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Testing the hypothesis of collusive behavior among OPEC members

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Abstract

This paper presents a test to discriminate among behaviors of producers of exhaustible resources. In contrast with previous empirical studies (Griffin, 1985), which studied the *static* implications of such behaviors, our approach is based on the possibility of testing the *dynamic* implications of the behavior of the "competitive" producer versus the "collusive" producer.

The behavior of a competitive producer of an exhaustible resource should follow an Euler equation. The existence markets for the fi~tures allows us to sidestep the difficult issues related to estimating future prices and demand. We use this theoretical framework to test the hypothesis of collusive behavior within OPEC between 1983 and 1991.

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1 Introduction

What was the role of OPEC in the 1980's? Did its members follow its rules or were they simply behaving as producers maximizing their own revenues individually?

As often happens in cartels, OPEC members have a tendency to produce more than the agreed quantity; moreover, since OPEC members have different resources, preferences, and costs of production, there is tension within the cartel regarding the optimal price path. Several theoretical models have attempted to provide a framework for a country's production decisions. Griffin (1985) has sought to discriminate empirically between the *static* implications of the various theoretical models; in particular, he tested collusive behavior (where the production of each producer depends also on the OPEC production as a whole) against the hypothesis of a competitive market (where every producer maximizes its own revenues without strategic considerations).

In this paper, we propose another way of testing strategic behavior against non strategic behavior, based on the different *dynamics* implicit in the two models.

The paper is divided into one theoretical ("the framework") and one empirical section ("testing the OPEC behavior").

2 The Framework

In the first part of this theoretical section, we specify what the behavior of the producers would be in absence of a cartel (subsection 2.1 on "Competitive Producer"), and in the second part (subsection 2.2 on "Producer in a Cartel") we specify a simple alternative hypothesis where the producers follow a revem~e-sharing agreement.

2.1 Competitive producer

Without the pressure of cooperating with OPEC, the government of an oil exporting country would face the standard problem of how to manage an exhaustible resource: i.e., choosing between current and future production. The dynamic maximization problem with discrete

time is solved by the following Euler equation:

$$U'(P_t * q_{t,i}) = \frac{1+d}{1+r} E_t U_t(P_{t+1} * q_{t+1,i} | Z_t) \tag{1}$$

In the above equation, U(.), is a generic utility function that depends only on the revenues in period t; P_t is the price of crude oil at time t; q_{ti} is the quantity extracted and sold in period t by the producer i; *Et* is the expectation operator, conditioned at the information known at time *t (Zt);* r is the real interest rate, and d is the discount rate. The following three assumptions are implicit in eq. 1[1].

[1] We use as equivalent the quantity produced and the quantity sold; in the case of the OPEC producers, this is not a very strong assumption, since for them it is much cheaper to keep oil in the earth that to extract and keep it in deposits.

1. the country is small; P_t and $E_t(P_t+1)$ are (therefore) exogenous parameters;
2. the costs of production are negligible; with positive costs, one simply replaces the term $[P_t * q_{ti}]$ with the term $[(P_t - C_{ti}) * q_{ti}]$, where C_{ti} is the marginal cost for producer i at time t; however, since the cost of extracting oil is small compared to the final price of oil, the hypothesis is reasonable.
3. The technical constraints (i.e., production per period, determined by the number of active wells) are not binding, since monthly capacity is chosen endogenously by the producer in previous periods. Furthermore, the presence of spare capacity in most oil producing countries reinforces our argument.

The next steps are to obtain readily testable implications from eq. 1. Rewriting 1:

$$U'(x_{t,}i) = q * E_t U'(x_{t+1,i}) \qquad \textbf{(2)}$$

where $x_{t,}i$ $(° P_t * qt,i)$ are the revenues at time t of country i and q ° $\frac{1 + d}{1 + r}$. Observe now that the marginal utility at time t+ 1 is a random variable, since the revenues at time t + 1 are not known at time t.[2] Given that $x_{t,}i$ @ $x_t+_{1,i}$

we can use a Taylor expansion of the marginal utility in the second period around $x_{t,}i$

$$U'(x_{t,}i) \text{ @ } q * E_t U'(x_t+_{1,i} - x_t i) * U''(x_{t,i})] \qquad \textbf{(3)}$$

Furthermore, reaxranging eq. 3 yields:

$$U'(x_{t,}i) \frac{1 - q}{q} * E_t(x_t+_{1,i} - x_{t,}i) * U''(x_{t,i})] \qquad \textbf{(4)}$$

The price in the future is not correlated with production, given the hypothesis regarding small producers, $E_t[P_{t+1,i} - q_{t+1,i}]$ can be written as $E_t[P_{t+1}] * q_{t+1,i}$. The next step is to find P^e_{t+1}.

2.1.1 Finding $\mathbf{P^e_{t+1}}$

To obtain an unbiased estimator of $\mathbf{P^e_{t+1}}$, we use the procedures employed by Pindyck (1991) and Campbell and Shiller (1987). Since oil, like other storable commodities, can be considered an asset, its price can be analyzed as the discounted sum of present and expected future payoffs:

$$P_{t=,} \, d \sum_{t=0}^{\infty} d^i E_t y_{t+1} \qquad \textbf{(5)}$$

where d is the discount rate, y_t the payoff at time t, and E_t the expectations at time t.[3]

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[2] We do not write each time that the expectations are conditional on Pt and F1,t, but *Et [Pt+1 Zt]* is actually $E_t[P_{t+1} / P_t, F_{1,t}]$, *as* is shown earlier in this section.

[3] We assume in eq. 5 that there are no bubbles in the determination of price. Tests of the sufficiency of the spot price and of future prices are used to determine whether P^e_{t+1} will confirm such hypothesis.

Equation 5 is the solution to the differential equation:

$$P^e_{t+1} = (1+m)^* P_t - y_t \quad \textbf{(6)}$$

where $m = 1/6 - 1$ is the commodity-specific one-period discount rate that can be decomposed in two components: r, the one-period risk-free rate, and p, the risk premitrm specific for crude oil. If the spot and futures markets are efficient, the following arbitrage condition must hold.[4]

$$y_t = (1+r)^* P_t - F_{1,t} \quad \textbf{(7)}$$

where $F_{1,t}$ is the price at time t of a futures contract expiring at the beginning of the following period. From eq. 7, y_t can be obtained for each period. Campbell and Shiller (1987) showed that if P_t and y_t are both integrated of order 1 and if eq. 5 holds, then the two series are also co-integrated with a co-integrating vector $m, - 1$ Combining eqs. 6 and 7, it is possible to derive the explicit result:

$$P^e_{t+1} = F_{1,t} + (m + r)^* P_t \quad \textbf{(8)}$$

Campbell and Shiller (1987) suggested another method to obtain P^e_{t+1}, exploiting the fact that, under the hypothesis of the present value model, if $F_{1,t}$ and P_t are integrated of order 1, they are also co-integrated with a co-integrating vector (1, p - 1). Consequently, if P_t and $F_{1,t}$ are both integrated of order 1, p can be estimated from the co-integrating regression of P_t on y_t. Using this fact, p can be estimated in the co-integrating regression of $F_{1,t}$ on P_t and used to obtain P^e_{t+1}:

$$P^e_{t+1} = F_{1,t} + p\, P_t \quad \textbf{(9)}$$

Consequently, taking expectations:

$$E_t\, [P_{t+1}] = F_{1,t} + p\, P_t \quad \text{or, equivalently,} \quad P_{t+1} = F_{1,t} + p\, P_t + e_{t+1} \quad \textbf{(10)}$$

where e_{t+1} can be considered an expectation error, orthogonal to all the variables known at time t.

2.1.2 Solution of the problem of the competitive producer

Now, that we can determine $E_t\, [P_{t+1}]$, we go back to the problem of the competitive producer. We Rearrange eq. 4 and use eq. 10 for $E_t\, [P_{t+1}]$, to obtain:

[4] The correct arbitrage condition should have f_T,t, the forward price at t for delivery at $T + t$, instead of the future price. The difference comes from the fact that payments are at the end of the period in the case of forward contracts and at the beginning in the case of futures. Problems can arise if the risk-free rate is stochastic and correlated with the price of the commodity. We assume that this is not the case.

$$F_{1,t} * q_{t+1,i} \cong P_t * q_{t,i} - \rho * P_t * q_{t+1,i} + \frac{1-\theta}{\theta}\frac{U'(P_t * q_{t,i})}{U''(P_t * q_{t,i})} + \epsilon_t * q_{t+1,i}. \quad \textbf{(11)}$$

This expression can be interpreted easily as an arbitrage condition; the production in the second period, evaluated at the futures price, is equivalent to the current revenue corrected by two factors: (*i*) the average excess return on oil above the risk free interest rate (r); and *(ii)* the risk aversion and the discount rate characteristic of each country $\frac{U'(P_t * q_{t,i})}{U''(P_t * q_{t,i})}$. Note that the error term in this equation is correlated with one of the explanatory variables $(P_t * q_{t+1,i})$. This fact calls for the use of instrumental variables in the testing. Eq. 11 provides us with the ~mportant information that, absent strategic considerations, a producer chooses his output for the next period by taking into account only his own current period revemms and future prices. Additional variables, in particular the level of production of the other producers, are irrelevant to solving his problem since all relevant information about the market is already contained in P_t and $F_{1,t.}$

The specific form of the utility function is not determined. In eq. 11, we allow for two classes of specification: constant absolute risk aversion (CARA) and constant relative risk aversion (CRRA). For the case of CARA, eq. 11 reduces to:

$$F_{1,t} * q_{t+1,i} \cong P_t * q_{t,i} - \rho * P_t * q_{t+1,i} - \frac{1}{\gamma}\frac{1-\theta}{\theta} + \epsilon_t * q_{t+1,i} \quad \textbf{(12)}$$

where γ is the coefficient of risk aversion. And, for the case of constant relative risk aversion,

eq. 11 is as follows:

$$F_{1,t} * q_{t+1,i} \cong P_t * q_{ti} - \rho * P_t * q_{t+1,i} - \zeta\frac{1}{(P_t * q_{t,i})} + \epsilon_t * q_{t+1,i} \quad \textbf{(13)}$$

where ς (stands for the constant term $(P_t * q_t * \frac{U'(P_t * q_{t,i})}{U''(P_t * q_{t,i})}$ (coefficient of relative risk aversion).

2.2 Producer in a cartel

The alternative hypothesis is that OPEC producers behave in a collusive way. Of the many types of collusive dynamics possible in cartels, we follow Adelman's (1982) suggestion to consider a market-sharing agreement in which each OPEC country receives a fixed fraction of OPEC's total revenues. This is, is fact, the arrangement largely followed by all OPEC members except for Saudi Arabia, which is a swing producer.

The model proposed is a necessary simplification; while it is undoubtedly true that many specifications of collusive behavior of OPEC can be proposed, the market-sharing agreement model is a plausible one. The same characterization of the producers' behavior under the cartel has been used by Griffin.

Moreover, this formulation corresponds to OPEC's official rule: a target price is chosen and, subsequently, some production shares are assigned to the members; the shares do not change with production. Saudi Arabia has the role of swing producer and allows its production to change to accommodate temporary shocks in the market. Hence, the market-sharing specification should hold for all members of the cartel with the exception of Saudi Arabia.

Consequently, to test this hypothesis, we consider that the production of each country at time $t + 1$ is a fixed share (π_i) of total *OPEC* production:

$$q_{t+1,i} = \pi_i * \mathrm{OPEC}_{t+1}. \quad \textbf{(13)}$$

3 Testing OPEC behavior

In this section, we test (α) some of the restrictions that the model imposes on the joint behavior of the spot price *(P_t)* and price for delivery in the following month ($F_{1,t}$), and (*b*) the hypothesis of collusive behavior versus competitive behavior.

Before testing, we explain our data. P_t is taken to be the price on the futures contract for light Arab oil expiring in month *t*, while the price on the futures contract for light Arab oil expiring at time *t + 1* is used to obtain $F_{1,t}$; this convention is often used, because it gives two series of exactly the same goods at a fixed interval.[5] Finally, the price chosen is that for the futures traded in New York the first working day of each month from April 1983 to January 1992.

The source of the data for monthly production for each country is the *Monthly Energy Review.* The period considered is from June 1983 to July 1990. The beginning of the period is determined by the fact that futures were not traded on a regular basis before June 1983; the end of the period is the last month before the invasion of Kuwait, an event that considerably perturbed the futures market.

We adopt the convention that the monthly revenues are determined by the monthly production times the price for the futures contract expiring at the beginning of each month. This conventions has two obvious drawbacks:

1. Oil is not a homogeneous product; there are several kinds of oil with different prices. However, since all the prices are pegged to the futures for Arab light in a rather stable way, the relative prices should not change significantly.
2. The production is sold daily and not just one day per month. However, the futures price for the following month is by and large stable for that month.

To address these and other possible measurement errors, we use instrumental variables. The choice of the instrumental variables is specified in the appendix.

3.1 Testing the joint behavior of the prices

To check the presence of unit roots in the series for spot prices and future prices, we run the

following regression for each series:

$$P_t - P_{t-1} = \alpha + \beta t + (\rho - 1) * P_{t-1} + \lambda * \Delta P_{t-1} + \epsilon_t. \qquad \textbf{(15)}$$

If a series is integrated of order 1 with drift, the coefficient β should be 0 and *p* should be 1.

The restricted regression for price is as follows:

$$P_t - P_{t-1} = \alpha + \lambda * \Delta P_{t-1} + \epsilon_t \qquad \textbf{(16)}$$

[5] Using the spot price for the same period is a worse procedure because the futures contract is not completely comparable with the spot market.

Variable	Coefficient	St. Error	t-stat
CONSTANT	-0.07743	0.1984	-0.39012
d2	0.37449	0.0918	4.0781
number of observations 104 degrees of freedom 102			

Moreover, the unrestricted regression for prices is:

(17)

$$P_t - P_{t-1} = \alpha + \beta t + (\rho - 1)P_{t-1} + \lambda * \Delta P_{t-1} + \epsilon_t.$$

Variable	Coefficient	St. Error	t-stat
CONSTANT	2.930918	1.045757	2.802675
TREND	-0.8099016E-02	0.7080566E-02	-1.143837
SPOTL	-0.1149611	0.3573257E-01	-3.217265
d2	0.4313958	0.9016081E-01	4.784738
number of observations 104		degrees of freedom 102	

We run the same restricted and unrestricted regressions for future prices, obtaining the statistic given below:

Variable	t-test
Spot price	5.22
Future price	4.60

Using the Dickey-Fuller tables, we can reject the null hypothesis of unit root at 10 percent confidence level for spot price. However, in the case of the future price, we cannot reject the null hypothesis of random walk even at 10 percent. These inconclusive results are due to the

fact that the period considered spans only 8 years (April 1983-December 1991), too few to obtain conclusive results on the random walk hypothesis.[6]

Since we need an estimate of p, we run a regression of $F_{1,t}$ on P_t

$$P_{1,t} = \text{constant} + (1 - p) * P_t \qquad \textbf{(18)}$$

Variable	Coefficient	St. Error	t-stat
CONSTANT	0.1912149	0.1546135	1.236728
PRICE	-0.9821176	0.00667705	147.6193
number of observations 105		degrees of freedom 103	

[6] 6Given the limited power of Dickey-Fuller test, the failure to reject the hypothesis of random walk for spot price is only weak evidence in favor of random walk.
The problem does not depend on the number of observations available but on the length of the period considered. Oil futures contracts were traded regularly only after 1983. Taking the daily data of the same period would not solve the problem.
Moreover, other regressions on price of commodities to check the existence of random walk have been tried but yielded poor evidence of random walk, even considering a longer period. For instance, Pindyck (1991) uses monthly observations for 20 years for heating oil, copper, lumber, and gold and obtains the same weak evidence; and Pindyck and Rubirdeld (1991) use annual observations for 116 years for copper, oil and lumber, and, nevertheless, cannot reject the hypothesis of unit root for the real price of lumber even considering such a long period.

We use the following regression to check if the residuals of this regression are I(0):

$$\Delta \hat{u}_t = \text{constant} + \gamma \hat{u}_{t-1} + \delta \Delta \hat{u}_{t-1} + \omega \Delta \hat{u}_{t-2} + \phi \Delta \hat{u}_{t-3}. \quad \textbf{(19)}$$

Variable	Coefficient	St. Error	t-stat
CONSTANT	-0.5860360E-01	0.1977698	-0.2963222
RES	-0.8447312	0.1494046	-5.653982
DRES1	0.2458638	0.1306478	1.881882
DRES2	0.2195385	0.1170086	1.876260
DRES3	0.9746233E-01	0.1025631	0.9502670
	number of observations 100		degrees of freedom 95

The *t* statistic of the term *res* (= $\hat{u}_{t-1}$) must be evaluated using the augmented Dickey-Fuller tables. The hypothesis H: *u*= I(1) is rejected at 1 per cent confidence level, so we can reject the hypothesis that spot and future prices are spuriously correlated.[7]

The second hypothesis we test is that P *t* and $F_{1,t,}$are sufficient in forecasting $P^e_{t+1.}$ We check this hypothesis with F-statistics with the regressions given below:

$$\Delta P_t = \alpha + \beta F_{1,t-1} + \gamma P_{t-1} + \delta\ \text{US}_t + \zeta\ \text{OPEC}_t + \phi\ \text{STOCK}_t + \theta\ \text{DOL}_t + \eta\ \text{INDUS}_t + \epsilon_t \quad \textbf{(20)}$$

where ΔP_t is the variation in price, and the other variables are explained at the beginning of the empirical section. These variables, US_t, OPEC_t, STOCK_t, DOL_t, INDUS_t, regarding the world demand and supply, could help in forecasting the change in the oil price beyond the spot and pictures prices. The results of the regression are the following:

Variable	Coefficient	St. Error	t-stat
CONSTANT	40.82057	16.35023	2.509133
FUTU	-0.2555975	0.6482886	-0.3942651
PRICE	0.1366839	0.6303065	0.2168530
US	-0.2844126E-02	0.9595904E-03	-2.963896
OPEC	-0.1407132E-03	0.1336648E-03	-1.052732
STOCK	-0.9458251E-03	0.2839866E-02	-0.3330527
DOL	3.936057	2.676289	1.470715
INDUS	-0.1131549	0.5560431E-01	-2.035002

[7] Sometimes the Durbin-Watson statistics is also used to test the hypothesis of a "spurious co-integration," even though the augmented Dickey-Fuller test is the correct one. In the present example, the hypothesis that the residuals follow a random walk (DW=0) is rejected at I percent: the critical value for 100 observations is 0.511, well below the DW statistics in the regression above (DW 2.004). In a co-integrated regression, the residuals do not need to be white noise. In particular, the residuals present heteroscedasticity; in fact, a Breusch Pagan test on the variance of the residuals fails to reject at 5 percent confidence level that the variance of the residuals is correlated over time.

number of observations 86	degrees of freedom 78

The F statistics for the joint restrictions d = q = z = f = h = 0 is 1.956, and the null hypothesis is accepted at 5 percent confidence level. So these variables (US, OPEC, STOCK, DOL, INDUS) are jointly not significant in forecasting the variation of oil prices.

These results allow us to rewrite equation 1 as:

$$U'(P_t * \ q_{t,i}) = \frac{1+\delta}{1+r} E_t U'(P_{t+1} * \ q_{t+1,i} | P_t, F_{1,t}) \qquad \textbf{(20)}$$

3.2 Testing the behavior of the producers

The estimation of eq.11 presents the problem that the residuals are correlated with the explanatory variable ($P_t * q_{t+1,i}$). Therefore, we use the method of *2SLS* in all the following regressions.

The choice of the set of instruments is naturally suggested by the model itself; since the instruments must be correlated with the revenues of each country but uncorrelated with its current production, we use instruments that typically affect the demand for crude oil of OPEC producers. Natural candidates are: the current industrial production in the OECD economies ($INDUS_t$), the level of stock of oil in the OECD economies ($STOCK_t$), the current production in the USA (US_t), a weighted index of the dollar (DOL_t),[8] and three dummy variables for seasonality in the demand of crude oil. All these instruments are correlated with the price, but unfortunately, some of them are also correlated with current production of some specific countries. For instance, the current oil production in the US is correlated with the price of oil but it is also correlated with the current production in Venezuela; so it cannot be used as an instrument in the equation for Venezuela, given the correlation with the residuals. So, for each country, we use only a subset of these variables as instruments for the explanatory variables ($P_t * q_{t,i}$ and ($P_t * q_{t+1,i}$). The choice depends on the correlation the

[8] The sources for the data for all these variables have been specified previously.

production of the specific country with these variables.

The following hypotheses are tested:

1. Supposing that the countries follow an Euler equation (eq. 11), do the data fit a utility function with constant *relative* risk aversion or constant *absolute* risk aversion?
2. Supposing that the countries have constant, absolute risk aversion, do the data fit the values imposed by the model: coeficient for $P_t{*}q_{t,i}\ i$ is 0 and the coefiicient for $P_t * q_{t+1,i}$)(-*p*) is -0.01457?

3. Do the producers follow an Euler equation or is there a cartel with a market-sharing agreement?

Constant relative vs constant absolute risk aversion. Results of a *t*-test on equation (eq. 11) for the null hypothesis H_0: $\varsigma = 0$ are:[9]

$$(F_{1,t} * q_{t+1,i}) = \alpha + \beta(P_t * q_{ti}) - \gamma(P_t * q_{t+1,i}) - \zeta\left(\frac{1}{(P_t * q_{ti})}\right) + \epsilon_t \quad \textbf{(22)}$$

COUNTRY	t-TEST	SIGNIFICANCE LEVEL
KUWAIT	0.82	0.37
IRAN	0.76	0.38
IRAQ	0.34	0.56
NIGERIA	1.45	0.23
QATAR	2.84	0.10
INDONESIA	1.71	0.38
UAE	0.10	0.92
VENEZUELA	2.36	0.13
LIBYA	0.93	0.33
SAUDI ARABIA	1.77	0.18

number of obs 86 degrees of freedom 78

We camot reject the null hypothesis of $\varsigma = 0$ even at 10 percent of confidence level (i.e. the hypothesis of constant absolute risk aversion cannot be rejected) for all the OPEC countries. Since the equations estimated present a high degree of multicollinearity among the explanatory variables, the sampling variances are very high,[10] and the estimates of the parameters are very sensitive to small variations in the data. An F-test on the joint restriction $\beta = \gamma = 0$ rejects the null hypothesis at an confidence level of I percent for each equation.

The results must be qualified because for some countries (Saudi Arabia and Libya) the Durbin-Watson

[9] the complete results of the regressions are in the appendix. It is not correct to estimate jointly eq. 21 for all countries or to use a methodology that takes into account possible correlations of errors across equations (SUR) because some equations are probably specified incorrectly (both the null and the alternative hypotheses are correctly specified only if all producers follow a Euler equation).

[10] This is also the reason why the t statistics associated with such parameters are often very low.

statistics in the unrestricted model (see the appendix) reveal a problem of serial correlation in the residuals.[11] This fact is probably due to the misspecification of the model for these countries. This is precisely what the model predicts for Saudi Arabia, given that the hypothesis of no market power underlying eq. 11 is not plausible for Saudi Arabia, the biggest oil supplier.

Do the data fit the restrictions on the parameters? The rational expectation model developed in the first part suggests some restrictions on parameters. In particular, eq. (12) imposes these restrictions on the parameters: the coefficient on the term ($P_t * q_{t,i}$)should be 1 and the coefficient on the term ($P_t * q_{t+1,i}$)should be equal to -*p* for all the countries. In the first part, we found ρ = 0.0178824. Using an F-test, we tested the joint restrictions β = 1 and γ = -0.0178824 in the following equation for each country:

$$(F_{1,t} * q_{t+1,i}) = \alpha + \beta(P_t * q_{t,i}) + \gamma(P_t * q_{t+1,i}) + \epsilon_t. \quad \textbf{(23)}$$

The reafits of the F-test for the null hypothesis H0 are: β = 1 and γ = -.0178825.

COUNTRY	F-TEST	SIGNIFICANCE LEVEL
KUWAIT	1.83	0.17
IRAN	0.32	0.73
IRAQ	0.06	0.94
NIGERIA	1.74	0.60
QATAR	20.68	0.00
INDONESIA	3.37	0.04
UAE	3.65	0.03
VENEZUELA	1.40	0.25
LIBYA	9.66	0.00
SAUDI ARABIA	26.65	0.00

number of observations 86   degrees of freedom 78

The results show that production by Iran, Iraq, and Algeria fit quite well the parameter restrictions imposed by the model derived from the Euler equation (H_0: β = 1 and γ = -.0178825), in contrast with the behavior of the other countries. This provides evidence of quite a different behavior of these countries and it is one of the main conclusions of this paper.

Note that, given that the parameter *p* has been estimated using a limited set of data (April 1983-January 1992), the value *p* = 0.0178825 used in the restrictions of the present regression is not completely reliable. Moreover, the

[11] Since the regression for Saudi Arabia and UAE the DW statistics are inconclusive, we report the Ljung-Box statistics based on 27 lags: $Q = T(T+2)\sum_{j+1}^{L} \frac{r_j^2}{T-j}$ where *T* is the number of observations (=85), r_j is the correlation between errors at *j* lags, and *L* is the number of lags considered. For Saudi Ararbia and UAE, the values of Q are respectively 37.17 and 42.41. The hypotheses of no serial correlation in errors are rejected at 10 percent confidence level for Saudi Arabia and at 5 percent for Libya.

model is valid only under the hypotheses discussed in the introduction (in particular the absence of market power) and with a constant absolute risk aversion utility. These underlying hypotheses are clearly not satisfied in the case of Saudi Arabia and other small countries (i.e. UAE) in the Gulf, whose production strictly correlated with that of Saudi Arabia. Therefore it is not surprising that the F-tests reject the null hypothesis for these countries.

Do the producers follow an Euler equation or do they follow a market-sharing agreement? In order to check the hypothesis that some producers simply follow a dynamic optimization rule against the alternative hypothesis that the cartel has market-sharing agreement, we use the nested model below to test the restriction that the coefficient of the term ($F_{1,t} *$ OPEC$_{t+1}$) is 0:[12]

$$(F_{1,t} * q_{t+1,i}) = \alpha + \beta(P_t * q_{t,i}) + \gamma(P_t * q_{t+1,i}) + \pi_i(F_{1,t} * \text{OPEC}_{t+1}) + \epsilon_t \qquad \textbf{(24)}$$

The t-tests for the restriction $\pi_i = 0$ give the following results [13]

COUNTRY	t-TEST	SIGNIFICANCE LEVEL
KUWAIT	0.80	0.37
IRAN	0.24	0.62
IRAQ	0.74	0.78
NIGERIA	0.11	0.74
QATAR	0.0005	0.994
INDONESIA	0.34	0.56
UAE	0.17	0.68
VENEZUELA	0.29	0.59
LIBYA	0.04	0.84
SAUDI ARABIA	4.07	0.05

number of observations 86 degrees of freedom 78

The above results should be qualified because eq. 24 is incorrectly specified for some countries (Saudi Arabia and Libya). The results indicate that for almost all the countries, the null hypothesis is not rejected at a very high level of significance. Given the specific form of the model for collusive behavior, this test gives only weak evidence against collusive behavior.

In his empirical study of the OPEC cartel, Gritfm also specifies collusive behavior with the help of a market-

[12] This procedure can be seen as a Hausman specification test, given that the modei as specified in eq. 24 is surely consistent (the producers behave either as members of the market-sharing cartel or as single profit maximizers). However, the estimation of eq. 24 with the restriction $p = 0$ is efficient only if the producers follow their own Enler equation.

[13] The complete results are in the appendix.

sharing agreement model. However, our empirical results are in contrast to his findings.[14] Griffin writes "... attempts to improve the performance of the competitive model by the introduction of a lagged oil reserves variable failed to alter the conclusion. Even experimentation with a dynamic demand formulation, allowing for lagged price effects, likewise failed to alter the overall conclusion." In this paper, we have shbwn that the use of the Euler equation, combined with hypothesis of the rational forecasting of prices, can give a valid specification for the competitive model that was lacking in Griffin's analysis.

4 Conclusion

The purpose of this paper was to test alternative theories of OPEC behavior. In contrast with previous empirical studies (i.e., Griffin 1985), our approach was based on the possibility of testing the *dynamic* implications of the behavior of the competitive producer versus the collusive producer.

Following Griffin, we modelled the collusive behavior as a market-sharing cartel. It makes sense to test the behavior of a competitive producer using Euler equations. Note that the use of an Euler equation sidesteps the difficult issues related to the demand estimation. The chief cost of estimating an Euler equation lies in the need to specify a utility function for the producers. We wish to point out that the estimation of the models proceeded under quite weak hypotheses on the specific shape of the .utility function (the tests are valid for all the functional forms with constant relative or absolute risk aversion).

The estimation of the Euler equation requires estimating $P^e_{t+1:}$. The first part of the paper dealt with the problem of the sufficiency of P_t and $F_{1,t}$ in forecasting P^e_{t+1}. We tested the presence of a unit root in the spot and in futures prices. The results were not conclusive because of the short period available. Nevertheless, we could not reject the hypothesis of a unit root only at a 10 percent confidence level in the spot price series, while rejection also was not possible in the case of futures prices. The tests for co-integration between spot and futures prices gave clear results; the hypothesis of no co-integration was rejected at 1 percent confidence level. The value of ρ (which is an element of the co-integrating vector and economically represents the monthly expected excess return on oil) was 0.0178824 (23.7 percent annually), quite a high value.

In the second part of the paper, we relied on the result that a linear combination of $_{Pt}$ and F $P_{1,t}$ provides a sutticient and unbiased estimator for $P^e_{t+1.}$ Our findings were as follows:

[14] Note that the samples are quite different: Griffin uses quarterly data in the period 1971-1983

- we could not reject the hypothesis of constant absolute risk aversion even at a 20 percent confidence level for all the countries except three (Venezuela, Qatar, Saudi Arabia);
- we tested jointly the restrictions on parameters imposed by the structure of the model of rational expectations of the price (i.e., the coeffiicient of the terms $(P_t *q_{t=1,i})$ and $(P_t * q_{t+1,i})$ should be, respectively, *-p* and 1). In this case we used the estimated value of ρ. The test cannot reject the restrictions on parameters even at a 60 percent confidence level for some countries (Iran, Iraq, Nigeria). For some countries (Saudi Arabia, Libya, Qatar), however, the hypothesis was clearly rejected at a 1 percent confidence level. We wish to emphasize that the above findings constitute one of the main conclusions of this paper;
- finally, we attempted to test the hypothesis of "competitive" behavior against the alternative hypothesis of a cartel with a market-sharing agreement. The results indicated that, except for Saudi Arabia, the hypothesis of "market-sharing cartel" could be rejected at a very high confidence level. However, this test provided only weak evidence of the absence of collusive behavior because the alternative hypothesis (market-sharing agreement) was only one of the possible cartel agreements. Even though our specification of "market-sharing cartel" was similar to that adopted by Griffin, our findings were different.

In all these regressions, Saudi Arabia showed singular behavior[15]. This was explained by the fact that Saudi Arabia is the largest producer in OPEC and the price of Saudi oil cannot be considered exogenous. On the other hand, Iraq, Iran, and Nigeria fit all the restrictions imposed by the model quite well - in particular, the restrictions imposed on the parameters in the second test (the hypothesis that these countries behave as dynamic profit maximizers with constant absolute risk aversion can be rejected only at a 60 percent confidence level, in contrast with the other OPEC countries).

Iraq and Nigeria were classified by Eckbo (1976) as the "expansionist fringe" in OPEC because of their continuous push to increase oil production; in the period considered, Iran also behaved as the expansionist fringe, compelled by the necessities of the war. Moreover, in the 1980s, there was a common view that these countries often cheated on the cartel agreements. The empirical evidence of this paper confirmed this division within OPEC' and indicated that this "expansionist fringe" behaved simply as a revenue maximizer that follows an Euler equation based on rational forecast. In the model provided by Griffin to test the hypothesis of competitive model versus

[15] The F-test gave a low value and the residuals seemed correlated.

monopolistic model for the period 1971-1983, the hypothesis that Iraq behaves in a competitive way could not be rejected even with a weak specification of the competitive model.

Future work should attempt to test collusive against competitive behavior more effectively; in particular, it will be necessary to specify more fully the cartel's behavior, taking into account the complexity of a dynamics with one strong producer (Saudi Arabia) and various weak producers (Nigeria, Indonesia, Iran).

5 Appendix: Note on the data

In all the regressions, the number of observations for each equation is 85. The t-statistics are in parenthesis below the parameters. For each regression, we use two-stage least squares. The instruments used are a subset of the following variables: $STOCK_t$, US_t, $LINDUS_{t-1}$. US_t is the production of oil in the USA, $STOCK_t$ is the total stock of oil in the OECD countries at the end of period t, DOL_t is a trade weighted index of the dollar, while $LINDUS_t$ is the logarithm of the synthetic index of total manufacturing activity in the OECD countries in period t. For Nigeria, UAE, Iran, and Qatar, $LINDUS_{t-1}$ is replaced by the index of manufacturing activity. For Venezuela and Kuwait, a dummy variable for winter is used. For Nigeria, Iran, and Venezuela we use $LINDUS_t$, while for all the other countries $INDUS_t$ was used instead. For UAE, Libya, Saudi Arabia, Qatar, Kuwait, and Iraq (the Arab countries) we used US_t instead of Us_{t-1}. The variable ($F_{1,t}$ * $OPEC_{t+1}$) was not instrumented since it was not correlated with the errors. For all the countries we used as instruments: $STOCKt_{t-1}$, US_t, $LINDUS_t$. For Nigeria, Venezuela, and Indonesia we used $STOCK_t$ instead of $STOCK_{t-t}$.

The sources are *Monthly Energy Review* for OPEC, STOCK, and US; *OECD Official Statistics* for INDUS; and *Financial Times* for DOL.

5.1 Estimation of eq. (22)

$$(F_{1,t} * q_{t+1,i}) = \alpha + \beta(P_t * q_{t,i}) - \gamma(P_t * q_{t+1,i}) - \zeta(\frac{1}{(P_t * q_{t,i})}) + \epsilon_t \qquad H_0 : \zeta = 0 \qquad \textbf{(25)}$$

Country	α	β	γ	ς	DW	R^2
NIGERIA	-9872	1.282	-0.140	0.14E+9	1.85	.986
	(-1.21)		(4.24)	(-.47)	(1.21)	
UAE	64.21	0.57	0.42	106796	1.61	.976
	(.046)	(2.17)	(1.60)	(0.10)		
QATAR	-1158	0.86	0.20	0.38E+7	2.04	.993
	(-1.77)	(7.57)	(1.52)	(1.69)		
INDONESIA	-5864	1.28	-.19	0.82E+8	1.71	.991
	(-1.01)	(0.78)	(-.n)	(1.00)		
IRAQ	-12531	0.07	1.07	0.29E+9	1.78	.968
	(-.56)	(0.11)	(1.34)	(0.59)		
LIBYA	-2959	0.71	0.34	0.32E+8	1.52	.990
	(-.98)	(3.20)	(1.54)	(0.97)		
S. ARABIA	-14190	0.80	0.26	0.66E+9	1.37	.994
	(-1.53)	(7.70)	(2.08)	(1.33)		
VENEZUELA	-7812	0.59	0.50	0.15E+9	1.59	.993
	(-1.54)	(1.27)	(1.04)	(1.54)		
KUWAIT	-6528	0.60	0.49	0.96E+8	1.58	.976
	(-0.86)	(2.16)	(1.54)	(0.91)		

A.2 Estimation of eq. (19)

$$(F_{1,t} * q_{t+1,i}) = \alpha + \beta(P_t * q_{t,i}) + \gamma(P_t * q_{t+1,i}) + \epsilon_t \qquad \textbf{(26)}$$

Country	α	β	γ	DW	R^2
NIGERIA	-1980	1.60	-.55	1.74	0.94
	(-.73)	(2.06)	(-.76)		
UAE	- 525	0.24	0.25	1.58	0.97
	(-.36)	(2.37)	(1.78)		
QATAR	- 236	0.84	0.18	1.94	0.99
	(-1.33)	(5.72)	(1.21)		
INDONESIA	- 541	0.66	0.35	1.94	0.99
	(-1.22)	(1.34)	(0.70)		
	1686	-.21	1.18 '	1.73	0.87
	(.74)	(-.24)	(1.29)		
	- 370	0.76	0.24	1.37	0.99
	(-.91)	(4.10)	(1.29)		
S. ARABIA	-2672	0.77	0.24	1.40	0.99
	(-1.77)	(6.48)	(1.99)		
VENEZUELA	-1090	0.25	0.77	1.94	0.99
	(-1.19)	(0.29)	(0.90)		
KUWAIT	- 307	0.56	0.44	1.60	0.97
	(-.24)	(1.74)	(1.36)		

A.3 Estimation of eq. (20)

$$\left(F_{1,t} * q_{t+1,i}\right) = \alpha + \beta\left(P_t * q_{t,i}\right) + \gamma\left(P_t * q_{t+1,i}\right) + \tau\left(F_{1,t} * \mathrm{OPEC}_{t+1}\right) + \epsilon_t \qquad \textbf{(27)}$$

Country	α	β	γ	t	DW	R^2
NIGERIA	- 37	0.48	0.48	0.002	1.71	0.95
	(-.40)	(0.82)	(0.77)	(0.28)		
UAE	- 85	0.57	0.41	0.001	1.61	0.98
	(-.i4)	(2.42)	(1.61)	(0.37)		
QATAR	- 59	0.83	0.17	0.00	2.01	0.99
	(-.41)	(5.30)	(1.14)	(0.01)		
INDONESIA	-373	0.06	0.93	0.01	2.55	0.97
	(-.39)	(0.05)	(0.75)	(0.15)		
IRAQ	389	0.58	0.40	0.00	1.42	0.99
	(0.66)	(2.29)	(1.54)	(0.38)		
LIBYA	- 41	0.81	0.17	0.001	1.30	0.99
	(-.~4)	(5.05)	(1.m)	(0.52)		
S. ARABIA	816	0.87	0.19	-.02	1.32	0.99
	(0.59)	(7.30)	(1.73)	(-1.90)		
VENEZUELA	-698	-.92	1.87	0.01	2.54	0.95
	(-.45)	(-.29)	(0.59)	(0.48)		
KUWAIT	-288	0.45	0.50	0.04	1.68	0.96
	(-.38)	(1.16)	(1.26)	(0.88)		

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