1.89 | | |
| **Libya** | | | | | | | | | | | |
| 1971 1982 | -1.35 | -0.62 | -0.15 | -0.01 | 2.56 | 0.47 | -0.43 | - | 0.76 | 1.75 | 0.40 |
| t stat | -0.98 | -5.19 | -1.43 | -1.17 | 1.96 | 7.86 | -1.23 | | 6.38 | | |
| **Nigeria** | | | | | | | | | | | |
| 1971 1986 | 10.15 | 0.06 | -0.13 | -0.03 | 1.54 | 0.19 | -0.30 | -1.01 | 0.35 | 2.02 | 0.61 |
| t stat | 4.31 | 0.96 | -3.53 | -2.77 | 3.17 | 8.93 | -2.37 | -3.39 | 2.59 | | |
| **Saudi Arabia** | | | | | | | | | | | |
| 1971 1986 | 3.96 | -0.40 | 0.02 | -0.01 | -2.07 | 0.51 | -0.16 | - | 0.78 | 1.91 | 0.54 |
| t stat | 7.51 | -3.99 | 0.47 | -1.56 | -4.12 | 10.00 | -0.81 | | 8.80 | | |
| **UAE** | | | | | | | | | | | |
| 1972 1986 | 3.23 | -0.17 | 0.05 | -0.02 | 0.07 | 0.34 | -0.31 | - | 0.55 | 1.68 | 0.69 |
| t stat | 3.13 | -3.52 | 0.90 | -2.75 | 0.15 | 8.25 | -2.36 | | 4.18 | | |
| **Venezuela** | | | | | | | | | | | |
| 1971 1986 | 6.13 | -0.36 | 0.17 | -0.01 | -0.84 | 0.18 | 0.37 | - | 0.41 | 1.80 | 0.75 |
| t stat | 7.87 | -5.23 | 3.68 | -1.59 | -3.20 | 3.90 | 1.01 | | 3.08 | | |

The $R^2$s imply that these variables explain between 36 and 94 per cent of the variation in exports. Although formal tests did not find countries to have the same coefficients, a number of qualitative similarities across countries are evident. The coefficient on wells is always inelastic and most often positive. Thus, drilling has tended to fall much faster than exports, which suggests excess capacity. The significantly negative coefficient for

Nigeria and Iraq may suggest difficulty in maintaining exports because the wells drilled increased as exports decreased.

As would be expected, the coefficient on cost is most often negative, as is the coefficient on the price of oil and the coefficient on the interest rate. The coefficient on investment is always positive and is one of the most significant variables. The implications of these coefficients on market structure are now examined formally.

The negative coefficient on the price of oil could be consistent with dynamic optimization in a Hotelling type of world with price rising and exports falling over time, with a non-competitive static world, or with a target revenue goal where exports rise to compensate for falling prices. We will consider each of these possibilities.

A key test of whether the model is static or dynamic is the coefficient on the interest rate. In a dynamic world, raising the interest rate would increase the value of oil in the bank over oil in the ground and should increase output, whereas decreasing the interest rate should decrease output. Thus, $\alpha_r > 0$ is consistent with a dynamic model. In a static model the interest rate is only a cost of production. An increasing interest rate would increase costs of production, decreasing exports and yielding a negative $\alpha_r$. Hypothesis 4 is that countries do not behave in a dynamic manner, versus the alternative that they do, or:

Hypothesis 4: Countries are dynamic, or for each OPEC country i

$$H_o: \alpha_{ri} = 0 \quad \text{for each } i$$
$$H_1: \alpha_{ri} > 0 \quad \text{for each } i$$

Surprisingly, in no case can we reject the null hypothesis in favour of the alternative that countries behave dynamically.[3] However, both the countries and the multinational oil companies operating in them have produced

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[3] These results supersede our preliminary results in Dahl and Yücel (1988). After updating and correcting all data and using a more complete specification, we no longer find much evidence consistent with dynamic optimization.

over the sample period, with the control of exports transferred over time from the multinationals to OPEC. Property ownership arguments suggest that the two groups might have different discount rates. The companies risking nationalization may have had a higher interest rate than the countries' social rate of interest. Alternatively, Adelman (1986) argued that countries whose economies are very dependent on an unstable oil market should have had higher discount rates than the companies. In either event, the use of one interest rate might result in a failure to detect dynamic behaviour.

To test this conjecture, we allow separate discount rates for the companies and countries and retest to determine whether they each display static or dynamic behaviour and whether their behaviour is similar. We hypothesize that the social rate $\beta r$ is some per cent of the private rate. Under this hypothesis, the rate of interest is a weighted average of the private and the social rate, or:

$$r = [r(1-G) + \beta rG] \tag{4}$$

Where G is the per cent of OPEC output controlled by the OPEC countries or the country participation rate and (1-G) is the share controlled by the multinationals. Substituting this expression into (1) gives us our testing equation:

$$\text{Ln QOIL} = \alpha_o + \alpha_p \text{ Ln POIL} + \alpha_w \text{ Ln WELLS} + \alpha_r\ [r(1-G) + \beta rG] + \alpha_y \text{ Ln GDP} + \alpha_I \text{ Ln Inv} + \alpha_c \text{ Ln COST} \tag{5}$$

This equation allows us to test property rights arguments asking whether the countries and the multinationals behave in the same way against the alternative that they behave differently.

Hypothesis 5: Multinationals and OPEC countries have the same discount rate or for each OPEC country i:

$$H_o\colon \alpha_{ri} = \beta\alpha_{ri} \quad \text{for each i}$$

$$H_1\colon \alpha_{ri} \neq \beta\alpha_{ri} \quad \text{for each i}$$

Only for Algeria do the multinationals and the country behave in a dissimilar manner; the coefficient for Algeria is negative and significant while that for the companies is positive and significant. Because the coefficient for Algeria is significantly negative, there is still no evidence that countries dynamically optimize, nor does this test support property rights arguments.

Given the lack of evidence for dynamic optimization, we proceed to analyse the implications of behaviour in a static framework. For static behaviour, we can further test market structure. In a competitive world we know that price equals marginal cost, and thus we would expect price and quantity to be directly related. We test the null hypothesis of no competitive behaviour against this alternative that the countries behave competitively:

Hypothesis 6: OPEC countries are competitive or for each OPEC country i:

$H_o$: $\alpha_{pi} = 0$ for each i

$H_1$: $\alpha_{pi} > 0$ for each i

Only for Iraq do we reject the null hypothesis in favour of competitive behaviour. An upward sloping supply curve would be necessary, but not sufficient, to indicate competitive behaviour. To further test for market structure, we investigate the implications of monopoly behaviour.

If OPEC countries are behaving in a monopolistic manner, we would expect that income in industrialized countries and perhaps non-OPEC supply would affect export patterns. Although a supply function may not exist for the monopoly case, comparative statics shows what the signs on P and Y might be expected to be. Totally differentiating the first order condition MR-MC = 0 gives:

$$(\partial MR/\partial Q - \partial MC/\partial Q)dQ + \partial MR/\partial y \, dy = 0. \qquad (6)$$

Rearranging we get:

$$dQ/dy = -(\partial MR/\partial y)/(\partial MR/\partial Q - \partial MC/\partial Q). \qquad (7)$$

$(\partial MR/\partial Q - \partial MC/\partial Q) < 0$ from second order conditions, while $\partial MR/\partial y$ equals:

$$= \partial[P(1-1/\epsilon_p)]/\partial y = \partial P/\partial y(1-1/\epsilon_p) + P(\partial\epsilon_p/\partial y)/\epsilon_p^2. \qquad (8)$$

Then $\partial P/\partial y$ is positive, $(1-1/\epsilon_p)$ is positive, and $(P\partial\epsilon_p/\partial y)/\epsilon_p^2$ is positive unless $\partial\epsilon_p/\partial y$ is negative, or equivalently demand gets more elastic as it is shifted out. Thus, because dQ/dy can be greater or less than zero, we will take significant coefficients on GDP of industrialized countries as evidence of monopoly behaviour. To determine what sign on the oil-price coefficient is consistent with monopoly behaviour, we totally differentiate P to get:

$dP = \partial P/\partial Q\ dQ + \partial P/\partial y\ dy$ or $dP/dQ = \partial P/\partial Q + (\partial P/\partial y)\ dy/dQ$. (9)

Because $\partial P/\partial Q <$ zero and $\partial P/\partial y >$ zero, a sufficient condition for dP/dQ to be negative is a negative dQ/dy. In the more likely event that dQ/dy is positive, the sign of dP/dq is ambiguous. Thus, a negative significant coefficient on Y will require a negative coefficient on price for us to conclude in favour of monopoly.

The null hypothesis is no monopoly behaviour against the alternative of monopoly behaviour.

Hypothesis 7: Monopoly behaviour or for each OPEC country i

$H_o$: $\alpha_{yi} = 0$ for each i

$H_1$: $\alpha_{yi} \neq 0$ for each i

By testing income we see that Algeria, Iraq, Kuwait, Nigeria, Saudi Arabia, and Venezuela are the candidates for monopoly behaviour as shown in Table 2. However, in Iraq, the sign on income is negative and significant and the sign on price is positive and significant, which is inconsistent with monopoly behaviour. Further, because export supply slopes upward and Iraqi exports are positively correlated with more competitive non-OPEC supply, we conclude that Iraqi behaviour is more consistent with competitive than monopoly behaviour. Whether the end of the Iran-Iraq war will result in Iraqi behaviour becoming more consistent with that of other Middle Eastern countries remains to be seen. The recent resolution of quota problems suggests movements in that direction.

Investment is the last variable to be discussed. The correlation between oil revenues and GDP per capita across the countries in our sample in 1986 was over 0.90. Thus, oil revenues are a major source of total income as well as investment income, which leads to the last hypothesis, the target revenue model. In the strict form of this hypothesis, let $Inv^*$ be the target revenue. Then $Inv^* = QOIL*POIL$ or $QOIL = Inv^*/POIL$. A log linear formulation of this hypothesis is for the coefficient on POIL to be -1 and that on $Inv^*$ to be +1.

Hypothesis 8: Strong target revenue, or for each OPEC country i:

$H_o$: $\alpha_{pi}=-1$ and $\alpha_{Ii}= 1$,

$H_1$: $\alpha_{pi}\neq-1$ and $\alpha_{Ii}\neq 1$

As can be seen in Table 2, this hypothesis is strongly rejected for all countries. This result led us to test a weaker form of the hypothesis, that is for the coefficients on POIL to be negative and that on $Inv^*$ to be equal and opposite in sign.

Hypothesis 9: Weak target revenue, or for each OPEC country i:

$H_o$: $\alpha_{pi}=-\alpha_{Ii}$,

$H_1$: $\alpha_{pi}\neq-\alpha_{Ii}$,

For three countries, - Iran, Libya and Saudi Arabia, we do not reject the weaker form of the hypothesis. Although formal tests of the target revenue model are most often rejected, investment is positive and significant in every equation. In most equations investment is the most significant variable, and this suggests that these countries earmark a significant portion of oil-export revenues for gross domestic capital formation.

Indonesia and the UAE are the only countries that are not consistent with at least one of the hypotheses tested. Of all the countries tested, Indonesia and the UAE have shown the least percentage variation in oil exports but are otherwise extremes. Indonesia has the lowest reserve over production ratio (less than twenty years), while the UAE has one of the highest (over 190 years). The t statistics suggest that the best forecaster for Indonesian exports is the number of wells, and this implies that the country has little excess capacity. Investment is almost as important, although Indonesia had the smallest and least significant coefficient on investment of all the countries tested. Indonesia also had the smallest percentage variation in oil exports, the lowest government-participation rate, and the smallest percentage variation in exports explained by these economic variables.

For the UAE, investment is by far the best predictor of exports, price is the second best predictor. The importance of investment and the opposite signs on the coefficients on the price of oil and investments suggest target revenues are important but not in as strong a form as either hypothesis tested here.

Our testing results have implications on the hypothesis that Saudi Arabia or a core of countries acts as swing producers. Because a swing producer would be non-competitive, the candidates for swing producer based on our analysis are Algeria, Nigeria, Saudi Arabia, Kuwait, and Venezuela. We eliminate Algeria from the swing producer category because falling Algerian production is more likely the result of capacity constraints. As for the other candidates, we would expect that a swing producer would show larger swings in production over the sample. Examining the evidence in Table 1 we can see that all four candidates have had large swings in oil exports as a percentage of average exports. Iran and Iraq also have had large swings but they may have been more related to war and revolution because our tests suggest that competitive or target revenues may be motivating their behaviour. Their large reserves, however, would certainly allow them to become swing producers now that the war has ended.

As with any study of this nature, data quality and multicollinearity present problems. We have found over the course of the study that our results are somewhat sensitive to specification, and we urge the reader to view the present conclusions from our most complete specification in that light.

## 5 CONCLUSIONS

So, is OPEC a cartel? Although a lot of uncertainty still surrounds OPEC decision-making, our econometric model developed through dynamic optimization suggests that various OPEC countries seem to behave in quite dissimilar ways. Hence, a strict market-sharing cartel hypothesis is not appropriate. Nor did we find any core of countries that had identical coefficients. Although countries did not behave like a strict cartel there is evidence of non-competitive behaviour for Algeria, Kuwait, Nigeria, Saudi Arabia, and Venezuela. This non-competitive behaviour coupled with large swings in production but dissimilar coefficients, leads us to qualify these countries, except for Algeria, as swing producers rather than as a cartel.

Although economic theory suggests that natural resource producers should dynamically optimize and OPEC has been widely modelled under this framework, we found little econometric evidence to support dynamic optimizing historically using either current or distributed lags on interest rates. One might argue that such myopic behaviour would be quite rational in a highly uncertain environment.

Although these results question the use of these models for forecasting, they still maintain their normative appeal because they provide a benchmark for optimizing behaviour. As OPEC shrinks to the key players and regains more market control, optimizing models can still provide strategies for OPEC pricing policy.

In addition to not finding evidence for dynamic behaviour, lag testing suggested rather short lags in adjustment. For many variables, current values were preferred, and only in two cases did lags add any information to the estimation (lagged interest rate in the Iraqi equation and buyer income in the Kuwaiti equation). The lag testing again suggests the short-term nature of OPEC's decision process.

Not surprisingly, there is little evidence that multinational oil companies dynamically optimized either, since the majority of the multinational production in these nations was gradually nationalized. Nor was the property rights argument supported.

There is evidence that some form of target revenues may be a goal for Iran, Libya, and Saudi Arabia. Although formal tests of the target revenue model were rejected in most cases, forecasters should note that investment is still an important, usually the most important, explanatory variable.

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