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*The views expressed in this article are solely those of the authors and should not be attributed to the Federal Reserve Bank of Dallas, the Federal Reserve System, MIT, or Louisiana State University.

Dynamic Modeling and Testing of OPEC Behavior

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Abstract

Although conventional wisdom suggests that OPEC is a cartel, many studies since 1973 have considered other underlying forces in order to understand and forecast OPEC behavior. Using the most general model to date on quarterly data from 1971:I to 1986:IV we econometrically test a variety of hypotheses. We find that the various OPEC countries behave in quite dissimilar ways suggesting that a cartel hypothesis is not appropriate. Under our specification there was no evidence for dynamic optimization or a strong target revenue model. There was some evidence that a form of target revenue may be included in the goals for Iran, Libya, Saudi Arabia, and the UAE. Iraqi behavior was most consistent with a static competitive market structure, while a static noncompetitive market structure was not rejected for Algeria, Nigeria, Saudi Arabia, Kuwait, and Venezuela. However given their divergence in behavior we do not conclude in favor of a weak cartel but that there is a noncompetitive core of swing producers that each swing to their own rhythm.

OPEC market structure has been a source of considerable debate since 1973/74 when large price increases catapulted OPEC into public attention. The debate continued with even larger price increases in 1978/79 but subsided in urgency with prices falling back closer to historical levels in 1986. Conventional wisdom suggests that OPEC is a cartel or at least a weakly functioning cartel, groping towards an optimal level of revenue with recent price decreases signaling that the cartel is losing its grip on the market.

The cartel argument, however, is not universally held.[1] A variety of arguments have been put forth to try to explain OPEC behavior. Since simulations of OPEC as a cartel or a monopoly did not simulate the high prices of the 1980's, some modelers explained continuing high prices with political arguments, changing OPEC behavior, or changing OPEC perceptions. Competitive arguments suggest that market forces led to high prices and then to lower prices. Property rights arguments suggest that they resulted from shifting property rights from the 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

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

been attained, suggests that higher prices lead to lower OPEC output.

Griffin (1985) is the first paper to systematically test OPEC market structure across competing hypotheses. Using quarterly data from 1971 to 1982 he estimates 4 simple static econometric models that represent four competing theories of OPEC behavior -- a cartel model, a competitive model, a target revenue model, and a property rights model - and concludes in favor of a market sharing cartel model for OPEC. Salehi-Isfahani (1987) using Griffin's data and model allows for expectations with a lagged price and concludes in favor of a target revenue model.

Neither of these studies 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 behavior would have on the competing hypotheses. Providing a strong theoretical base allows us to test directly rather than assume whether static or dynamic behavior 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 has been done earlier. We use this more general model to first test whether each country in OPEC is characterized better by a static or a dynamic model. We use the results of these tests to test the earlier hypotheses: whether property rights models with lower discount rates for OPEC than for the multinational oil companies are appropriate for explaining OPEC behavior, whether there is evidence for noncompetitive behavior, and whether target

revenue appears to be the primary goal for any of the OPEC countries. We also do formal testing across the various OPEC countries to see if they have the same economic goals and the same lags in behavior.

Data limitations precluded either of these studies from including cost in their model. Recently available cost information allowed 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 and estimating using 2 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.

I. Model

For a producer of a nonrenewable resource economic theory sugest a dynamic optimization model. Since assuming such a Hotelling type of behavior does not preclude static behavior, hypothesizing such a model allows us to test both static and dynamic behavior within this single framework. We start with producers maximizing the present value of profits from exports over a finite time horizon.

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

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. The Hamiltonian for this problem is

$$H = [f(Y,q)q - C_1(R)q - C_2(w)]e^{-rt} + \phi_1(G-q) + \phi_2 G$$

The first order conditions are:

$$H_q = [f_q q + f - C_1(R)]e^{-rt} - \phi_1 = 0$$

$$H_w = -C_{2w}e^{-rt} + G_w(\phi_1 + \phi_2) = 0$$

$$\dot{\phi}_1 = -H_R = C_{1R}qe^{-rt}$$

$$\dot{\phi}_2 = -H_x = -G_x(\phi_1 + \phi_2)$$

Although we cannot obtain an explicit expression for q, one can see from the above first order conditions that an implicit function of q would be

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

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. Since non OPEC supply is heavily dependent on price, price and income may represent a

reduced form for OPEC demand. We will also add nonOPEC production directly along with price and income to test if it 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. Since 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:

$$\text{Ln QOIL} = \beta_0 + \beta_p \text{ Ln POIL} + \beta_q \text{ Ln Qw} + \beta_w \text{ Ln WELLS} + \beta_r \text{ r} + \beta_y \text{ Ln GDP} + \beta_I \text{ Ln Inv} + \beta_c \text{ Ln COST} \quad (1)$$

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 the 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 a wide array of lag testing to determine what sorts of lags might best capture OPEC behavior. Interest rates, already in percentage form are entered directly. All other

variables are entered as logs and hence their coefficients are elasticities.

II Data and Estimation Technique

This model is estimated on quarterly data for 1971:I to 1986:IV for the countries where all data are available - Algeria, Indonesia, Kuwait, Nigeria, Saudi Arabia, and Venezuela; 71:I to 85:IV for Iran; 71:I to 82:IV for Iraq and Libya; and 72:I to 86:IV for UAE. Gabon, Qatar, and Ecuador with too much missing data are left out of the analysis. The price of oil in dollars, supplied by Griffin, is updated by the OPEC Annual Statistical Bulletin and the 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. Our export data is acquired by adjusting Griffin's data through 1982 and updating from monthly observations of oil exports from the Oil and Gas Journal. 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 U. S. treasury bills, and the proxy for GDP for buyers of OPEC crude oil is an index of real GDP for the industrial world from the IMF. Investment numbers, only available on an annual basis from the IMF, are made into quarterly data by interpolations based on a one year lag on oil revenues. A one year lag is used since regressions experimenting with annual lags up to three years suggests that it provides the best fit. Oil price in U.S. dollars is deflated by

the U.S. GDP deflator base year 1982. Investment is converted to U. S. dollars by the exchange rate and then deflated by the U.S. 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 took a moving average of the previous five years costs and interpolated to make it quarterly.

We estimate and test using seemingly unrelated regressions unless otherwise specified. Given the difficulty in programming with differing sample sizes, we estimate on 4 sample sizes 71:I-86:IV, 71:I-85:IV, 72:I-86:IV, and 71:I-82:IV. All countries with sufficient data are included in each of the runs. The tests are done on the longest sample in which the country is included. In the initial estimates the Durbin Watson statistic suggested first order serial correlation was a problem for all but Iraq, which would lead to biased and inconsistent estimates of the variance covariance matrix. To obtain consistent estimates the data was adjusted by a rho, which was estimated using a Hildreth-Lu search procedure for each equation. Further, some of the OPEC exporters have significant market shares. If their exports influence the price of oil, oil price endogeneity will bias estimates. A Sims'(1972) exogeneity test on each equation rejected the hypothesis that the price of oil was exogenous for Iran, Kuwait, the UAE, and Venezuela.[1] For these countries an

---

1.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.

instrumental variable was substituted for the price of oil by regressing the price of oil on lags of the other variables.

III Hypothesis Testing

Table 1 shows a wide variation in reserves, production, costs, and absorption capacity for OPEC economies.

Table 1: Variables representing OPEC's production capacity, costs, absorptive capacity, and export variance.

	OIL RESERVES	R/P	WELL DEPTH	NUMBER	PRODUCTION 1000	/ WELL	ARTIF	POP.	PER CAP.	Exports Average	Range
	mb	in yr	feet	WELLS	b/d	b/d	LIFT	1000	GDP	1000	1000
COUNTRY	1987	1987	1986	1987	1987	1987	1986	1986	1986 US$	b/d 71:1-86:4	b/d
Algeria	8500	35.94	8565	840	648	771.43	205	21720	2566	631	958
Ecuador	1615	28.18	7848	922	157	170.28	802	9650	1153	-	-
Indonesia	8400	19.40	4501	577	1186	205.40	514	166940	451	959	799
Iran	92850	108.62	7743	361	2342	6487.53	0	44210	3362	3113	5355
Iraq	100000	130.71	NA	615	2096	3408.13	NA	11120	1225	1618	3036
Kuwait	91920	229.78	3717	363	1096	3019.28	20	1790	9556	1538	2702
Libya	21000	56.41	1230	661	1020	1543.12	NA	3600	5514	1587	2574
Nigeria	15980	35.34	NA	125	1239	988.83	NA	98520	374	1593	1719
Qatar	3150	30.39	7750	174	284	1632.18	2	330	15000	420	388
Saudi A	166980	112.85	5870	588	4054	6894.56	NA	11540	6446	6347	7769
UAE	96605	194.47	8688	680	1361	2001.47	223	1380	1545	1450	1351
Venezuela	56300	96.89	NA	979	1592	162.50	851	17320	2808	1402	1809

Data Definitions: b/d = barrels per day, mb = millions of barrels, yr = years. There are approximately 7.4 barrels per metric ton of oil.

Sources: Oil and Gas Journal, Dec. 1987
Opec Annual Statistical Bulletin,
International Financial Statistic

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 are to formally test this conjecture for OPEC and for two cores of producers using equation 1 and current values of all variables.

Hypothesis 1: All OPEC Countries share a similar market structure and have similar coefficients. Let i and j represent

all OPEC countries, then

$$
\begin{aligned}
H_0:\ & \beta_{pi} = \beta_{pj} \quad \text{for all } i \neq j \\
& \beta_{wi} = \beta_{wj} \\
& \beta_{qi} = \beta_{qj} \\
& \beta_{ri} = \beta_{rj} \\
& \beta_{yi} = \beta_{yj} \\
& \beta_{Ii} = \beta_{Ij} \\
& \beta_{ci} = \beta_{cj} \\
H_1:\ & \beta_{pi} \neq \beta_{pj} \quad \text{for all } i \neq j \\
& \beta_{wi} \neq \beta_{wj} \\
& \beta_{qi} \neq \beta_{qj} \\
& \beta_{ri} \neq \beta_{rj} \\
& \beta_{yi} \neq \beta_{yj} \\
& \beta_{Ii} \neq \beta_{Ij} \\
& \beta_{ci} \neq \beta_{cj}
\end{aligned}
$$

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.

These three hypotheses are tested using Chi Square tests. The significance levels of these tests and all subsequent hypotheses tests are given in Table 2. Since degrees of freedom and test statistics vary, for economy and clarity of exposition, we report significance levels rather than the test statistic. Since all testing is done at the 5% significance level, any significance level less than 5% results in a rejection of the null hypothesis.

Table 2: Significance Levels for all Hypothesis Tests

	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

All hypotheses that all countries or a core of countries are similar are strongly rejected using current values of all variables. Before proceeding to complete our hypothesis testing we investigate whether current values or some lag structure better explains these countries' behavior. To do so separate regressions are run with lags from 0 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, σ is the estimated standard error of the regression and T is the number of observations. Cost is not including in the testing because it is a five year running average and already has 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 8 quarters or less. To further investigate lags in behavior the lags resulting from the above testing are included in each equation and the model is reestimated to determine whether lags added any information. Only those lags whose sum is significantly different from zero is 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, the coefficient on Non-OPEC free world production is examined to determine if it added any information to the model. Only for Nigeria and Iraq is its coefficient significantly different from zero leading to its inclusion in our

preferred results. These results, which are used for all subsequent hypothesis testing, are given in Table 4. The first row of numbers next to the sample years are the estimated coefficients while the second row of numbers are the t statistics.

The R^2s imply that between 36 and 94 percent of the variation in exports is explained by these variables. Although formal tests did not find countries to have the same coefficients, there are a number of qualitative similarities across countries. The coefficient on wells is always inelastic and most often positive. Thus, drilling has tended to fall much faster than exports suggesting excess capacity. The significantly negative coefficient for Nigeria and Iraq may suggest difficulty in maintaining exports since wells drilled increased as exports decreased.

As would be expected, the coefficient on cost is most often negative. The coefficient on the price of oil is most often negative, that on the interest rate is almost always negative, while that on investment is always positive and 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 noncompetitive static world, or with a target revenue goal where exports rise to make up for falling prices. Each of these possibilities will be considered.

Table 4: Econometric Estimates of OPEC Exports

Algeria	C	Poil	Wells	r	Y	Inv	Cost	QW	rho	DW	R2
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	C	Poil	Wells	r	Y	Inv	Cost	QW	rho	DW	R2
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	C	Poil	Wells	r	Y	Inv	Cost	QW	rho	DW	R2
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	C	Poil	Wells	r(L9)	Y	Inv	Cost	QW		DW	R2
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	C	Poil	Wells	r	Y(L17)	Inv	Cost	QW	rho	DW	R2
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	C	Poil	Wells	r	Y	Inv	Cost	QW	rho	DW	R2
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	C	Poil	Wells	r	Y	Inv	Cost	QW	rho	DW	R2
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 Arab	C	Poil	Wells	r	Y	Inv	Cost	QW	rho	DW	R2
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	C	Poil	Wells	r	Y	Inv	Cost	QW	rho	DW	R2
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	C	Poil	Wells	r	Y	Inv	Cost	QW	rho	DW	R2
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		

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, while decreasing it should decrease output. Thus $\beta_r > 0$ is consistent

with a dynamic model. In a static model the interest rate is only a cost of production. An increasing rate of interest would increase costs of production decreasing exports and yielding a negative β_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

$$H_0: \beta_{ri} = 0 \quad \text{for each } i$$

$$H_1: \beta_{ri} > 0 \quad \text{for each } i$$

Surprisingly, in no case can we reject the null hypothesis in favor of the alternative that countries behave dynamically.[1] However, both the countries and the companies have produced over the sample period with the control of exports transferred over time from the multinationals to OPEC. Property ownership arguments suggest that they 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) argues 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 behavior.

To test this conjecture we allow separate discount rates for the companies and countries and retest to determine whether they

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

each display static or dynamic behavior and if their behavior is similar. We hypothesize that the social rate αr is some percent of the private rate. Under this hypothesis the rate of interest is a weighted average of the private and the social rate or:

$$r = [r(1-G) + \alpha rG] \qquad (2)$$

Where G is the percent 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:

$$\text{Ln QOIL} = \beta_0 + \beta_p \text{ Ln POIL} + \beta_w \text{ Ln WELLS} + \beta_r [r(1-G) + \alpha rG] + \beta_y \text{ Ln GDP} + \beta_I \text{ Ln Inv} + \beta_c \text{ Ln COST} \qquad (3)$$

This equation allows us to test property rights arguments or whether the countries and the multinationals behave the same against the alternative that they behave differently or:

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

$$H_0: \beta_{ri} = \alpha\beta_{ri} \quad \text{for each i}$$

$$H_1: \beta_{ri} \neq \alpha\beta_{ri} \quad \text{for each i}$$

Only for Algeria, where the coefficient for Algeria is negative and significant while that for the companies is positive and significant, do the multinationals and the country behave in a dissimilar manner. Since 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 no evidence for dynamic optimization we proceed to analyze the implications of behavior in a static framework.

For static behavior, we can further test market structure. In a competitive world we know that price equals marginal cost and would thus expect price and quantity to be directly related. The null hypothesis of no competitive behavior is tested against this alternative that the countries behave competitively:

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

$$H_0: \beta_{pi} = 0 \quad \text{for each } i$$
$$H_1: \beta_{pi} > 0 \quad \text{for each } i$$

Only for the case Iraq do we reject in favor of competitive behavior. An upward sloping supply curve would be necessary but not necessarily sufficient for competitive behavior. To further test for market structure we investigate the implications of monopoly behavior.

If OPEC countries are behaving in a monopolistic manner, we would expect that income in industrialized countries and perhaps NonOPEC 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:

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

Rearranging we get:

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

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

$$= \partial[P(1-1/\mathcal{E}_p)]/\partial y = \partial P/\partial y(1-1/\mathcal{E}_p) + P(\partial E_p/\partial y)/\mathcal{E}_p^2.$$

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

$$dP = \partial P/\partial Q\ dQ + \partial P/dy\ dy \text{ or } dP/dQ = \partial P/\partial Q + \partial P/\partial y\ dy/dQ.$$

Since $\partial P/\partial Q$ < 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 favor of monopoly.

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

Hypothesis 7: Monopoly behavior or for each OPEC country i

$$H_0: \beta_{yi} = 0 \quad \text{for each } i$$

$$H_1: \beta_{yi} \neq 0 \quad \text{for each } i$$

We can see from Table 2 that the candidates for monopoly behavior by testing income are Algeria, Iraq, Kuwait, Nigeria, Saudi Arabia, and Venezuela. 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 behavior. Further, since export supply is upward sloping and Iraqi exports are positively correlated with more competitive NonOPEC supply

conclude that Iraqi behavior is more consistent with competitive than monopoly behavior. Whether the ending of the war with Iran changes Iraqi behavior to be more consistent with other Middle Eastern Countries remains to be seen. 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 .90. Thus, oil revenues are a major source of total income as well as investment income leading 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: Target revenue strong or for each OPEC country :

$$H_0: \beta_{pi} = -1 \text{ and } \beta_{Ii} = 1,$$

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

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

Hypothesis 9: Target revenue weak or for each OPEC country :

$$H_0: \beta_{pi} = -\beta_{Ii},$$

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

Three countries do not reject the weaker form of the hypothesis - Iran, Libya, and Saudi Arabia. Although formal tests of the target revenue model are most often rejected,

investment is positive and significant in every equation. In most equations it is the most significant variable suggesting that a significant portion of oil export revenues are earmarked for gross domestic capital formation.

Indonesia and the UAE are the only countries not consistent with at least one of the hypotheses tested. Both have shown the least percentage variation in exports of all countries tested but are extremes otherwise since Indonesia has the lowest reserve over production ratio, less than 20 years, while the UAE has one of the highest, over 190 years. The t statistics suggest that wells is the best forecaster for Indonesian exports, implying 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 exports, the lowest government participation rate, and the smallest percent of variation in exports explained by these economic variables.

For the UAE, investment is by far the best predictor of exports with price running second. This importance of investment and the fact that the coefficient on the price of oil and investments are opposite in sign 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 some core of countries act as swing producers. Since a swing producer would be noncompetitive, the candidates for swing producer from the above analysis are Algeria, Nigeria

Saudi Arabia, Kuwait, and Venezuela. Further, 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 five have had large swings in exports as a percent of average exports. Iran and Iraq have had large swings as well but they may have been more war and revolution related since the testing suggested competitive or target revenues may be motivating their behavior.

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 urge the reader to view the present conclusions from our most complete specification in that light.

IV Conclusions

So is OPEC a cartel? Although a lot of uncertainty still surrounds OPEC decision making, our econometric model developed out of 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 noncompetitive behavior for Algeria, Kuwait, Nigeria, Saudi Arabia, and Venezuela. This noncompetitive behavior coupled with large swings in production but dissimilar coefficients leads us to qualify these countries as swing producers rather than as a cartel.

We were disappointed to find little evidence of dynamic optimization using either current or distributed lags on interest

rates. Although such myopic behavior might well be quite rational in a highly uncertain environment. This econometric work is consistent with the disappointing results obtained by dynamic optimization models and supports efforts of modelers to move away from them. In addition to not finding evidence for dynamic behavior, lag testing suggested rather short lags in adjustment. For many variables current values were preferred and only in two cases (lagged interest rate in the Iraqi equation and buyer income in the Kuwaiti equation) did lags add any information to the estimation. The lag testing again suggests the short term nature of the decision process.

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

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

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