Testing for the cartel in OPEC: noncooperative collusion or just noncooperative?

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Abstract

This paper extends the framework of Green and Porter (1984) and Porter (1983a) to nest the case of a cartel (OPEC) faced by a competitive fringe (non-OPEC oil producers). Estimation of a simultaneous equation switching regression model allows us to examine which market structure better characterizes the world oil market during the 1974-2004 period and to test whether switches between collusive and noncooperative behavior occurred. The null hypothesis that no switch occurred is rejected in favor of the alternative that both cooperative and non-cooperative behavior was observed. We find that, although there were periods in which oil prices were measurably higher due to collusion among OPEC members, overall OPEC has not been effective in systematically raising prices above Cournot competition levels. Our results suggest that, on average over the period of study, OPEC's behavior is best described as Cournot competition in the face of a competitive fringe constituted by non-OPEC producers.

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1 Introduction

The Organization of Petroleum Exporting Countries (OPEC) was formed at the Baghdad Conference on September 10–14, 1960 with the aim of coordinating and unifying petroleum policies among the member countries[1] "in order to [among other purposes] secure fair and stable prices for petroleum producers".[2] In spite of this goal, the history of crude oil prices since the formation of OPEC suggest to some that prices are instead determined in a competitive market, perhaps interspersed by occasional attempts to restrict output that invariably unravel. That is to say that, as a cartel, OPEC has not been successful in controlling oil prices. Indeed, there appears to be no clear consensus in the empirical literature regarding OPEC's stability as a cartel or its ability to influence prices.

However, it is well-known that in an environment with significant demand shocks, the optimal strategy for a cartel could result in periods of price wars that help enforce collusion in the long run (Green and Porter, 1984; Porter, 1983a). That is, periods of price wars may represent the equilibrium outcome of a dynamic noncooperative game as shown in Green and Porter (1984). Thus, whether fluctuations in the crude oil price reflect switches from collusive to non-cooperative behavior or whether they reflect the normal behavior of a competitive market is ultimately an empirical question. The objective of this paper is to address this issue using a modified version of Porter's (1983a) model to test whether such switches in OPEC's behavior took place during the 1974-2004 period.

By following Porter's (1983a) approach, the analysis in this paper departs from the previous literature on OPEC behavior in several aspects. First, we estimate a structural model instead

[1] The five founding members are Saudi Arabia, Iran, Iraq, Kuwait and Venezuela. The current members also include Algeria, Indonesia, Nigeria, Libya, Qatar and the United Arab Emirates. Angola joined the organization in 2007 and Ecuador returned to the orginaization in 2007 after suspending its membership in 1992. Indonesia suspended its membership in OPEC effective January, 2009.

[2] See http://www.opec.org/opec_web/en/about_us/23.htm

of relying on a reduced form estimation approach. Whereas a fair number of theoretical models for OPEC behavior were put forward in the last 25 years, of the few that have been empirically tested, the vast majority follows Griffin's (1985) seminal work in its single-equation approach. In contrast, we start from an equilibrium model of dynamic oligopoly, which in conjunction with specific functional forms for the demand and cost functions determines a simultaneous switching equations model to be estimated.

Second, we study the organization as a whole, instead of considering the individual supply functions for each member country separately as in Griffin (1985). As a result, we are able to estimate a collusive indicator for OPEC. That is, Porter's (1983a) framework enables us to test for switches between collusive and non-cooperative behavior, to identify the periods in which these switches occurred, and to estimate the probability of being in a collusive period.[3]

Beyond these econometric advantages, there are good theoretical and institutional reasons for treating OPEC as a whole. First, in Green and Porter's (1984) model the organization is considered as a whole, e.g. punishment phases should begin jointly. Second, to the extent that oil prices are calculated as the average of the members' crude oil streams,[4] it appears to be reasonable to assume that firms use this market price to monitor collusion, which imperfectly reflects output levels of other countries (Green and Porter, 1984). Third, from the institutional perspective, there is ample evidence that individual members frequently respond directly to other members' outputs in such a way that overall OPEC behavior vis-à-vis the world market remains roughly unchanged (see for instance Gately, 1989).

[3] Modified versions of the Green and Porter (1984) and Porter (1983a) methodology has been applied to study the U.S. airline industry (Brander and Zhang, 1993; Busse, 2002), the U.S. bromine industry (Levenstein, 1997), the U.S. online book sale market (Clay, Smith and Wolff, 2004), Ontario's oil industry (Grant and Thille, 2001), the Australian coal mining companies behavior (Fleming, 2000), entry into the British merchant shipments in periods of price wars (Scott-Morton, 1997); and Spain's electricity market (Fabra and Toro, 2004). Yet, to the best of our knowledge, it has not been used to study OPEC's cartel stability.

[4] As of June 2005, OPEC's reference basket now consists of eleven crude streams representing the main export crudes of all member countries.

In addition to taking a different approach to testing OPEC's behavior we also extend Porter's (1983a) setup to reflect how OPEC differs for the Joint Executive Committee railroad cartel examined by him. Specifically, we allow for non-OPEC producers to be treated as a competitive fringe. Because OPEC's production accounts for only 40% of the world's supply of crude, in considering whether to deviate from the collusive outcome, an OPEC member must take into account how the fringe will respond to the resulting price decrease. This modification is key in testing for switches in cartel behavior and in exploring which market structure better fits the world oil market during the period under analysis. That is, our specification permits us to test across many potential market structures including perfect competition and alternative specifications of imperfectly competitive market structures with and without a competitive fringe.

A novel result of this paper is our finding of significant switches between collusive and noncooperative behavior during the 1974-2004 period. That is, we find evidence of collusion, especially during the early 1980s. We estimate the probability of being in a cooperative period to be 34%, with periods of collusion resulting in 69% higher oil prices relative to periods of quantity competition and a 11% decline in OPEC production. Interestingly, the magnitude of the increase in prices and the decline in OPEC's production is more than that estimated to result from military confrontations involving any OPEC member country. As a result, whereas periods of collusion result in a 49% rise in OPEC revenues, the increase resulting from the negative supply shock that represents a military conflict represents a 32% increase in OPEC total revenues.

Regarding the market structure that best fits the world oil market during the 1974-2000 period, we find statistical evidence that, on average, OPEC did not behave as an effective cartel but as a non-cooperative oligopoly. Overall, our estimates are consistent with OPEC behaving as in Cournot competition in the presence of a competitive fringe.

The remainder of this paper is organized as follows. Section 2 briefly reviews the literature on the behavior of OPEC. Section 3 presents the model and the hypotheses that are tested. In Section 4 the data used is described. In Section 5, the results and interpretations obtained are discussed and Section 6 concludes.

2 OPEC Cartel Behavior: A Brief Literature Review

Not surprisingly, the rising preeminence of OPEC in the late 1970s and the increased perception that the organization could influence world oil prices, spurred empirical investigations into OPEC's behavior as a cartel.[5] Yet, there appears to be no clear consensus in the literature regarding OPEC's ability to influence prices. On one hand, a number of studies in the 1980s and early 1990s contend that OPEC behaved as a collusive cartel during some or all of the 1970s and early 1980s. For instance, the seminal work of Griffin (1985) tests individual countries' behavior among both OPEC and non-OPEC members for the period 1971-1983. He finds that most OPEC members behave as if they were part of a collusive cartel while non-OPEC countries behave as if in Bertrand competition. Later work by Jones (1990) finds analogous results for the 1983-1988 period, whereas Loderer (1984) suggests that OPEC was only able to influence oil prices between 1981 and 1983.

On the other hand, later studies such as Spilimbergo (2001) find no support for the hypothesis that OPEC was a market sharing cartel during the 1983-1991 period. Similar results have been found by other authors using different econometric techniques. For instance, Gülen (1996) examines whether OPEC is a cartel whose members agree on their role assigned by the organization in an output rationing framework, and whether OPEC has the power to affect the market price of oil by adjusting its production. Using cointegration tests for the period 1965-1993, he finds that overall OPEC is not a cohesive organization. Griffin and Xiong (1997) calculate joint-profit-

[5] See Alhajji and Huettner (2000) and Smith (2005) for excellent summaries of the extant literature.

maximizing price paths and find evidence that for some countries it is more profitable to cheat on the assigned quota, despite the possibility of punishment if caught. Alhajji and Huettner (2000) test the dominant producer hypothesis for OPEC, the OPEC core and Saudi Arabia when non-OPEC oil producers are treated as a competitive fringe. They find evidence that neither OPEC nor the OPEC core can be considered as dominant producers. More recently Smith (2002) concluded that OPEC's market structure lies between a non-cooperative oligopoly and a cartel.

As we will see later, our work sheds some light on this controversy as it not only explores which market structure better fits the data for the overall 1974-2004 period, but also estimates an indicator of collusion periods. In fact, our estimation results suggest longer periods of collusion during the 1970s and early 1980s than during the later part of the sample. This result is consistent with the findings of earlier studies, which suggest OPEC behaved as a collusive cartel during some or all of the 1970s and early 1980s. On the other hand, the estimated indicator of collusion points towards longer periods of price wars during the mid-to-late 1980s, the 1990s and early 2000s. This result falls in line with the findings of later studies that, using longer or more recent samples, find that OPEC does not behave as a cohesive organization.

3 The Econometric Model

In this section we describe the model employed by Porter (1983a) to test the cooperative behavior hypothesis for the Joint Executive Committee of railroads (hereafter JEC), modified to reflect the structure of the world oil market. The econometric model proposed by Porter is aimed at estimating the Nash equilibrium model developed in Green and Porter (1984) using 1880-1886 data for the JEC. Hence, he proposes a simultaneous equation switching regression model in which the regime classification is unknown and the parameters of the demand and cost functions are estimated using aggregate output and price data. Furthermore, he estimates the level of competition in a market where each of the cartel members assumes that a drop in demand could be explained either as an exogenous shock to the demand function or as a member's deviation from the collusive output, which may trigger a punishment stage.[6]

Similarly, in this paper, we are interested in testing for switches in OPEC's behavior and evaluating whether the pattern of switches is consistent with the model proposed by Green and Porter (1984). However, whereas the JEC controlled virtually all of the freight shipments during the 1880's in the U.S., the market share of OPEC is significantly smaller (42% on average over the sample). Hence, to reflect the structure of the oil market we modify Porter's supply function so as to enable us to treat non-OPEC members as a competitive fringe. Furthermore, this modification allows us to test the whether or not the fringe exerts a statistically significant impact on OPEC's ability to act as a cartel.

Following Green and Porter (1984), we assume the demand for OPEC oil is given by a loglinear function of price and a set of demand shifters:

$$\ln opec_t = \alpha_0 + \alpha_1 \ln p_t + \alpha_2 OECD_t + \alpha_3 \ln nopec_t + \alpha_4 dummies_t + U_{1t}, \tag{1}$$

where $\ln opec_t$ is the logarithm of OPEC's oil production, $\ln p_t$ is the logarithm of world oil prices, $OECD_t$ is the log growth of GDP for OECD countries, $\ln nopec_t$ is the logarithm of oil production by non-OPEC countries, and $dummies_t$ is a vector of seasonal dummies. U_{1t} is an error term assumed to be i.i.d. normal with mean zero and variance σ_1^2.

The coefficient α_1 is the price elasticity of demand for OPEC oil, which is expected to be negative and greater than 1 in absolute value if OPEC indeed maximizes profits as a dominant producer operating in the elastic segment of the demand curve.[7] To proxy for the effect of changes

[6] See Tirole (1988) p. 262 for a concise summary of the model.
[7] See Alhajji and Huettner (2000).

in the world's income on the demand for oil we use the log change in $OECD_t$ production. Although we are aware that a measure of global GDP would be a better proxy, data for the world's GDP is not available at a quarterly frequency. In addition, we use the log growth and not the log of output to ensure that all variables in the demand function are stationary. Thus, it is important to note here that α_2 cannot be interpreted as the elasticity of demand with respect to income. That is, a negative sign on this coefficient does not imply that oil is an inferior good; a negative sign would merely represent the (positive) rate at which demand for OPEC oil decreases when the income for OECD countries increases. Finally, the coefficient on $\ln nopec_t$, α_3, is expected to be negative, since it is the substitute good for OPEC oil.

For the supply equation, it is assumed that OPEC chooses the quantity to be produced (which is consistent with the stated policy at a majority of their meetings). Then the world price is set and the competitive fringe produces where the world price equals their marginal cost. World demand, Q^w, is given as the sum of non-OPEC output, Q^{no}, and OPEC output, Q^o, where OPEC output is the sum of each OPEC country's production:

$$Q^w = Q^o + Q^{no}, \text{ where } Q^o = \sum q_i. \tag{2}$$

Each OPEC member country, indexed by i, maximizes the usual profit function,

$$\pi_i = p_t q_{it} - C_i(q_{it}). \tag{3}$$

Here $C_i(q_{it})$ is the cost of production for country i. The first order condition for country i is obtained by differentiating (3) with respect to quantity supplied, so that:

$$\frac{\partial \pi}{\partial q_i} = 0 \Rightarrow p_t + q_i \frac{\partial p_t}{\partial q_i} = MC_i \Longleftrightarrow p_t + q_i \frac{\partial p_t}{\partial Q^w} = MC_i. \tag{4}$$

Where the final equivalency follows from $\frac{\partial p}{\partial q_i} = \frac{\partial p}{\partial Q^w}\frac{\partial Q^w}{\partial Q^o}\frac{\partial Q^o}{\partial q_i} = \frac{\partial p}{\partial Q^w}$, with $\frac{\partial Q^w}{\partial Q^o} = \frac{\partial Q^o}{\partial q_i} = 1$.

The first order condition (4) can be rewritten as

$$p_t\left[1 + \frac{q_i}{p_t}\frac{\partial p_t}{\partial Q^w}\right] = MC_i. \tag{5}$$

Furthermore, defining the market share for OPEC as $s^o = Q^o/Q^w$ and the market share of country i within the organization as $s_i = q_i/Q^o$, then the share of country i's production in world output is given by $q_i/Q^w = s_i \times s^o$. As in Porter (1983a), we assume that the oil produced by each country is of similar (i.e., equivalent) quality. Therefore, in equilibrium, each OPEC country obtains the same price. Thus, rearranging the first order condition (5) it follows that

$$p_t\left[1 + \frac{\theta_{it} \times s^o}{\epsilon^w}\right] = MC_i, \tag{6}$$

where $\epsilon^w = \frac{\partial Q^w}{\partial p}\frac{p}{Q^w}$ is the price elasticity of world oil demand.

Notice that in line with Porter's derivation, the parameter θ_{it} is included in Equation (6) and defines five market structures as follows:[8]

1. If OPEC members exhibit noncooperative behavior and they price at marginal cost then we have evidence of Bertrand competition. In this case, $\theta_{it} = 0, \forall i, t$, which implies that OPEC has no power to set oil prices.

2. For Cournot competition with a competitive fringe, $\theta_{it} = s_i$. In this case OPEC members first choose output levels and then world prices are defined; yet, world prices are also conditional on production levels by non-OPEC suppliers.

3. For Cournot behavior without a fringe, $\theta_{it} = s_i/s^o, \forall i, t$. In this scenario OPEC members

[8] See the Appendix for a more detailed derivation.

choose the production level and then world prices are set conditional only on OPEC's output.

4. If OPEC members maximize joint profits or, equivalently, follow efficient cartel behavior using the collusive outcome in presence of a competitive fringe, then $\theta_{it} = 1$.[9] In other words, OPEC is the only entity defining world oil prices.

5. For an efficient cartel without a fringe, $\theta_{it} = 1/s^0$. Although we consider this scenario for completeness, it seems highly unlikely for the oil industry.

For estimation purposes we use aggregate output and price data, thus we derive the aggregate supply relationship in the following manner. We first multiply Equation (6) by each country's market share and sum over all the countries to obtain:

$$\sum_i s_i p_t \left[1 + \frac{\theta_{it} \times s^o}{\epsilon^w}\right] = p_t \left[1 + \frac{s^o \times \theta_t}{\epsilon^w}\right] = \sum_i s_i MC_i, \tag{7}$$

with $\theta_t = \sum_i s_i \theta_{it}$.

Let $C_i(q_{it}) = a_i q_{it}^{\delta} + F_i$ be the cost function for member country i, δ is the constant elasticity of variable costs with respect to output, a_i is a country-specific shift parameter, and F_i is the fixed cost of firm i. Then, the marginal cost for country i can be rewritten as

$$\sum s_i MC_i(q_{it}) = DQ^{\delta - 1}. \tag{8}$$

Notice that the left hand side of Equation (8) equals the right hand side of Equation (7), thus,

$$p_t \left[1 + \frac{\theta_t \times s^o}{\epsilon^w}\right] = DQ^{\delta - 1}, \tag{9}$$

[9] See Church and Ware (1999) for a detailed model of a dominant firm with a competitive fringe.

where D is a function of the country-specific shift parameter and the constant elasticity of demand.

Taking the logarithm of Equation (9), the aggregate supply relationship can thus be written as

$$\ln p_t = \beta_0 + \beta_1 Q_t + \beta_2 Z_t + \beta_3 I_t + U_{2t}, \tag{10}$$

where I_t is a dummy variable that equals 1 when the industry is in a cooperative period and 0 when it is in a reversionary period. The error term U_{2t} is assumed to be i.i.d normal with mean zero and variance σ_2^2. The variable Z_t captures other factors that may affect OPEC's supply of oil such as military confrontations involving any of the OPEC countries. The parameters β_0, β_1, β_3 are given by

$$\begin{aligned} \beta_0 &= \ln D, \\ \beta_1 &= \delta - 1, \\ \beta_3 &= -\ln\left(1 + \frac{s^o \times \theta_t}{\epsilon^w}\right). \end{aligned} \tag{11}$$

Although the market structure for an individual OPEC member can be estimated from Equation (6), we opt instead to estimate and test a model of overall OPEC collusive behavior. The motivation for this choice is twofold. First, there is evidence that some countries have adjusted their quotas for a short period of time in order to compensate for a shortage of production from another member country, thus keeping the production level of the organization unchanged. This behavior would give a wrong signal of overproduction for some countries in cases where the increased production was clearly aimed at stabilizing OPEC's total output. Second, as we mentioned before, the objective of this paper is to test OPEC's collusive behavior and the market structure as a whole, focusing on possible switches between collusive and non-cooperative behavior over time.

Letting the Herfindahl index equal $H = \sum s_i^2 \approx 0.08$ in the oil market, and assuming it is time invariant, then β_3 simplifies to $-\ln(1 + s^o\theta/\epsilon^w)$. Additionally, in our sample, $s^0 = 0.412$ as OPEC accounted for 41.2% of world oil production over the period in examination (see Table 1). We can thus restate the market structure hypothesis to be tested in the following terms:

Hypotesis 1 *Given the model described by Equations (1)-(11), $H = \sum s_i^2 \approx 0.08$, and assuming $\theta_t = \theta$ for all t, then:*

1. *$\theta = 0$ for perfectly competitive behavior,*
2. *$\theta = H \approx 0.08$ for Cournot behavior with a fringe,*
3. *$\theta = H/s^0 \approx 0.19$ for Cournot behavior without a fringe,*
4. *$\theta = 1$ for a perfectly collusive cartel with a fringe, and*
5. *$\theta = 1/s^0 \approx 2.43$ for an efficient monopolistic cartel without a fringe.*

Note that in Porter (1983a), where there is no competitive fringe, the parameter θ only controls for Bertrand, Cournot, or perfectly collusive firms. In the present model the market structure parameter allows us to test not only for these three market structures, but also for the significance of the competitive fringe represented by non-OPEC producers within the previous market structures. Thus, we have five possible cases.

In the OPEC framework, we *a priori* expect the competitive fringe to be significant due to the size of non-OPEC production. Unless, however, the market is perfectly competitive with OPEC and non-OPEC countries behaving as in Bertrand competition. Moreover, if there is no fringe and OPEC is an effective cartel, the price and quantity used by the organization are the same as those of a profit-maximizing monopolist.

Equilibrium implies that quantity demanded equals quantity supplied. Therefore, from Equation (1), $\epsilon^w = \alpha_1 \times s^o$, since α_1 is the price elasticity of demand for OPEC oil, and

$$\theta = \alpha_1 \left[\exp(-\beta_3) - 1\right]. \tag{12}$$

After obtaining the price elasticity of demand from (1) and the collusive behavior coefficient (β_3) from (10), the value of θ can be computed from Equation (12).

In the OPEC setting, the supply function is given by

$$\ln p_t = \beta_0 + \beta_1 \ln opec_t + \beta_2 war_t + \beta_3 I_t + \beta_4 break_t + \beta_5 dummies_t + U_{2t}, \tag{13}$$

where war_t is a dummy variable that controls for military conflicts involving an OPEC member country; $dummies_t$ denotes a vector of seasonal dummies,and U_{2t} is a normally distributed error term.

This brings us to the second hypothesis to be tested, which concerns switches between collusive and noncooperative behavior:

Hypotesis 2 *Given the model described by Equations (1) and (13), then $\beta_3 > 0$ if switches between collusive and noncooperative behavior took place with equilibrium prices being higher during collusive periods.*

Equations (1) and (13) constitute a simultaneous equation model, in which $\ln p_t$ and $\ln opec_t$ are the two endogenous variables. If the I_t variable is the true indicator of collusion for the cartel, the system can be estimated by three stage least squares. If, instead, the indicator of collusion is assumed to be unknown but independent of time and following a Bernoulli distribution, then the estimation is done using the E-M algorithm first proposed by Kiefer (1980).

Specifically, following Porter's notation, assume that I_t equals 1 with probability λ and 0 with probability $1-\lambda$. Rewriting Equations (1) and (13) in matrix form we get:

$$By_t = \Gamma X_t + \Psi I_t + U_t, \tag{14}$$

where $y_t = (\ln opec_t, \ln p_t)'$, $X_t = (1, OECD_t, \ln nopec_t, war_t, break_t, dummies_t)'$, $U_t = (U_{1t}, U_{2t})'$ and $dummies_t$ is a 3×1 vector consisting of the seasonal dummies. The error vector U_t is assumed to have a normal distribution with mean 0 and variance Σ.

$$B = \begin{pmatrix} 1 & -\alpha_1 \\ -\beta_1 & 1 \end{pmatrix}, \Psi = \begin{pmatrix} 0 \\ \beta_3 \end{pmatrix}, \Gamma = \begin{pmatrix} \alpha_0 & \alpha_2 & \alpha_3 & 0 & 0 & \boldsymbol{\alpha}_4 \\ \beta_0 & 0 & 0 & \beta_2 & \beta_4 & \boldsymbol{\beta}_5 \end{pmatrix}, \Sigma = \begin{pmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{12} & \sigma_2^2 \end{pmatrix}, \tag{15}$$

where $\boldsymbol{\alpha}_4$ and $\boldsymbol{\beta}_5$ are 1×3 vectors.

Because the variable I_t is unknown, the probability density function is defined as:

$$\begin{aligned} f(y_t|X_t, I_t) \quad &= \quad (2\pi)^{-1/2}|\Sigma|^{-1/2}|B|[\lambda \exp\left\{-\frac{1}{2}\left(By_t - \Gamma X_t - \Psi\right)\Sigma^{-1}\left(By_t - \Gamma X_t - \Psi\right)\right\} + \\ &\quad (1-\lambda)\exp\left\{-\frac{1}{2}\left(By_t - \Gamma X_t\right)\Sigma^{-1}\left(By_t - \Gamma X_t\right)\right\}]. \end{aligned} \tag{16}$$

With an initial estimate of the regime classification sequence $(w_1^0, .., w_T^0)$ where $w_t^0 = \Pr(I_t = 1)$, an initial estimate of λ is constructed as the mean of the classification sequence.[10] Hence, maximizing the product of the density functions, initial estimates $B^0, \Gamma^0, \Psi^0, \Sigma^0$ are obtained. Using Bayes' formula, the new classification series is updated. Thus,

$$w_t^1 = \Pr(I_t = 1|y_t, X_t, \Psi^0, \Gamma^0, \Sigma^0, B^0, \lambda^0) = \frac{\lambda^0 h(y_t|I_t = 1)}{\lambda^0 h(y_t|I_t = 1) + (1-\lambda^0)h(y_t|I_t = 0)}, \tag{17}$$

[10] The initial classification sequence I_t is constructured a using the Oil Price chronology of the U.S. Department of Energy, as described in the Section 4 below.

where $h(y_t|I_t)$ is the probability density function of y_t given I_t.

Then the switching probability λ is updated: $\lambda^1 = \frac{1}{T}\sum w_t^1$. This procedure is repeated until the correlation between two consecutive estimates of w_t exceeds .999. As Hamilton (1994) notes, this procedure yields consistent and asymptotically Gaussian estimates of B, Γ, Ψ, and Σ. Furthermore, robust standard errors can be constructed using the usual formulas in Hamilton (1994).

4 The Data

The data used in this paper spans the period between 1974:1 and 2004:4. Oil quantities and prices are obtained from the U.S. Department of Energy, and converted from a monthly to a quarterly frequency by taking the average over the quarter. The variable $\ln opec_t$ is the logarithm of OPEC oil supplied in period t measured in thousands of barrels per day. The variable $\ln nopec_t$ denotes the logarithm of the oil production by all non OPEC countries, measured in thousands of barrels per day, where the majority of non-OPEC production is accounted for by Canada, China, Egypt, Mexico, Norway, the U.S.S.R. (and the nations that formerly comprised it), the United Kingdom, and the United States. As a measure of the real world oil prices we use the Refiner Acquisition Cost of imported crude oil in U.S. dollars per barrel reported by the U.S. Department of Energy deflated by the U.S. CPI for all urban consumers, which is obtained from the Bureau of Labor Statistics. Thus the variable $\ln p_t$ denotes the logarithm of the real price of oil measured in U.S. dollars of 2000.[11]

The set of demand shifters comprises the log growth of GDP for the OECD, $OECD_t$; the logarithm of the quantity of oil sold by non-OPEC producers, $\ln nopec_t$; a dummy that controls

[11] Depending on the lag length, the null of a unit root in real $\ln opec_t$, $lnnopec_t$, and $\ln p_t$ can be rejected using either the Augmented Dickey Fuller, Dickey Fuller-GLS (Elliott, Rothenberg, and Stock, 1996) or Elliott and Jansson (2003) unit root tests. Yet, because the null of a unit root cannot be rejected in a number of cases, we tested for cointegration between these variables using Johansen trace test. This cointegration test suggests one cointegration relation.among the three variables. Consequently, in the following section we proceed to estimate the system given by (14) using the variables in levels.

for the U.S. price decontrols since the beginning of 1981, $break_t$; and a vector of seasonal dummy variables, $dummies_t = (quarter1, quarter2, quarter3)'$.

As mentioned in the previous section, $OECD_t$ is intended as a proxy for world income. On average over the sample period, real GDP of the OECD amounts roughly to 3/4 of the world's GDP and its oil demand accounts for roughly 2/3 of the world's oil demand. This variable is computed as the first difference of the logarithm of GDP for OECD countries, measured in millions of U.S. dollars. The data source for $OECD_t$ is the OECD Economic Outlook.

The collusive behavior variable, PO_t, is computed using the Oil Price Chronology of the U.S. Department of Energy (Energy Information Agency, 2007). PO_t takes on the value of one when there is evidence that OPEC was in a cooperative period, and zero otherwise. Specifically, to compute PO_t the production quotas assigned by OPEC are compared to the actual production levels: If actual production in period t is at least 5% over the quota established for that period, and there is no evidence that overproduction was a consequence of an increase in world demand, PO_t is set to zero. PO_t is used as the sequence of regimes I_t in the $3SLS$ estimation and as the initial sequence I_t in the maximum likelihood estimation, whereas the variable PN_t corresponds to the $\widehat{I}_t$ sequence that results from the maximum likelihood estimation.

Finally, to control for shifts in OPEC production due to military confrontations, the dummy variable war_t is included in the supply equation. War_t equals one when there is a military conflict involving an OPEC country at time t, and zero otherwise. This variable includes the Iran-Iraq war, and the invasion of Kuwait in 1990.

Before proceeding to the econometric analysis, consider the historical evolution and time series properties of the variables of interest. Figure 1 plots world, OPEC, and non-OPEC oil production. The world production has been roughly constant between 50 and 70 millions barrels per day with a slightly increasing trend. OPEC decreased its production from 1980 to 1983, but has been increasing it ever since. Supply by non-OPEC members has been more stable over time, yet it also exhibits a slight increasing trend. Indeed, oil production by non-OPEC countries surpassed OPEC's production in 1979.

In Figure 2, we plot real world prices and the collusive behavior indicator PO_t. The figure also reports major historical events that were related to large fluctuations in world oil prices. For instance, the Iranian revolution resulted in a drop of 3.9 million barrels per day of crude oil production between 1978 and 1981. Even though other OPEC members raised their production seeking to maintain the same total output, the revolution appears to have lead to higher oil prices. This trend was reversed after the U.S. removed the price and allocation controls on the oil industry in 1981. The elimination of the price controls, together with a decrease in oil demand, an increase in non-OPEC production, and Saudi overproduction, resulted in OPEC loosing control of world oil prices by 1982. By December 1985, and despite several cutbacks in OPEC production, an abundance of oil in the market was evident. This situation triggered a price decline that ended in the so-called crash of 1986. Since 1987 oil prices have been more stable, except for the five-month peak caused by the Kuwait invasion at the end of 1990.

As Figure 2 illustrates, the indicator variable PO_t seems to be a fair indicator of collusive behavior. Even though oil prices have been more stable after 1987, the variable indicates that there has been significant overproduction compared to levels of effective cartel output. According to this initial estimate of collusive periods, PO_t, there are 42 cooperative periods out of 124 quarters between 1974 and 2004 (see Table 1). This initial estimate thus suggests that OPEC acted in a collusive manner on approximately 34% of the quarters in the sample.

To get a better grasp of the production share of each OPEC member, Table 2 reports statistics about oil production by each of the member countries.[12] Notice that the OPEC "core," which is

[12] Gabon and Ecuador are excluded from the analysis, even though they were part of OPEC for most of the period to be examined (Ecuador 1973:11-1992:11, Gabon 1973:12-1995:01), their combined production was less than 1% of

formed by Saudi Arabia, the United Arab Emirates (U.A.E.), Kuwait, Qatar, and Libya, accounts for over 50% of total OPEC production, with about 30% of OPEC's oil being produced by Saudi Arabia alone. Of interest is also the effect of the Persian Gulf war on the supply of oil. Note that zero values are reported for periods of no production for Iraq (February and March of 1991) and Kuwait (February to May of 1991 for Kuwait). As for the OPEC's share in the world market, the organization's supply accounted for an average 41.2% of the world oil production over the 1974-2004 period (see Table 1). This corresponds to about 59 millions of barrels of crude oil per day.

As a measure of industry concentration, consider the evolution of the Herfindahl index for the world oil market, which is plotted in Figure 3. This index is a more accurate measure of concentration than the concentration-ratio since it gives more weight to large firms (or countries). Using the U.S. Department of Justice classification of concentrated industries, Herfindahl indices between 0.1 and 0.18 are moderately concentrated, those above 0.18 indicate concentrated market structures (U.S. Department of Justice, 1997). Notice that, with the exception of the rapid increase and fall in the early 1980s when the Herfindahl index reached levels around 0.11, the index fluctuates between 0.05 and 0.1 for the period under analysis. The large increase and following decrease in the index during 1980-1983 reflects the decline in Iran and Iraq's supply, which was compensated by Saudi Arabia. During these years total OPEC output remained essentially at the same level, but Saudi Arabia's share increased significantly (see Figure A1 in the Appendix). A similar, but less pronounced increase can be observed during the Gulf War when Saudi Arabia made up for Kuwait's and Iraq's shortages. Nevertheless, when the production of Iraq, Iran, Kuwait and Saudi Arabia is taken as a whole, the market share remains roughly constant over time (see Figure A2). In the 1990s the index declines to a level lower than that observed during the 1970's; this decline is largely due to the dissolution of the U.S.S.R. in 1991 and the resulting increase in the number

total OPEC oil production.

of oil producing countries.

Table 3 shows OPEC quotas, production allocations and the Herfindahl index for four selected periods: (i) the last quarter of 1978, before the Iranian Revolution and the U.S. decontrol; (ii) 1983 when OPEC starts using quotas instead of royalty rates; (iii) 1990, before the Gulf War and (iv) November 1997, which constitutes the last year of Iraq's participation in OPEC's agreements regarding production quotas and before its participation in the oil-for-food program.[13] As shown in Figure 3, the Herfindahl index is at a high level in 1983, though somewhat lower than its peak in 1981. This is reflected in Saudi Arabia's share of over 40% of total OPEC production and about 10% of the world's crude production. After 1984, Saudi Arabia's share in OPEC production declined to a level between 25% and 30%, even though its production level had been constantly increasing. At the same time, the share of some of the smaller producers, that were already producing close to their maximum capacity, decreased. Over time, other countries like Venezuela, Nigeria and the U.A.E. slightly increased their production level; yet, their share in OPEC's output remained roughly constant.

5 Estimation Results

The estimation results are presented in Table 4. The first column in panel (1) reports the parameter estimates for Equations (1) and (13) obtained by Three Stage Least Squares ($3SLS$), under the assumption that the constructed cheating variable is an accurate classification of the regimes. The corresponding robust standard errors are reported in parenthesis. The estimates obtained using the E-M algorithm described in the previous section are repored in panel (2) and the corresponding robust standard errors are reported in parenthesis.

[13] For 1978 the reported production corresponds to the fourth quarter of the year, for all other years it corresponds to the allocated production quota The Herfindahl index is presented in percentage terms.

Focusing first on the $3SLS$ estimates, note that the parameter estimates have the anticipated sign. In the demand equation we obtain a negative price elasticity that is significantly less than one in absolute value, thus suggesting an inelastic demand for OPEC's oil. According to these estimates, OPEC does not maximize profits as a dominant firm given that it does not produce on the elastic part of its demand curve. When non-OPEC production increases by 1%, demand for OPEC oil is estimated to decrease roughly by the same percentage ($\alpha_2 = 0.76\%$). The coefficient on the OECD's GDP growth is not statistically different from zero.

The estimates of the supply equation predict suppliers' prices to be 19% higher during cooperative periods, 61% higher when an OPEC country is involved in a war, and 57% lower after the price decontrols in 1981. All three variables are significant at the 5% level or lower. The production level is estimated to have no significant effect on the price of oil suppliers. As for the seasonal dummies, they appear to have no significant effect in either the demand or the supply equation.

Regarding OPEC's behavior, using Equation (11) we obtain an estimate of $\theta = 0.0327$. We can reject the hypothesis that $\theta = 0$ at a 5% level of significance and we can reject the hypothesis of $\theta = 0.08$ at the 1% level of significance. Thus, the $3SLS$ results suggest OPEC's behavior is between Bertrand competition and Cournot competition with a fringe (see Hypothesis 1.1).

Consider now the case when the regime classification is unknown and the parameter estimates are obtained by numerically maximizing the likelihood function (16) using Kiefer's E-M algorithm (panel (2) in Table 4). Notice that the goodness-of-fit for the demand and supply equations is better when we estimate the system of equations using the E-M algorithm than when we use $3SLS$, as the R^2 for both the demand and supply equations increases in the MLE versus the $3SLS$ estimation.

The demand equation presents an intercept for the pre-1981 period similar in magnitude to the $3SLS$ estimate. Likewise, the price elasticity of demand is roughly the same magnitude across the two estimations; 0.23 for MLE versus 0.19 for $3SLS$. As before, a 1% increase in non-OPEC production decreases OPEC production by almost 1% which is expected, given that OPEC and non-OPEC countries are the only two oil producers. Further, the coefficient of GDP for $OECD$ countries is still negative and statistically insignificant. As for the elasticity of demand, the coefficient is significant and less than one in absolute value, thus suggesting that OPEC does not maximize profits as a dominant firm as it operates on the inelastic segment of the demand curve.

Regarding the supply equation, the estimation results predict periods of collusion to result in a 56% increase in oil suppliers' price, whereas the coefficient on the *war* dummy suggests a 39% increase during periods of wars involving any of the OPEC countries. Furthermore, the coefficient on *break* suggest that the average oil suppliers' price has been 69% lower since the early 1980s.[14]

The value of θ implied by the MLE estimates of α_1 and β_3 is 0.0996, which is significantly different from zero at a 1% level. Note that this value of θ is consistent with Cournot behavior with a competitive fringe, as we cannot reject the null that $\theta = 0.08$ (see Hypothesis 1.2) at any traditionally acceptable level of significance ($t - stat = 0.7396$). Interstingly, the estimated θ for the oil market is smaller than that estimated by Porter for the JEC where $\theta = 0.336$ is in line with Cournot behavior during cooperative periods. Our estimate of θ suggests that, on average over the 1974-2004 period, OPEC has not been effective in raising prices over quantity competition levels. More importantly, as predicted by Porter (1983b), prices during cooperative periods exceed those consistent with competitive price setting, but are smaller than those implied by joint profit maximization.

To evaluate the effect of political disruptions and periods of collusion on the equilibrium quantity produced by OPEC and the equilibrium world crude price, we use the MLE estimates reported in panel (2) of Table 4. Table 5 reports the reduced-form estimates for price, quantity and total revenue, when all explanatory variables but *war*, PN, and *break* are evaluated at their sample

[14] A likelihood ratio test for the null of no break in 1981 takes the value of ($LR = 217.98$), which leads us to reject the null at a 1% level.

mean. Our estimates suggest that, in equilibrium, cooperative periods lead to an 11% decrease in OPEC's production, a 69% increase in prices and 49% higher revenues for OPEC. Periods of wars involving one of OPEC's members have a lower impact on OPEC's total revenues. In fact, on average, our estimates suggest periods of wars result in a 8% decrease in OPEC's production, 49% higher prices, and a 32% increase in OPEC's total revenue.

Regarding the probability of being in a cooperative period, the estimate obtained from the maximum likelihood procedure equals 0.340. This probability is slightly higher than the initial value of $\lambda = 0.339$, which is equivalent to the mean of the collusive variable PO_t used in the $3SLS$ estimation where PO_t is taken to be an accurate classification of the regimes. Thus both the inferred (MLE estimate) and the constructed ($3SLS$ estimate) suggest that noncooperative periods represented about 65% of the quarters between 1974 and 2004. Furthermore, the statistical significance of β_3 ($t-stat$ 4.72) provides evidence of switches between collusive and non-cooperative behavior at the interior of OPEC. This result is confirmed by the fact that a likelihood ratio test statistic from the test comparing this model to one where β_3 is restricted to zero equals 43.538, which allows us to reject the null of no switch at a 1% level. In brief, changes in oil prices and in the quantity of oil produced by OPEC cannot be totally attributed to structural changes and exogenous shifts in demand.

Finally, to illustrate switches between collusive and noncooperative periods, Figure 4 plots the historical price, the value of PO_t and the estimated value of PN_t. Note that both variables indicate periods of collusion in the late 1970s and in the early 1980s, with PO_t suggesting collusion in the mid-1970s as well. In contrast, the late 1980s and the 1990s are characterized by long periods of price wars. Yet, there are differences in the periods of noncooperation predicted by the two variables. First, the constructed cheating variable, PO_t, indicates longer periods of collusion than the estimated variable, PN_t, and a slower reversion to price wars. Second, although both PO_t and

PN_t suggest a period of collusion around the Gulf War, PN_t indicates a longer period of collusion than PO_t. In particular, PN_t suggests collusion through the end of the war (February 1991) and up to the second quarter of 1991, whereas PO_t suggests collusion during the third and fourth quarters of 1990 but not during 1991. Likewise, both variables provide some evidence of collusion during the 2000s, with PN_t indicating that collusion took place during the run-up of oil prices observed during 2004.

Summarizing, we find that, on average over the 1974-2004 period, OPEC's behavior is better described as Cournot competition with a competitive fringe (Hypothesis 1.2). We find evidence that various reversions to noncooperative behavior took place in OPEC over the 1974-2004 period, with significantly lower prices and higher production during these quarters. Our estimation results suggest that these reversions occurred in the mid-to-late 1980s, the 1990s and the early 2000s.

6 Conclusion

This paper extends the framework of Porter (1983a) to include the case of a market characterized by the presence of a cartel (OPEC) and a competitive fringe (non-OPEC oil producers). Estimation of a simultaneous equation switching regression model allows us to examine two questions. First, we ask which market structure (perfect competition, Cournot with a fringe, Cournot without a fringe, perfectly collusive cartel with a fringe or efficient monopolistic cartel) better characterizes the world oil market during the 1974-2004 period. Our result suggest that, on average over the period of study, OPEC's behavior is best described as Cournot competition in the face of a competitive fringe constituted by non-OPEC producers. Hence, our results suggest that despite spells of collusive behavior, OPEC cannot be viewed as an effective cartel during the whole time period.

Second, we test whether switches between collusive and noncooperative behavior took place during the period under analysis. The null hypothesis that no switch occurred is rejected in favor of the alternative that both cooperative and noncooperative behavior was observed during the 1974-2004 period. We find statistical evidence that changes in oil prices are a result not only of exogenous shifts in demand and structural changes in the world oil market, but also a result of switches between collusive and noncooperative behavior among members of OPEC. In fact, we estimate that periods of collusion result in a 69% increase in equilibrium oil prices and a 11% decrease in the quantity of oil supplied by OPEC. The increase in prices is roughly 1.4 times higher than the price increase due to military conflicts involving any of the OPEC member countries. In brief, the econometric evidence presented in this paper suggest that reversions from collusive to noncooperative behavior took place over the 1974-2000 period and were mainly concentrated during the 1990s.

Finally, our results shed light on the literature's lack of consensus regarding OPEC's cartel stability. On one hand, evidence of collusion during the late 1970s and early 1980s is consistent with the findings of earlier literature, which suggests that OPEC behaved as a collusive cartel during some or all of the 1970s and early 1980s (e.g., Griffin, 1985; Jones, 1990; Loderer, 1984). On the other hand, both evidence of price wars during a large proportion of the time between the mid-1980s and mid-2000s and the relatively low probability of collusive behavior over the 1974-2004 sample ($\lambda = 0.340$) suggest that econometric studies using a longer sample period, but not allowing for switches, are likely to find that on average OPEC did not behave as a cohesive organization.

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Table 1. Summary statistics

	Mean	Std. Dev.	Min	Max
OPEC production (Thousands of barrels per day)	25,071.3	4,558.5	15,159.3	33,556.7
World Prices (US$ per barrel)	33.34	15.66	11.36	75.94
War	0.2823	0.4519	0	1
I	0.3387	0.4752	0	1
Non-OPEC production (Thousands of barrels per day)	35,646.3	4,238.6	25,110.0	42443.7
GDP growth for OECD countries (Percentage)	0.649	0.475	-0.988	2.03

Sources: Oil price data comes from the U.S. Department of Energy, OECD GDP comes from the OECD Economic Outlook

Table 2. OPEC members production in thousand of barrels per day

Variable	Mean	Std. Dev.	Min	Max
Algeria	1168.77	174.18	860.66	1715
Indonesia	1440.76	145.24	1088	1698.66
Iran	3442.39	1236.12	887.33	6604.66
Iraq	1731.6	924.48	85.34	3661
Kuwait	1723.66	590.65	16.89	2889.33
Libya	1412.86	327.94	654.33	2154.66
Nigeria	1891.38	361.67	820	2546.66
Qatar	485.63	153.26	208.33	835
Saudi Arabia	7488.79	1814.88	2686.66	10298
U.A.E.	1909.25	427.78	1053.66	2602
Venezuela	2376.27	479.34	1490	3423.57

Source: U.S. Department of Energy

Table 3. OPEC production quotas, shares and Herfindahl index for four selected years

	1978		1983		1990		1997	
	Share (%)	Production (Millions of barrels per day)	Share (%)	Production (Millions of barrels per day)	Share (%)	Production (Millions of barrels per day)	Share (%)	Production (Millions of barrels per day)
Total Production	1	31	1	17.15	1	21.61	1	27.5
Saudi Arabia	0.32	9.97	0.42	7.15	0.25	5.38	0.32	8.76
Iran	0.12	3.81	0.07	1.20	0.15	3.14	0.14	3.94
Iraq	0.09	2.98	0.07	1.20	0.15	3.14	0.05	1.31
Venezuela	0.07	2.32	0.09	1.50	0.09	1.94	0.09	2.58
Nigeria	0.07	2.17	0.08	1.30	0.07	1.61	0.07	2.04
Indonesia	0.05	1.58	0.08	1.3	0.06	1.37	0.05	1.45
Kuwait	0.07	2.31	0.05	0.80	0.07	1.50	0.08	2.19
Libya	0.06	2.13	0.04	0.75	0.06	1.23	0.06	1.52
U.A.E.	0.05	1.83	0.06	1.00	0.05	1.09	0.09	2.36
Algeria	0.04	1.37	0.04	0.65	0.04	0.82	0.03	0.90
Qatar	0.01	0.52	0.02	0.30	0.02	0.37	0.01	0.41
Herfindahl Index	0.093		0.100		0.075		0.055	

Source: U.S. Department of Energy

Note: "Share" is the share of each OPEC member country in OPEC's production. Production is the assigned production quota, except for 1978 where it denotes actual production.

Table 4. Estimation results

Variables	3SLS with break (1) Demand	Supply	MLE with breaks (2) Demand	Supply
constant	18.7659***	1.7790	20.1794***	0.1508
	(1.5243)	(2.8754)	(1.7791)	(0.9752)
$ln\,(opec)$		0.1811		0.3507***
		(0.2773)		(0.0948)
$ln(p)$	-0.1891***		-0.2310***	
	(.0391)		(0.0483)	
$OECD$	-4.1007		6.1826	
	(3.2893)		(3.9876)	
$ln(nopec)$	-0.7597***		-0.8878***	
	(0.1387)		(0.1608)	
war		0.6093***		0.3866***
		(0.1086)		(0.1237)
I		0.1900**		0.5644***
		(.0744)		(0.1195)
break		-0.5695***		-0.6871***
		(0.0966)		(0.0687)
quarter 1	-0.0461	-0.0120	-0.0063	-0.0641
	(0.0439)	(0.0717)	(0.0623)	(0.0748)
quarter 2	-0.0445	0.0139	-0.0824	-0.0062
	(0.0437)	(0.0721)	(0.0539)	(0.0708)
quarter 3	-0.0209	-0.0059	-0.0036	0.0166
	(0.0436)	(0.0715)	(0.0579)	(0.0749)
theta	0.0327**		0.0996***	
	(0.0131)		(0.0265)	
R^2	0.2344	0.6104	0.2674	0.7572

Note: robust standard errors reported in parenthesis. ***,** , and * denote significance at 1, 5 and 10% level, respectively.

Table 5. Price, quantity and total revenues for different periods and different values of war and I

Price							
		1974-1980				1981-2004	
		war				war	
		0	1			0	1
I	0	\$38.96	\$55.71	I	0	\$20.64	\$29.51
	1	\$65.67	\$93.91		1	\$34.78	\$49.74
Quantity							
		1974-1980				1981-2004	
		war				war	
		0	1			0	1
I	0	23,202	21,361	I	0	26,871	24,741
	1	20,565	18,935		1	23,818	21,929
Total revenue							
		1974-1980				1981-2004	
		war				war	
		0	1			0	1
I	0	\$903,950	\$1,190,021	I	0	\$554,617	\$730,107
	1	\$1,350,503	\$1,778,185		1	\$828,390	\$1,090,748

Note: calculations based on MLE estimates reported in panel (2) of Table 5.

Figure 1. Oil Production (thousands of barrels per day)

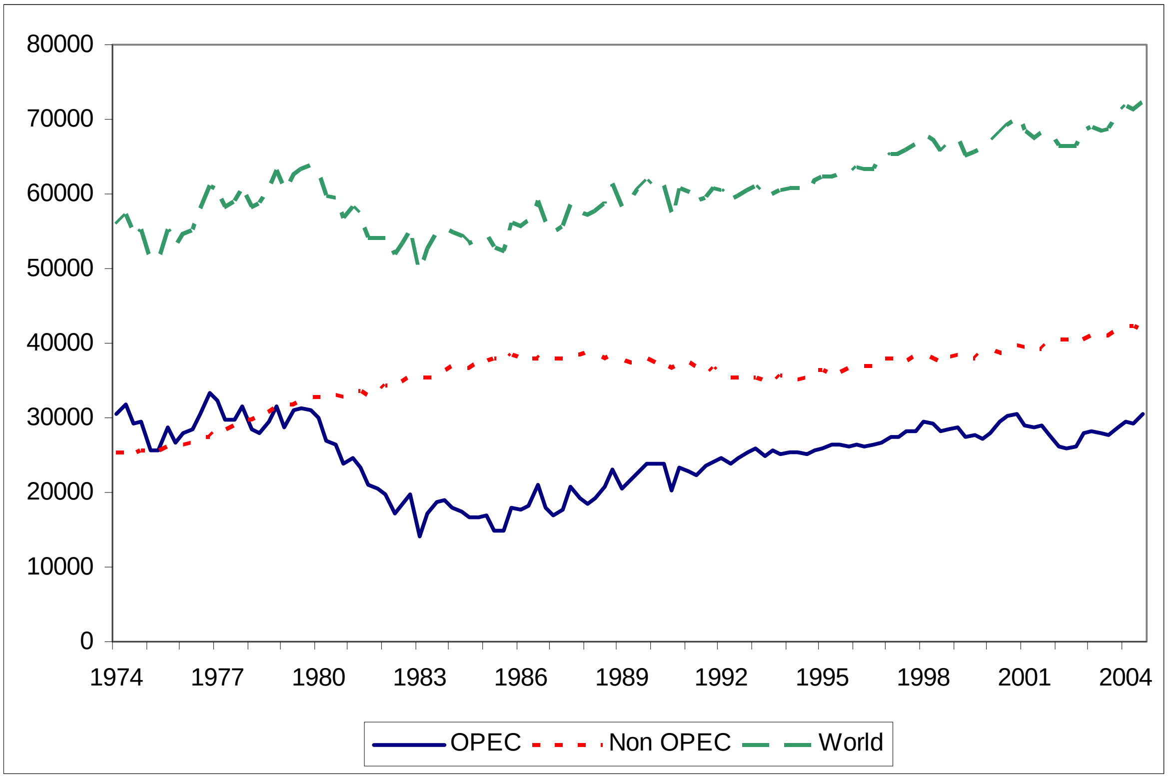
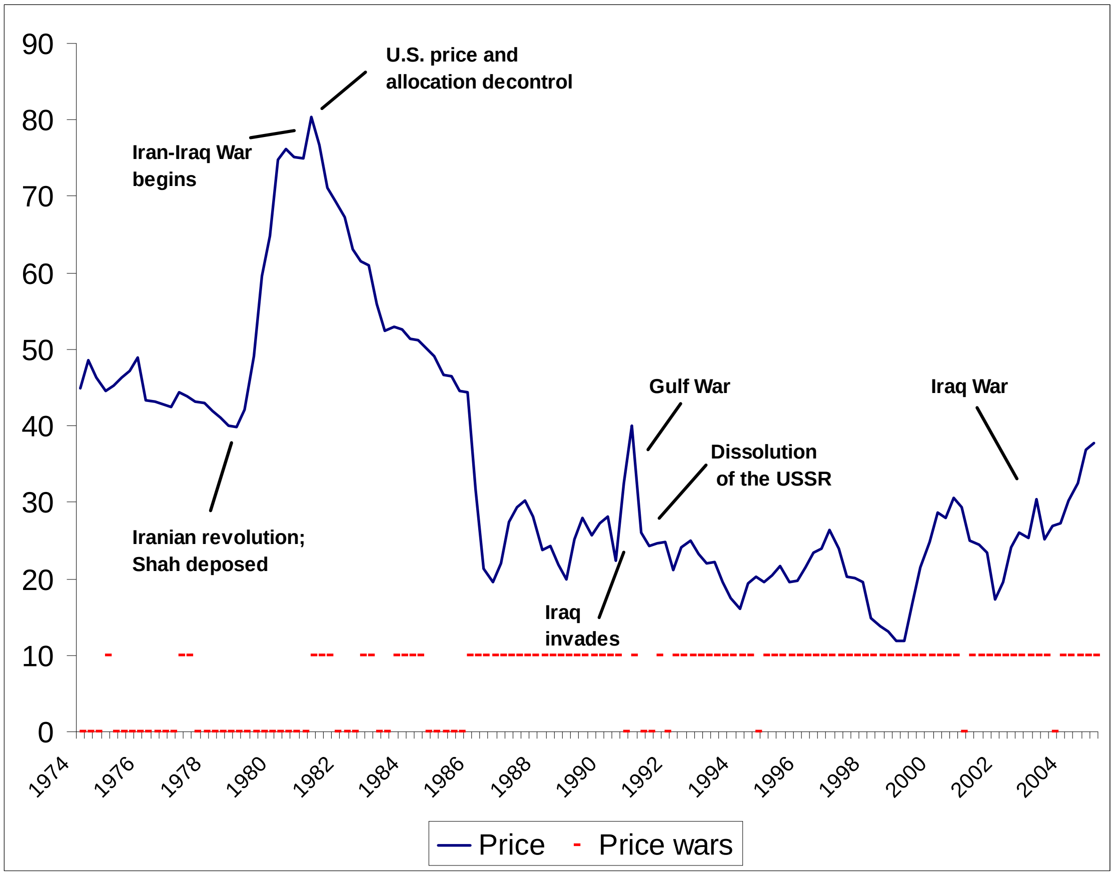
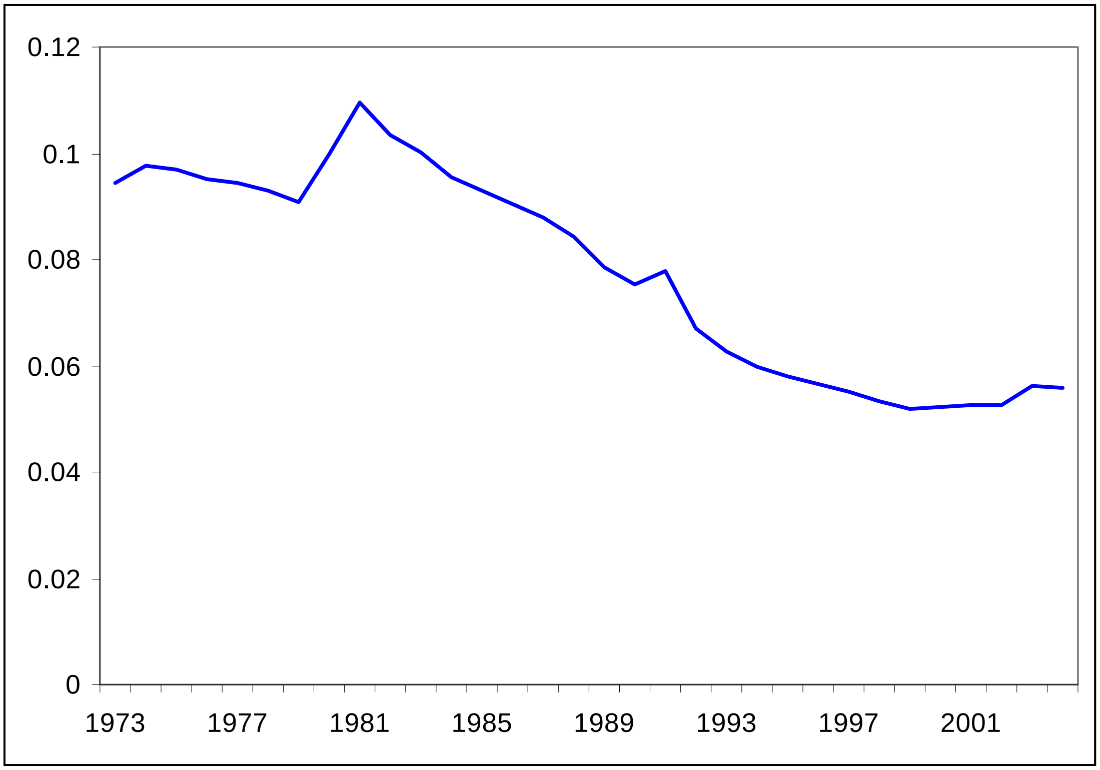


Figure 2. Real Prices, Price Wars and Selected Historical Events



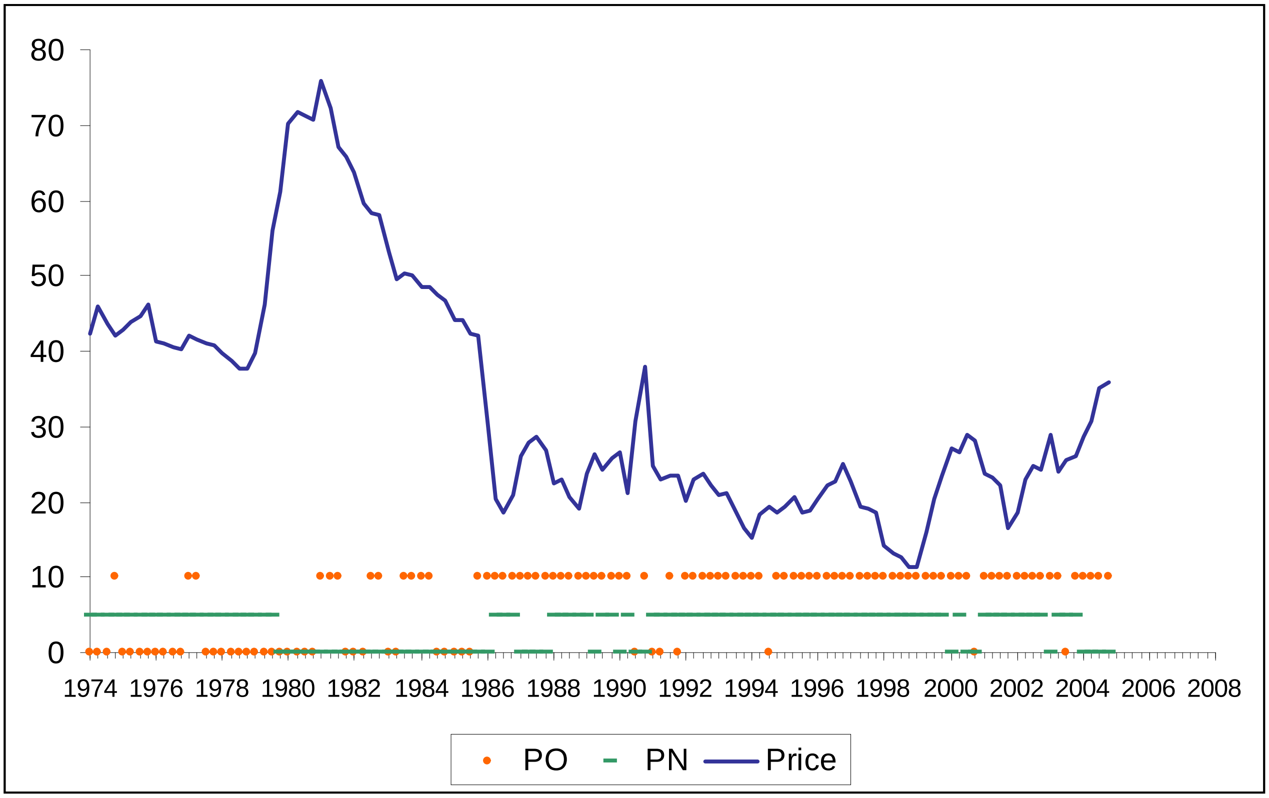
Note: Prices are measured in dollars of December 2002. Price wars takes the value of 10 for non-cooperative periods and 0 for cooperative periods, as implied by the initial collusion variable PO_t.

Figure 3. Herfindahl Index 1973-2004



Note: Herfindahl Index calculated as $\sum_i s_i$ where s_i denotes the share of country i in the world's oil production.

Figure 4. Price of oil and indicators of collusion



Note: The variables PO_t and PN_t have been rescaled. $PO = 0$ takes on the value of 10 for periods of noncooperation; PN takes the value of 5 for periods of noncooperation.

Appendix

Derivation of Equation (6):

From the profit function of member i, $\pi_i = p_t q_{it} - C_i(q_{it})$, the first order condition with respect to the production quantity is

$$\frac{\partial \pi_i}{\partial q_{it}} = p_t + \frac{\partial p_t}{\partial q_{it}} q_{it} - MC_i = 0 \Longleftrightarrow p_t + \frac{\partial p_t}{\partial q_{it}} q_{it} = MC_i.$$

$$\text{Using the chain rule we get } \frac{\partial p_t}{\partial q_{it}} = \frac{\partial p_t}{\partial Q^w} \frac{\partial Q^w}{\partial Q^o} \frac{\partial Q^o}{\partial q_{it}},$$

$$\text{where } \frac{\partial Q^w}{\partial Q^o} = \frac{\partial Q^o}{\partial q_{it}} = 1.$$

Then $\partial p_t / \partial q_{it} = \partial p_t / \partial Q^w$, hence, we can rewrite the first order condition as

$$p_t + \frac{\partial p_t}{\partial Q^w} q_{it} = MC_i \text{ or } p_t + \frac{\partial p_t}{\partial Q^w} \frac{Q^w}{p_t} q_{it} \frac{p_t}{Q^w} = MC_i,$$

using the definition of the world elasticity of demand,

$$\epsilon^w = \frac{\partial Q^w}{\partial p} \frac{p}{Q^w},$$

and $s_i = q_i / Q^o$, the first order condition becomes

$$p\left[1 + \frac{s_i s^o}{\epsilon^w}\right] = MC_i. \tag{18}$$

Writing the first order conditions of each of the possible market structures we obtain:

1. Bertrand competition implies $p = MC_i$; hence, $\frac{s_i s^O}{\epsilon^W} = 0$. Note that in Bertrand competition the firm maximizes with respect to prices instead of quantity, however in the derivation prices are not replaced by the demand function (e.g. $p = 1 - q$), hence we can still compare the first order condition, since it is solved as an implicit derivative.

2. Cournot competition in presence of a competitive fringe implies:
   $p\left[1 + s_i s^o / \epsilon^w\right] = MC_i$. This is the case of the first order condition derived above in Equation (18).

3. Cournot competition without the fringe indicates: $p\left[1 + s_i / \epsilon^w\right] = MC_i$. Following the same derivation as the previous market structure, but with no competitive fringe, the oligopoly has all the market share ($s^o = 1$), hence the price elasticity of demand depends only on the producers of the oligopoly.

4. Cooperative cartel in presence of a competitive fringe implies $p\left[1 + s^o / \epsilon^w\right] = MC_i$. This is the same as a dominant producer in the presence of a competitive fringe, as in Church and Ware (1999). The result is obtained defining the price elasticity of demand in terms of the elasticity of the dominant firm and of the competitive fringe as $\epsilon^w = \epsilon^o s^o + \epsilon^f (1 - s^o)$, where ϵ^f is the price elasticity of demand for the good of the competitive fringe. This market structure can be interpreted from Equation (18), s_i also equals 1 since there is only one dominant

producer, but s^o represents the market share of that producer in world production because the competitive fringe has a market share of $1 - s^o$.

5. Cooperative cartel points to: $p\left[1 + 1/\epsilon^w\right] = MC_i$. This is the first order condition for a regular monopoly and can be derived as follows:

$$\pi = (p-c)q \tag{19}$$

$$\frac{\partial \pi}{\partial q} = \frac{\partial p}{\partial q}q + p - c = 0 \Longleftrightarrow p\left[1 + \frac{\partial p}{\partial q}\frac{q}{p}\right] = c. \tag{20}$$

   The inverse price elasticity of demand is $\frac{1}{\epsilon} = \frac{\partial p}{\partial q}\frac{q}{p}$, hence we obtain the specified condition. From Equation (18) it implies that s_i and s^o equal 1, where s^o represents the market share of the monopolist, that in this case equals 1 as there is no fringe. And s_i is the market share of each producer, that in the case of a monopoly also equals 1 because there is only one producer.

Therefore including the parameter θ_{it} in Equation (18), the first order condition becomes:

$$p\left[1 + \frac{\theta_{it} s^o}{\epsilon^w}\right] = MC_i, \tag{21}$$

where θ_{it} can be tested for each of the five market structures for each member. As the purpose of this paper is to test for an overall behavior of the organization rather than for each member country, instead of directly testing Equation (21) we find an aggregate relationship to test OPEC's behavior.

Figure A.1. Market Shares

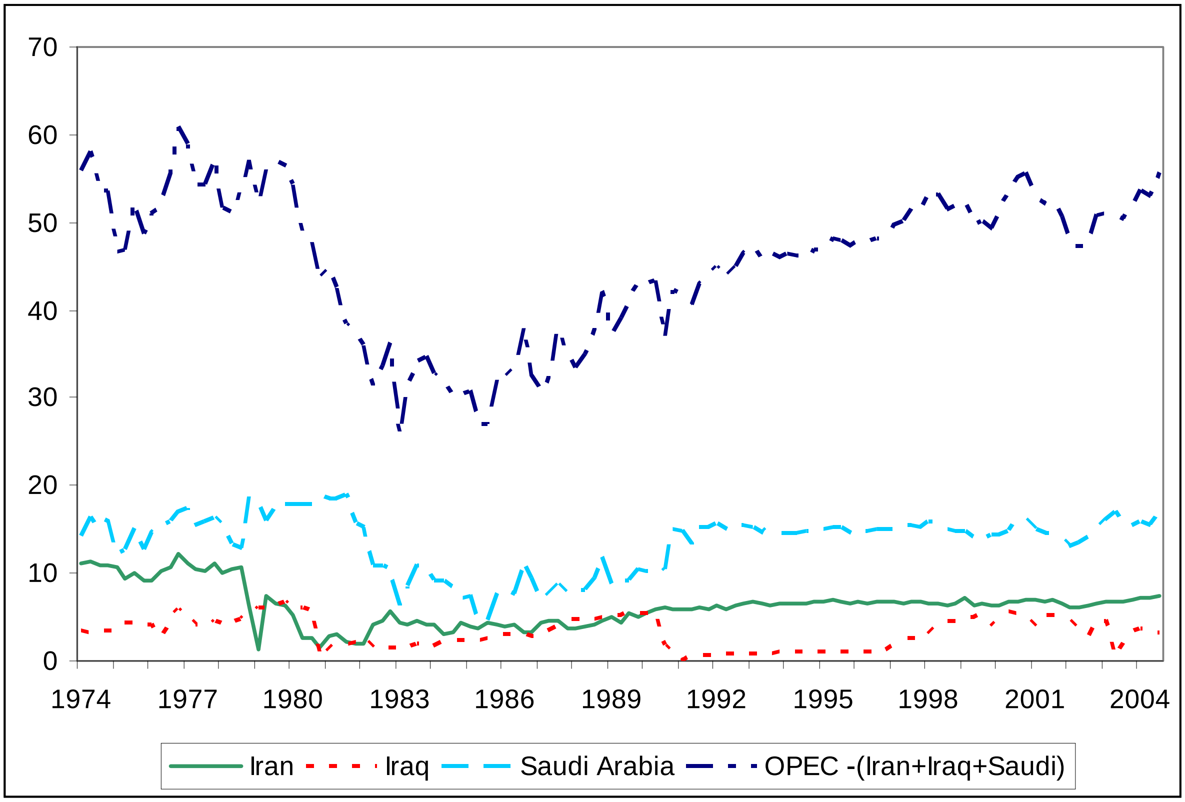


Figure A.2. Combined Share for Iran, Iraq, Kuwait and Saudi Arabia