Are Markups in Oil Market Caused by Exhaustibility or OPEC Market Power? An Empirical Test

Abstract

According to "Hotelling rule" price of an "exhaustible resource" exceeds its marginal cost of production in perfect competition equilibrium by amount equal to the opportunity cost of depleting the resource now rather than next periods. This cost is called "scarcity rent". Oil price exceeds its marginal extraction costs significantly. This can be attributed two different sources: effect of scarcity of oil on prices or exercising market power by OPEC (collusion). In this paper I use Porter (1983) approach to identify collusive and non-collusive periods in oil market considering that there might be a "scarcity rent" component involved in price-marginal extraction cost observed in the oil market. I use cost of production data in most costly oil wells in USA and calculate margins between price and marginal extraction cost to derive a proxy for scarcity rent. I will employ time series data on world oil production and oil prices to test empirically whether switch between cooperative and non-cooperative periods in fact occurred in oil market. Two benchmark cases, where scarcity rent is either zero (non-exhaustible resources hypothesis (Adelman 1990)) or equal to minimum price-cost margin in oil industry are considered. The results show that in both cases OPEC failed to cooperate effectively and in second case, market conduct estimated is closer to Cournot behavior.

1. Introduction

1.1. Purpose and Plan

The goal of this research project is to test whether the margin between price and marginal extraction costs observed in oil market is caused by exhaustibility of oil or by OPEC market power? I propose a dynamic model for oil market and test for OPEC market power during 1986-2006 period empirically. My estimation approach would be similar to Porter (1983) except that I account for exhaustibility of oil and its effect on producers' optimization problem. The rest of introduction will be consisted of OPEC background and brief discussion of related literature on identifying collusion in oil market. In section 2 I will propose the theoretical model and how I will deal with difficulties raised by exhaustibility issue. Section 3 describes the data used in the estimation procedure. Section 4 describes the estimation procedure and results. Section 5 concludes and suggests further extensions.

1.2. OPEC Background

According to OPEC official website, “The Organization of the Petroleum Exporting Countries (OPEC) is a permanent, intergovernmental Organization, created at the Baghdad Conference in September 1960, by Iran, Iraq, Kuwait, Saudi Arabia (major crude oil producers in Middle East) and Venezuela. Nine other members joined later in 1960’s.” According to BP Statistical review 2007, OPEC countries account for 41% of oil production and they own 75% of oil reserves today. OPEC is a classic textbook example of collusion. Although it seems to have a large market power, many researchers have argued that OPEC countries in fact lack a commitment device to coordinate their actions so the price volatilities observed in the market is caused by other factors such as major supply or demand shocks and exhaustibility effect of crude oil rather than collusion and price wars among cartel members. (Cremer, Salehi(1991)).

1.3. Cartel Test in Oil Market: Static Model

James Griffin (1985) tests several alternative hypotheses about oil market and OPEC behavior. In each case he considers a static optimization problem and tries to test the hypotheses. These hypotheses include cartel models, competitive market, revenue targeting etc. In cartel model he tests whether the observed price can be a result of collusive behavior or not. In competitive model he tests MacAvoy’s (1982) suggestion that the price of oil is determined mainly according to market fundamentals such as supply and demand interaction in a competitive market rather than collusion among oil market players. The revenue targeting case is about the assumption that Oil producing countries have target revenue goals. This assumption is justified in an imperfect international capital market so the oil producing countries cannot borrow or lend in periods of excess or shortage of oil revenue.

Griffin derives a model for any of the cases described above and tests using the quarterly data from 1971 to 1983. The results of empirical tests are that the cartel model is not rejected for 7 major OPEC countries while other models are rejected.

Spilimbergo(2001) uses a similar approach to Griffin but uses a dynamic model for the competitive case. In this case an oil producing country solves an optimization problem of extracting an exhaustible resource. As studied in Pindyck (1978). He considers a dynamic optimization of an agent in a competitive market of an exhaustible resource and tests the hypotheses of a competitive market against a cartel assumption of Griffin. He uses the quarterly data from 1983-1991. He finds that the hypothesis of cartel is rejected for all the countries except Saudi Arabia.

1.4. Exhaustible Resource and Hotelling Rule

Hotelling (1931) is one of the most influential prices of literature in economics which investigates the exhaustibility of resources. His result mostly referred to as “Hotelling rule”, states that given a zero marginal extraction cost and fixed amount of resource and in absence of substitute goods, there is an implicit opportunity cost associated with depleting an exhaustible resource due to its being non-renewable. The owner of a natural resource should be indifferent between selling the resource today or keeping the resource and selling it next period. As a result, the price of an exhaustible resource must grow at a rate equal to the rate of interest both along a monopolistic extraction path and the competitive resource industry.[1] However, price of exhaustible resources seem to be random walk rather than growing. This is caused by different sources: changing extraction costs may increase the prices, probability of discovering a substitute may decrease the opportunity cost of depleting the resource and uncertainty about actual size of the stock of exhaustible resource may affect scarcity rent because in case another stock of resource is discovered, it may be considered less exhaustible than before (see Farzin (1992) and Just, et al (2005))

1.5. Cartel Stability in JEC: Identifying Collusion in Transportation Market

Porter(1983) studies cartel stability in a homogenous goods market (railroad transportation) among Joint Executive Committee members. To identify the collusive and non-collusive periods he uses an application of Green and Porter (1984) theoretical model. Firms’ profit functions are time separable so each firm solves a static problem in each period except considering the possibility of collusion and possible benefit of not deviating from collusive behavior. In an exhaustible resource case, each firm’s optimization problem inherently bears a dynamic aspect due to exhaustibility of the resource. Porter then derives a FOC depending on market conduct:

$$p_t\left(1+\frac{\theta_t}{\alpha_1}\right) = DQ_t^{\delta-1}$$

In which p_t is price at period t, α_1 is price elasticity of demand, D is a function of specific parameters and Q_t is quantity supplied to the market. θ takes values 1, $\sum s_{it}^2$ or 0 in collusive, Cournot and perfect

[1] See Devarajan and Fisher 1981

competition, respectively. He uses a switching regressions approach proposed by Kiefer (1980) and finds model parameters including market conduct using maximum likelihood estimation. He also identifies collusive periods from non-collusive ones in an iterative process: taking an initial guess for collusion dummy variables, calculating model parameter values, taking these values as given calculating collusion probabilities in each period and updating the parameter estimates and continuing this process until convergence. Porter (1983) provides a novel framework for studying cartel stability however one should be careful about the assumptions and the nature of the market. For example, in transportation cost, there are some close substitutes available which are not present in oil market. Also the exhaustibility of oil would cause a positive margin between extraction cost and price even in a perfectly competitive market (for a confusion of marginal extraction cost and marginal total cost see Almoguera and Herrera(2007))

1.5. Applying Porter (1983) Approach to Oil Market

Almoguera and Herrera(2007) apply Porter(1983) approach to oil market using quarterly data from 1974-2004. They use the same functional form assumptions as Porter (1983) about oil market. Their estimation result shows that oil market was more in a Cournot competition rather than collusion especially in last 20 years. Although they derive reasonable results, they do not consider differences of oil with railroad transportation. First of all, they do not enter the exhaustibility of oil into their optimization problem. Second problem with their approach is that their demand function specification is exactly like Porter's specification for railroad transportation which does not seem to be necessarily true. In contrast, the literature on oil demand estimation uses another specification which is described in section 2. This specification might be problematic because they do not consider that there is no good substitute for oil so its demand is pretty persistent in short-run. Many researchers include lagged consumption as a measure of infrastructure installed which depend on oil consumption like power plants, cars, factories etc in estimation of oil demand. The result of their estimation for price elasticity is relatively high rather than other estimates in literature. (See Gately and Huntington (2002) and Cooper (2003))

2. Model

2.1 Optimization Problem

Demand function specification is derived from Gately and Huntington (2002) as follows:

$$\log Q_t = \alpha_0 + \alpha_1 \log p_t + \alpha_2 g_t + \alpha_3 \log Q_{t-1} + U_{1t}$$

$$\text{Equation(1): Demand function}$$

Where p_t denotes crude oil price in period t, Q_t denotes total quantity of crude oil consumed in period t, g_t denotes growth in world real GDP and U_{1t} is error term which is assumed to be iid normal across periods.[2] Including lagged value of consumption is widely accepted in estimation of demand for oil because this variable incorporates the fact that there is not a good substitute for oil, at least in short run, so the demand is expected to be relatively persistent in consequent periods.[3]

I assume a simple differentiable convex extraction cost function for tractability of model. Although this function cannot perfectly describe production behavior in long run, it can serve as a good approximation in the short run. However, due to huge variability of extraction costs[4] across different regions and oil fields, I assume that cost functions are producer specific:

$$C_i(q_{it}) = a_i q_{it}^{\delta} + c_0$$

$$\text{Equation(2): Cost function}$$

Where $\delta > 1$ so that extraction of an extra unit of oil becomes more and more costly as extraction rate increases.[5]

In order to incorporate exhaustibility of oil, I will consider the simplest case for the moment where each producer exactly know S_0, total oil reserves at time 0, extraction cost function $C(q_{it})$, is only a function of amount produced q_{it}, at each time period t, hence does not change over time, and producers have perfect foresight about prices. I will assume a competitive fringe (Non-OPEC producers) and a potentially collusive section (OPEC) in the market. Each producer solves the following problem:

$$\max_{q_{it}} \{\sum_{t=0}^{\infty} \beta^t (p_t q_{it} - C_i(q_{it}))$$

$$\text{Equation(3): profit maximization problem}$$

[2] I have tested equation (1) for serial correlation among error terms and the hypothesis for $\alpha_3 = 0$ was rejected (with a t-statistic=49) and the corresponding Durbin-Watson d-statistic is 1.929 which in fact shows that assuming no serial correlation is reasonable.

[3] Furthermore, price elasticity of demand for oil is asymmetric but for simplicity I will assume a simpler specification similar to third approach in Gately and Huntington (2002).

[4] According to Energy Information Administration, extraction of a barrel of oil using water injection in deep oil wells in west Texas would cost $45 in 2006 while in some oil wells in other parts of world it cost less than $5.

[5] Considering technical issues regarding life cycle of oil wells, there is an optimal maximum extraction rate from any specific oil well so extracting more than that rate destroys the oil well so in fact costs more to producer.

Subject to exhaustibility of the total oil reserves she owns:

$$\sum q_{it} \leq S_0$$

Equation(4): exhaustibility constraint

Using Lagrange multiplier λ for the exhaustibility constraint, one can derive the FONC as follows:

$$\beta^t(p_t + \frac{q_t\, \partial p_t}{\partial q_t} - C_i'(q_{it})) = \lambda$$

Equation(5): FONC

Rewriting the FONC using $\beta = \frac{1}{1+r}$ we can derive:

$$p_t + \frac{q_t\, \partial p_t}{\partial q_t} - C_i'(q_{it}) = \lambda(1+r)^t$$

Equation(6)

Equation (6) has important implications: First notice that in a competitive market, where change in quantity of a single producer would not affect the market price, equation(6) reduces to a version of Hotelling rule which states the price-cost margin of an exhaustible resource will increase exponentially over time with the interest rate:

$$p_t - C'(q_{it}) = \lambda(1+r)^t \;\Rightarrow \frac{p_{t+1-C'_i(q_{it+1})}}{p_t - C_i'(q_{it})} = (1+r)$$

Equation(7): Hotelling Rule

Second, given our demand specification in Equation (1), price elasticity of demand is α_1 so we can rewrite Equation (6) to derive:

$$p_t + \frac{q_t\, \partial p_t}{\partial q_t} - C_i'(q_{it}) = \lambda(1+r)^t \;\Rightarrow\; p_t + \frac{q_t\, \partial p_t}{\partial Q_t}\frac{\partial Q_t}{\partial q_t} = C_i'(q_{it}) + \lambda(1+r)^t$$

$$\Rightarrow\; p_t + \frac{q_t p_t}{\alpha_1 Q_t}\frac{\partial Q_t}{\partial q_t} = C_i'(q_{it}) + \lambda(1+r)^t$$

$$\Rightarrow\; p_t + \frac{p_t\, s_{it}}{\alpha_1}\frac{\partial Q_t}{\partial q_t} = C_i'(q_{it}) + \lambda(1+r)^t$$

$$\Rightarrow p_t\left(1+\frac{\theta_{it}}{\alpha_1}\right) = C_i'(q_{it}) + \lambda(1+r)^t$$

$$\text{Equation(8): Market structure equation}$$

Where θ_{it} is the elasticity of total output w.r.t firms own output. This will be equal to zero, 1 or $s_{it} = \frac{q_{it}}{Q_{it}}$ respectively in perfectly competitive, collusive or Cournot competition cases[6]. It can be shown that given specification of demand and cost functions, market shares are constant over time. Multiplying both sides of equation (8) with market shares and summing over all producers, world oil supply equation can be derived:

$$p_t\left(1+\frac{\theta_t}{\alpha_1}\right) = DQ_t^{\delta-1} + \lambda(1+r)^t$$

Where $D = \delta\left(\sum_i a_i^{\frac{1}{1-\delta}}\right)^{1-\delta}$ and $\theta_t = \sum_i s_{it}\theta_{it}$.

Porter (1983) derives a similar equation but without a scarcity rent term: $\lambda(1+r)^t$. He then proceeds by taking logs and hence deriving a log linear supply function. Note that I can not apply the same approach because there exists an extra additive term that would not come out of logarithm function. Using exact Porter approach one cannot estimate all the parameters and they would not be identified[7]. I will try to get around this problem by finding a proxy for scarcity rent in a way that I can estimate the above model.

2.2. Scarcity Rent Problem

If information on marginal extraction cost in a competitive market was available we would be able to take margin between price and marginal extraction cost as scarcity rent. Although oil market is relatively concentrated, it also has a competitive fringe. I will estimate scarcity rent in each period by looking at active oil wells with highest production costs and take the margin between these costs and oil price as scarcity rent. The rationale for this approach is that most costly wells are just indifferent between producing and not producing considering all costs including scarcity rent. By taking these observations on highest cost producing wells I am in fact looking at last entrant in the market and since

[6] For a further discussion of different market conducts for oil market see: Almoguera, and Herrera (2007)
[7] For a naive application of Porter approach to oil market which results in a misspecified FOC see: Almoguera, and Herrera (2007)

these last entrants will just break even, their marginal revenue of extracting one barrel of oil (price) should equal their marginal total cost which is consisted of marginal extraction cost plus the scarcity rent:

$$SR_t + Marginal\ extraction\ cost = marginal\ total\ cost \leq price$$

For last entrant, the inequality above should bind. This margin will serve as a measure for scarcity rent. Of course there are lower cost producers in the market but their price-cost margin would be the scarcity rent plus some cost advantage in production[8].

Looking at data about this margin, it seems to be almost a constant fraction of oil price in each period. The ratio of price-cost margin to oil price,k, for these wells is estimated[9] to be 0.2377 with R-squared ratio of 0.84 so I will employ this estimation and insert it into the Equation(8) to derive the following equation:

$$p_t\left(1+\frac{\theta_t}{\alpha_1}\right) = DQ_t^{\delta-1} + kp_t$$

$$p_t\left(1+\frac{\theta_t}{\alpha_1} - k\right) = DQ_t^{\delta-1}$$

Equation(9): Simplified Market structure equation

2.3: Further Notes on Estimating Scarcity Rent

"Scarcity rent" refers to opportunity cost of selling a unit of exhaustible resource today rather than keeping it to the next period and selling it then. As a result in a perfect competition case, price of an exhaustible resource would be equal to its "user cost" which equals marginal extraction cost plus scarcity rent. If our simplifying assumptions about extraction of an exhaustible resource at the beginning of section 2 were not too strong then the Hotelling rule would predict that this scarcity rent would exponentially increase. However, there are some issues that challenge Hotelling rule. First, there is a lot of uncertainty about probable amount of oil in earth. As a clarifying example assume that an

[8] Note that the assumptions behind this argument is that First, the oil produced in different wells is almost homogenous which is not a very strong assumption specifically because the minor differences in quality of different oil types is offset by minor differences in their prices. Second assumption is that scarcity rent for different types of oil is almost the same which given the previous assumption about homogeneity, and noting that scarcity rent is in fact the opportunity cost of selling oil today rather than keeping it to the next period, is again not a very strong assumption.

[9] For detailed estimation process refer to section 3.

extraordinarily huge oil field, comparable to total proved reserves, is discovered today. As a result of this discovery the exhaustibility of oil becomes less relevant so scarcity rent would decrease.[10] On the other hand, expectations of future prices play a crucial role on the "opportunity cost" of selling a resource today. This is because if for any reason owners of the exhaustible resource believe that next period's price will fall (due to an innovative backstop technology or low economic growth), then the opportunity cost of selling the resource today will decline. All mentioned above make it difficult to derive a straight forward estimate for scarcity rent.[11] However, looking at data as described in section 3 we could infer that due to contribution of all different sources to scarcity rent, empirically we observe a constant ratio of price to be an upper bound for scarcity rent so I will employ that estimate.

Legal contracts on royalties paid to the owner of a natural resource could also be a candidate for estimating of scarcity rent but there are 2 problems: First, Legal contracts on oil fields are usually long term which do not reflect changes in scarcity rent in short term.[12] Second issue could be observed especially when the price of oil declines and as a result previously operative oil wells become inactive although according to their contracts the royalty rate is a fixed portion of the production revenue which is in fact not realized (because revenue of the oil well is zero in inactive periods.)

2.4: Identifying Collusion

Given the above functional form assumptions, the estimation process is similar to that of Porter(1983). Suppose $\{I_t\}$ is a sequence of zero and one in which one indicates a collusive regime. Taking logarithm from both sides of Equation(9) we can derive the supply relationship:

$$\mathrm{Log}\ p_t = \beta_0 + \beta_1 \,\mathrm{Log}\ Q_t + \beta_2 S_t + \beta_3 I_t + U_{2t}$$

$$\text{Equation}(10)\text{: Supply function}$$

Where S_t are shocks to supply in oil market and U_{2t} are assumed to be iid normal across periods. Furthermore,

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[10] For example coal is sometimes said to be non-exhaustible because at current consumption rates it will last for more than 3000 years so in fact there is not much exhaustibility rent associated with coal.

[11] For a detailed discussion of dynamics of scarcity rent see Farzin(1992)

[12] For example as a result of anticipating a recession, price of oil in future may be expected to fall so the scarcity rent would decrease. After this concern regarding recession is removed, the scarcity rent would increase again so the scarcity rent is almost as volatile as oil price itself.

$$\beta_0 = \log D$$

$$\beta_1 = \delta - 1$$

$$\beta_3 = -\log\left(1 + \frac{\theta_t}{\alpha_1} - k_t\right)$$

Given these parameter values, we can calculate the value of θ_t as follows:

$$\theta = \alpha_1(\exp(-\beta_3) - 1 + k_t)$$

Depending on values of θ we can classify the conduct of market. If $\theta = 1$, OPEC members are following an optimal cartel behavior and market has a competitive fringe[13], if θ=0, The market is in perfect competition and if $\theta = \sum s_{it}^2$=0.08[14] the market conduct is more close to a Cournot behavior with a competitive fringe[15]. However, it is important to notice that in equilibrium $\theta = 1$ might not be supported by the set of trigger strategies and punishments. In fact, at $\theta = 1$ agents could earn maximum profit but on the other hand they have more strong incentive to deviate from optimal cartel behavior because the gain from deviation would be higher in case all other members of cartel are following the optimal cartel behavior. As a result, we would not expect to see $\theta = 1$ case in equilibrium of this repeated game but a $\theta \in (0,1)$ which as θ gets closer to 1 the regime is more collusive and as it goes to zero, it will be more competitive.

Similarly, when the scarcity rent is present in a market, in case of perfect competition the price is higher than marginal cost so the difference between the payoff from colluding or deviating to a non-cooperative case is less than a market in which scarcity rent effect is not present. As a result, we would expect that in a market with a high scarcity rent collusion is more sustainable, frequency of punishment periods is low and their duration is also short.

If the collusive and non-collusive periods were known, the estimation of parameters of above model would be straight forward using a two step least squared method but unfortunately this is not the case. However, using simultaneous switching regressions approach proposed by Kiefer(1980) we can use

[13] For a detailed discussion of a dominant firm with a competitive fringe see Church and Ware (1999).
[14] To see a detailed calculation of this index refer to Almoguera, and Herrera (2007).
[15] For a detailed discussion of market conduct and some less probable classifications see Almoguera, and Herrera (2007)

maximum likelihood estimation approach to estimate both parameters of the model and also identify the collusive and non-collusive periods.[16]

3. Data

In this section I will discuss about data sources and summary statistics. To estimate scarcity rent, I obtained the marginal extraction cost of oil wells from EIA(2003) and EIA(2007) which have annual extraction cost data from 1986-2006. The above mentioned reports have detailed cost data for different categories of oil wells. Data for each category is generated by taking average of costs for 10 typical oil wells of the category. I picked the highest cost wells which were most costly oil wells in USA due to their characteristics (8000ft depth) and also costly extraction technology (water injection) used in extracting oil. I also use price of the corresponding oil type (West Texas Intermediate) for estimation of scarcity rent.

Since scarcity rent estimated is central to the estimation procedure and it could vary according to major regime changes in other periods of time, and also because I did not have cost data from years before 1986, I preferred to limit the dataset time span to cost data time span. To maintain consistency and validity of my estimations, I use the same time span for my estimations although I use quarterly data[17] to be able to obtain better estimations. Hence, I will use quarterly data on oil production and real prices (2006 Dollars) from 1986 quarter 1 to 2006 quarter 4[18]. This data were obtained from Energy Information Administration website. To construct supply and demand shocks I used information on EIA annual chronology of oil market to find major supply and demand increase or decreases. The data on real GDP growth was obtained from World Bank development indicators. The data is summarized in table 1.

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[16] For a detailed discussion of the estimation process refer to Porter(1983)

[17] Although the data are quarterly, because the demand for oil at every period is worldwide which has all different kind of weather I have not included seasonal dummies. Besides that, since the supply chain of oil is in most cases vertically integrated, it takes several weeks from the start of extraction until the retailers deliver the product to consumers and hence the effect of seasonal changes is not so significant.

[18] In comparison, Almoguera, and Herrera (2007) use a similar data in frequency but their data span is from 1974 to 2004 but the rest of common data are similar. I use cost data that they don't use.

Variable	Mean	Minimum value	Maximum value	Standard deviation	Measurement unit
World consumption	72441	61163	83719	15949.5	Thousand barrels
World oil price	45.795	26.45	65.14	27.35796	2006 Dollars/barrel
World real GDP growth	0.035821	0.033745	0.037897	0.002936	Percentage growth
Marginal Extraction costs	23.89808	11.2316	36.56457	17.91311	2006 Dollars/barrel
West Texas Intermediate oil price	46.81898	27.58796	66.05	27.19677	2006 Dollars/barrel

4. Estimation Results

In this section I will discuss about estimation procedure and estimated results.

4.1. Scarcity Rent

Figure.1 shows marginal extraction cost (black) and crude oil price (grey) for 10 oil wells in west Texas during 1986 and 2006. According to EIA(2007), these oil wells were most costly oil wells in USA due to their characteristics (8000ft depth) and also costly extraction technology (water injection) used in extracting oil. The data for this estimation was obtained from EIA(2003) and EIA(2007) reports. These reports include operating cost information in several types of oil wells across USA. I used data operating cost of different types of oil wells with different extraction technologies and calculated per unit extraction costs and selected the most costly wells which are deepest oil wells (800ft) with the water injection extraction technology which results in the highest marginal extraction cost.

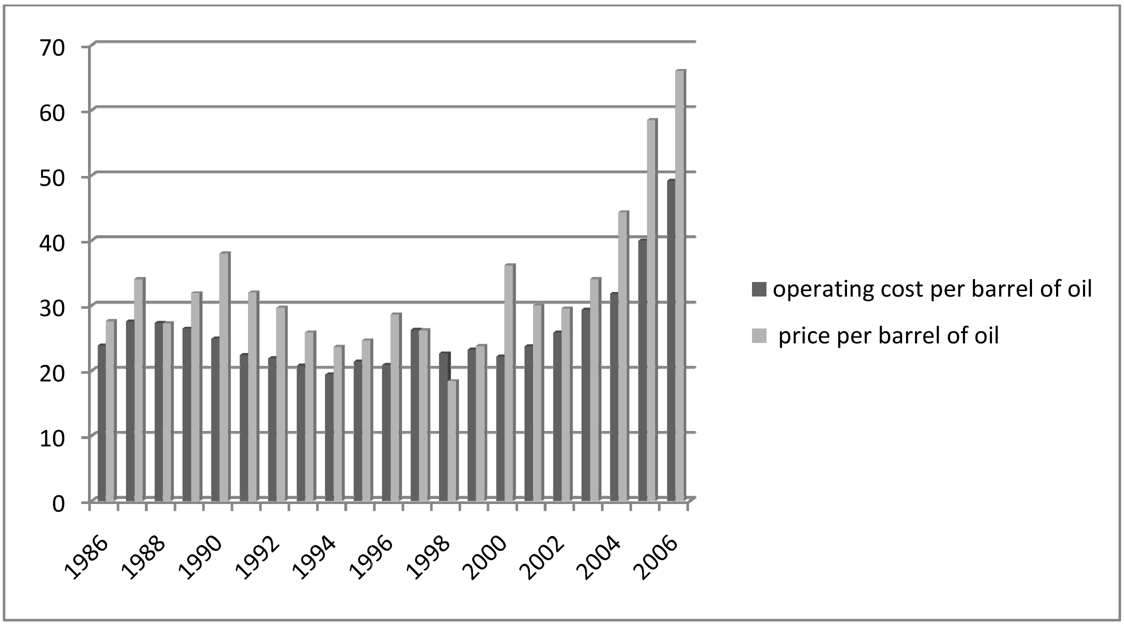

Figure 1. Oil price and operating costs for most costly wells in West Texas. (2006 dollars)

Source: EIA(2003) and EIA(2007)

I run a regression to test for a relationship between price-cost margin and price at any given point in time. The estimated coefficients are reported in table 2.

Price-cost margin (scarcity rent)	Coefficient	Standard error	95% confidence interval
Price	0.237688	0.02287	0.1901 0.2853
			R-squared= 0.8437

Table 2: Estimation of Scarcity rent from most costly producing wells

4.2. Supply Function Estimation

Although there is not a consensus about estimation of oil supply function but literature on oil demand estimation is well established and agreed upon. I will employ estimation of demand function parameters, specifically a modified version of Gately and Huntington (2002) and insert these estimates[19] into my likelihood function and try to estimate supply function parameters and market conduct. [20] I will use quarterly data on oil production and prices obtained from Energy Information Administration webpage. To construct supply and demand shocks I used information on EIA annual chronology of oil market to find major supply and demand increase or decreases. The data on GDP growth was obtained from World Bank development indicators.

I developed Matlab[21] programs for estimating Maximum likelihood estimators.[22] The supply estimates are displayed in table 3. The standard errors are calculated using BHHH method. Unfortunately they are higher than expected and the estimation results are relatively poor. They can probably be improved by choosing better instruments for my estimation. Standard errors are reported in parenthesis.

Variable	Supply coefficient estimate
β_0	−3.23 (1.31)
β_1	3.08 (0.96)
β_2	0.21 (0.14)
β_3	−30.21 (12.73)

Table 3 : Supply function estimated coefficients. (Standard error in parenthesis)

From above estimations we can derive:

$$\beta_1 = 3.08 \Rightarrow \delta = 4.08$$

[19] The estimates of Gately and Huntington is modified to match the data structure I have here and the parameter values are $\alpha_0 = 1.27,\ \alpha_1 = -0.05,\ \alpha_2 = -0.02\ and\ \alpha_3 = 0.91$

[20] I have also tried to jointly estimate both supply and demand functions but parameter estimates in that case where poor and my attempt was unsuccessful. However in next stages of this research I will try to find better instruments for supply and demand and try to jointly estimate supply and demand parameters.

[21] Matlab files are available upon request.

[22] For detailed discussion of this approach refer to Porter(1983)

$$\beta_3 = -30.21 \Rightarrow \theta = 0.038$$

It is worth noticing that $\delta = 4.08$ represents a relatively inelastic supply function which is a reasonable result. Also resulted estimate for $\theta = .038$ is almost consistent with Cournot behavior rather than collusion.

The estimated sequence of $\mathrm{I_t}$ converged to zero for all periods of sample which indicates that according to my estimates in fact OPEC failed to effectively cooperate on increasing prices in this sample period. This can be justified by high incentives to deviate from optimal collusive behavior among OPEC members because most OPEC countries governments are heavily dependent on oil revenue. This estimate for $\mathrm{I_t}$ is in fact consistent with Lin(2007) result which does not find evidence on collusion during 1989-2004 period. My result is to some extent consistent with Almoguera and Herrera (2007) which identify rare collusion periods during same period of time. However, Almoguera and Herrera(2007) demand function specification is different from mine because in contrast with the literature on demand estimation for oil, they do not include lagged consumption in their demand function so their price elasticity is relatively high which may result in some bias in estimating collusive periods. However, if I impose SR=0, my estimate of θ would become 0.0521. They have derived this number to be 0.1161 which should be the effect of difference in demand specification we have rather than scarcity rent.

It might seem unreasonable that I_t is zero in all periods in my estimation. In fact it would be better if our estimates showed that for some periods this sequence is nonzero. However, this will not result in a problem with identification of β_3 *or* θ . This is because in fact the sequence would not converge to 0 itself but it is derived from regime classification probabilities when the stopping criterion is reached. Similar to Porter(1983), in my estimation, I calculate the regime classification sequence $\{w_1, \dots, w_T\}$. As Lee and Porter (1984) show, the total probability of misclassification would be minimized if classification series $\hat{I}_t$ is generated according to the rule that

$$\hat{I}_t = 1 \; iff \;\; \widehat{w}_t > 0.5$$

And =0 otherwise. So as it is clear from discussion above, even if $\hat{I}_t$ is equal to zero for all periods, it does not mean that the probability of being 1 is zero but it means that this probability is less than half.

It is important to notice that, if we assume that oil is not exhaustible, the estimation that we derive for θ is higher than when we consider exhaustibility. This shows that some of market power estimated for OPEC in the literature might in fact be exhaustibility effect rather than pure market power. To summarize, including Scarcity rent would decrease our estimate for OPEC market power so at least a fraction of markups observed in the market can be attributed to exhaustibility.

5. Conclusion

In this paper I tried to test whether OPEC exercises market power in oil market or exhaustibility causes a positive price-cost margin. I considered the exhaustibility of oil and formulated an infinite horizon optimization problem that producers face. I imposed some functional form assumptions. To get a equation form that can be estimated I estimated scarcity rent empirically. Using this estimation I derived a loglinear supply function. I estimated supply function parameters and also identified collusive and noncollusive periods using Porter(1983) approach. The estimation showed that there is not much evidence on collusion during this period of time and including scarcity rent would even decrease the level of market power estimated by model. Supply function parameters estimates are also reasonable.

Next step for this research would be trying to estimate both supply and demand functions jointly. In order to do so I will need to find some supply and demand shocks to be able to estimate the simultaneous supply and demand equations. I have made strong functional form assumptions that should be relaxed in next versions of this paper. My operating cost data was limited to 1986-2006 which resulted in a limitation of time period investigated. I will try to find other proxies for scarcity rent that could serve for a longer period of time so that I can expand the time scope of this estimation to include more variation in prices which will increase the probability of including collusive periods in my sample.

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