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OPEC AND THE MONOPOLY PRICE OF WORLD OIL*

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The paper presents a dynamic model of the behavior of OPEC viewed as a monopolist sharing the oil market with a competitive sector. The main conclusion is that the recent increase in the price of oil was a once and for all phenomenon due to the formation of the cartel and that prices should remain approximately constant during the next twenty years.

1. Introduction

The last four years have seen the price of oil skyrocket to its present level of over $11 per barrel. Even if we take into account reasonable 'user cost' estimates, such a price is far above extraction costs for OPEC members (or, for that matter, other oil-producing nations).

Some economists seem to think the current price is too high for OPEC's own best interest. As a consequence, they believe it will come down eventually. Others seem reconciled to future oil prices of the order of magnitude of current levels or expect them to go even higher. Obviously it is difficult to resolve such an issue in the abstract, without explicit or implicit reference to some model of OPEC's oligopolistic behavior.

In this paper we report numerical results from a crude model aimed at quantifying, roughly, what long-term oil prices would be if the members of OPEC colluded in rational, concerted action to maximize present discounted profits. In order to study the influence of long-term considerations on the price of oil, we have built a dynamic model of the capital theoretic type. A distinctive feature of our approach is that all economic agents (including the so-called 'competitive fringe') act like rational profit-maximizers rather than follow some (other) behavioral rule.

The model predicts a current world price slightly lower than the actual prevailing price of petroleum. But the difference is well within the error margin due to the data.

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Our most striking and important result is that oil prices do not increase much during the next twenty years. In our preferred specification they rise by only $0.50/barrel, expressed in 1975 dollars. If our model is believable, the sharp price increases of the recent past are a once-and-for-all phenomenon connected with the formation of OPEC and are unlikely to be repeated again.

Model-builders will probably be interested in the qualitative result that long-run considerations seem to be of secondary importance in determining near-term oil prices. For the next twenty years the standard static monopoly model, using the same data, yields prices less than a dollar lower than our complete dynamic model. However, the static framework does not predict well the quantitative consequences of changes in such parameters as the discount rate, the rate of growth of demand, etc.

It is important to emphasize that our model is really very crude. Uncertainty, including price uncertainty, is ignored. Cost estimates, extending over long periods of time, are necessarily rough (both conceptually and quantitatively). Our modeling of imperfect competition as applied to the oil cartel is at best an approximation. Also, the assumption of rational behavior may not be appropriate to the present problem.

Nevertheless, we believe our model to be basically valid. Fortunately, the main conclusions appear to be relatively robust given the basic framework of the model and reasonable variations in the data.

The model is of the long-term dynamic type familiar in capital theory. This makes the formulation complicated to begin with. Unfortunately, there is no meaningful way of compressing our problem into a static monopoly framework. The fact that the dynamic and static problems yield similar answers is a fortunate coincidence dependent on the data rather than some necessary theoretical property of our formulation.

This paper is divided into six sections. Following the introduction, section 2 describes the model. Sections 3 and 4 discuss the data and results of our preferred specification. Section 5 analyzes the consequences of changes in the data. Finally, section 6 is the conclusion.

2. The model

The model tells the following story. The monopolist decides on a sequence of prices for all future periods. The 'competitive fringe'[1] takes those prices as given and considering extraction costs, sets its production schedule so as to maximize present discounted profits. The difference between the total demand and the competitors' production is the net demand OPEC must meet. It chooses the

[1]We model all non-OPEC members as 'competitors' and give them the collective name 'competitive fringe'. Our formulation dictates this sharp distinction, but we do not mean to prejudge in any way the issue of oligopolistic behavior by oil companies.

prices (or, equivalently, its production) so as to maximize its present discounted profits.

Obviously, the assumption that the monopolist in effect announces all future prices is very unrealistic. However, given the present state of theory, we believe it more attractive than the alternatives. Clearly, long-term decisions are made according to expectations about the future. Past experience is but one element in the generation of those expectations. For the problem at hand, however, past prices are very poor predictors of future prices. As time goes by, oil is being extracted at greater and greater costs. Furthermore, as the quantity of oil left in the ground is decreasing, the 'user costs' are increasing. We believe that in this case, our perfect-certainty rational-expectations framework is preferable to models where production decisions are based entirely on lagged prices.

The basic rationale of our approach is that the competitors 'feel' what future prices will be, and maximize profit accordingly, given their extraction costs. In our opinion, this is a far more attractive formulation than one based on somewhat arbitrary behavioral supply-like reaction to past prices.

2.1. The competitors' problem

We assume that the competitors have a cumulative cost functions $F(x)$, representing the total cost of producing x units of petroleum at 'normal' extraction rates. F is meant to include all costs associated with oil extraction—including exploratory, development, drilling, operating and transportation costs.

Let x_t be the cumulative amount of oil extracted at the beginning of period t; then $x_{t+1}-x_t$ is the amount extracted during period t. The cost of production in period t is

$$c_t=F(x_{t+1})-F(x_t). \tag{1}$$

The assumption of increasing costs requires

$$F''(x) \geqq 0. \tag{2}$$

There is no question that accepting a formulation of extraction costs in terms of a cumulative cost function is in part an act of faith. Obviously, costs rise as the better deposits give out, but the exact relation is much more complicated than our specification shows. In particular, costs depend on the rate of extraction, as well as the total amount. This may be critical because oil-producing capacity cannot expand at an arbitrary rate, due to exploration and investment lags. We deal with this issue somewhat inflexibly by assuming that in each period there is a preset upper bound on production of the competitive sector. This limit is the amount of oil which could be extracted if investment in new facilities had continuously run at its maximum from time zero. For convenience the capacity constraint grows geometrically. In other words the operative constraint is of the form

$$x_{t+1}-x_t \leqq \beta(1+\alpha)^t, \tag{3}$$

where β is equal to the capacity of the competitors in 1975, and α is the maximum allowable growth rate of capacity. Likewise for convenience, the discount rate appropriate to the competitors, r_c, is presumed constant over time.

Assuming that competitors know the sequence $\{P_s\}$ of prices for all future periods, they face the problem of

$$\text{Max.} \sum_{t=0}^{\infty} [P_t(x_{t+1}-x_t)-C_t]\frac{1}{(1+r_c)^t}, \tag{4}$$

subject to

$$x_{t+1} \geqq x_t,$$

$$(x_{t+1}-x_t) \leqq \beta(1+\alpha)^t,$$

$$C_t = F(x_{t+1})-F(x_t),$$

$$x_0 = 0.$$

2.2. The monopolist's problem

The answer to the preceding problem is a set of functions:

$$S_t(\{P_s\}), \tag{5}$$

which relate competitive production in different periods to the *entire* sequence of prices.

Throughout this exercise we assume that the demand for crude oil in period t is a function of that period's price,

$$D_t(P_t). \tag{6}$$

Obviously, in a more complete specification we would want to consider the fact that D_t is really a function of past and future prices. However, our problem is already sufficiently complicated that we decided to take the simplest possible specification for demand. As we are interested in middle to long-run analysis, this should not be a real handicap.

Subtracting (5) from (6), we have net demand function

$$ND_t(\{P_s\}) = D_t(P_t) - S_t(\{P_s\}). \tag{7}$$

This is the demand function the monopolist faces.

The Persian Gulf and North African members of OPEC are treated as if they were a single monopolist. This is attributing to them more monopoly power than they actually possess.

Let G be their cumulative cost function, y_t the cumulative production up to period t, and r_m the monopolist's discount rate. They seek to

$$\underset{\{P_s\}}{\text{Max.}} \sum_{t=0}^{\infty} [P_t ND_t - (G(y_{t+1}) - G(y_t))] \frac{1}{(1+r_m)^t}, \tag{8}$$

subject to

$$y_{t+1} \geqq y_t,$$

$$y_{t+1} - y_t = D_t(P_t) - S_t(\{P_s\}),$$

$$y_0 = 0.$$

One could include a constraint similar to (3) in this problem, but it would never be binding with reasonable data.

The solution of (8) is a dynamic equilibrium. The monopolist is doing all in his power to maximize profits given the competitive reaction functions. And the competitive suppliers are doing all in their power to maximize profits given the pattern of current and future prices. Thus, there is no incentive for anyone to deviate from the prescribed solution of (8).

3. Data for the preferred specification

In this section we present the data for our preferred specification of the model. We do not feel committed to specific figures and present our numbers more as an indication of the relevant order of magnitude. In a later section, we will study the sensitivity of our results to variations in the data. It will be shown that the basic conclusions are quite robust.

3.1. Demand

The price of oil has reached its current level so recently and so quickly that no econometric study has found enough data points to estimate with confidence a demand function. We have chosen a long-run elasticity of 0.4 at \$10/bl, where the demand is set equal to 15 bbl/yr. This is a fair representation of current thinking on the demand for world oil. If we look for a linear demand curve with those properties, we get

$$D = 21 - 0.6\,P. \tag{9}$$

The demand is zero at \$35/bl, which seems not an unreasonable price for a backstop technology to come on line.

Note that in order to simplify the model, we have in effect assumed there is only one oil-consuming region in the world. In our preferred specification we assumed that demand increases at 3% per year. This is low in comparison to its rate of growth since the end of WW II. However, it may be a reasonable assumption for the future, as the development of alternative technologies and environmental constraints will probably dampen the growth of demand. Thus, our preferred specification for world oil demand (starting with $t=0$ in 1975) is

$$D_t(P_t) = (21 - 0.6\,P_t)(1+g)^t,$$

where g is the one-period growth of world demand.

3.2. Supply

Because data was more easily available in this form, we assumed that OPEC was composed only of the oil-producing countries from the Persian Gulf and North Africa. This also corresponds, in our opinion, to a more realistic appraisal of who constitutes the monopoly kernel of OPEC.

For our purposes the cost of supplying oil is composed of two parts. The capital costs (exploration and development of new fields) depend on the amount of oil left in the ground. Transportation and current costs, on the other hand, are independent of the amount of oil already extracted.

Following Hubbert's and Nordhaus' analysis, we assume that capital costs are inversely proportional to the quantity of unexploited reserves. Letting $K(t)$ be the capital cost at time t, we have

$$K(t) = \frac{K_0 R_0}{R_0 - x(t)}, \tag{10}$$

where K_0 and R_0 are respectively capital costs and reserves at time 0, and $x(t)$ is the total amount extracted between time zero and time t.

The value of β was chosen equal to the production of non-OPEC (by our definition) countries in 1975; α was fixed at 3% per year.

Both current and transportation costs are assumed invariant with time. Transportation costs are estimated to North America or European markets, whichever is closest.

Our estimates for capital, current and transportation costs are presented in the appendix.

3.3. *Rates of interest*

There is no foolproof way of choosing current discount rates for such a problem. In our preferred specification, r_m is set at 5% and r_c at 8%. The 8% figure seems reasonable as a current cost of capital in competitive markets, after inflation has been subtracted out. The discount rate for OPEC is made somewhat lower due to a belief that these countries have fewer productive outlets for accumulated funds. As we will see later, only a lowering of r_m has any effect on short-term prices.

4. Results

Time periods are ten years. This corresponds to our notion that the model, if at all accurate, has validity only for showing medium- to long-run trends.

On the first line of table 1, we present the result of our preferred specification. All prices in table 1 are constant prices, in 1975 dollars. Note that the price of oil hardly increases in the first twenty years. However, in the following period it increases sharply, to reach $20 per barrel in the period 2005–2015.

Table 1[a]

Specification	1975–1985		1985–1995		1995–2005		2005–2015		Static monopoly price
1. Preferred	$9.8	5/13*	$10.3	6/17*	$14.7	14/12	$20.8	21/4	8.9
2. $\alpha=0.05$	8.7	4/14*	9.7	5/19	15.4	15/10	21.0	21/3	8.0
3. $\alpha=0.01$	10.7	5/12*	12.7	8/13*	14.9	11/14*	19.3	20/7	9.6
4. $\beta=\infty$	6.1	0/20	9.9	10/13	15.6	15/10	21.1	21/3	
5. $r_m=3\%$	11.1	4,13*	11.9	5/17*	16.7	10/14	22.4	19/2	8.9
6. $r_c=5\%$	9.7	5/13*	10.9	18/5	16.2	0/23	21.8	18/5	8.9
7. $r_c=12\%$	9.8	5/13*	10.4	6/17*	15.0	13/12	20.9	22/3	8.9
8. $g=1\%$	8.1	4/13*	7.0	5/14	10.5	8/11	15.1	11/6	8.0
9. $g=6\%$	12.3	6/13*	15.7	12/17*	20.6	24/15	27.6	36/2	10.1
10. $a=25$ $b=1$ $E=2/3$	12.3	7/13*	8.9	8/17*	11.8	17/11	15.8	23/4	7.6
11. $a=19.3$ $b=0.43$ $E=0.29$	11.2	4/13*	11.9	5/17*	17.7	12/13	25.8	20/4	10.2
12. Reasonable cost changes			Virtually no differences						

[a]First number is price per barrel, second and third OPEC and non-OPEC annual production (bbl), respectively. The preferred specification uses the following data: $\alpha=0.03$, $\beta=11$, $r_m=5\%$, $r_c=8\%$, $g=3\%$, $a=21$, and $b=0.6$. For all the variations of the demand curve the demand at $10/bl is 15 bbl/year. E is the elasticity of demand at that price. In the preferred specification it is equal to 0.4. Cost data is presented in section 4. Note that in the preferred specification final demand is zero at a price of $35. Asterisks indicate that the competitive fringe is producing at maximum capacity.

For the first twenty years, OPEC produces less than a third of total world production. Its share starts increasing in 1995 until it eventually holds a complete monopoly.

It is of interest to compare the results of our model with those of a static model built along analogous lines except for the dynamic element. Such a model might fix the output of the competitive fringe at full capacity and have the monopolist solve:

$$\max_{P}\ (D_1(P)-\beta)(P-C), \tag{11}$$

where C is the cost of production for OPEC at the beginning of the first period (with any reasonable production schedule OPEC's cost of production changes very little over the first period).

As can be seen in the last column of table 1, the solution of problem (11) is \$8.9 with the data of our preferred specification. 'User costs' account for less than a dollar of the 1975 price.

On the fourth line of table 1 we present the results for a computer run which assumes no limit on non-OPEC production. As expected, prices in the first twenty years are much lower than in our preferred specification. However, from 1995 onwards those two experiments yield very similar results.

We will end this section by discussing in some detail the strategy of the monopolist. In the first periods, OPEC must balance several considerations. In the first place profits made early are more valuable, but prices will go up eventually, which gives an incentive to preserve oil. As in the pure Hotelling monopoly problem, an equilibrium is found, which depends on the demand and cost functions. In this case, however, the problem is complicated by the necessity of taking into account the competitors' reactions.

If the competitive fringe was able to increase its production without restrictions, OPEC would let it take over the market in the next ten years and run up extraction costs before progressively coming in. In our complete model OPEC's ability to induce the other countries to deplete their reserves is limited. Alternatively viewed, the competitive fringe's ability to respond is limited. Therefore, the price is set close to the level which maximizes short-term profits, given full-capacity competitive output.

5. Sensitivity analysis

Lines 2 to 11 of table 1 present the results of simulations in which we have changed, one by one, the assumptions of our preferred specification.

Lines 8 and 9 show the effect of a change in the rate at which demand for oil grows. The direction of change is predicted by the static monopoly model; however, it is misleading as far as orders of magnitude are concerned. In particular, it could not predict the 1985 drop in price when g is equal to 1%.

In this latter case, the growth of demand is slowed, and therefore complete monopoly in the long run is less valuable to OPEC. Furthermore, the rise in price necessary for the competitive fringe to produce at full capacity would reduce so drastically the residual demand that the short-term profits would be very small. As a consequence, OPEC does not attempt to run the competition out of oil as quickly as in other specifications.

The consequences of modifying the demand curve are shown in lines 10 and 11. It turns out that the static monopoly model predicts very well these changes in the short run. Note that the price of oil continues to remain relatively stable over the next 20 years, although its starting point varies with alternative demand specifications.

In lines 2 and 3 of table 1 are shown the consequences of changes in α, the rate of growth of the competitors' production capacity. Once again the static monopoly model predicts quite well the short-term effects of parameter changes, and prices are nearly constant over the next twenty years.

Recently, OPEC countries have voiced strong objections to a plan which would guarantee a minimum price of oil. The purpose of this plan is to increase the rate of growth of non-OPEC capacity by reducing the risks of exploration and development of new fields. In terms of our model, it is aimed at increasing α. It is therefore of interest to note that the monopolist's discounted present profit declines by only 5% when α increases from 1% to 5%. Furthermore, when all limits on the competitors' production are lifted ($\beta = \infty$), OPEC's present discounted profit is slightly higher than in the $\alpha = 5\%$ case.

The paradox is due to the interplay of two forces. When α increases, the short- to medium-term net demand for OPEC's oil decreases; on the other hand, it can run down the competitor's oil reserves quicker and therefore increase its long-term profits. It turns out that the two effects are of the same order of magnitude and cancel each other out as far as OPEC's profits are concerned.

A lowering of OPEC's interest rate to 3% has drastic effects on short-term prices. As future profits become more valuable, oil is kept in the ground for use in the future, when prices are higher. Obviously, a change in the interest rate does not influence the static monopoly price. Our computational technique did not produce results when r_m was raised to 8%. Changes in the competitors discount rate hardly influence prices in the short term or in the long term. Reasonable changes in costs and reserves also have negligible effects. For instance, if the capital costs of OPEC are increased by 50% when those of the rest of the world are decreased by 33% first period prices increase by only $0.05.

We believe the most significant result of those experiments is the consistent finding that real oil prices will not change much in the next twenty years. The various alternative specifications affected the initial price of world oil but did not challenge the conclusion that this price should not change sharply over the next two decades. If our model is believable, the drastic price increases in petroleum are a once and for all phenomenon not likely to be repeated in the near future.

6. Conclusion

We have built a simple, theoretically complete model of the world oil petroleum market. The basic results look plausible. The most drastic simplifications concern the modeling of the cartel's aims, the assumption of a single monopolist being without doubt very unrealistic. The assumption of perfect knowledge of future prices is not, we believe, crucial to our main quantitative result; petroleum prices should stay approximately constant, at a level close to the static monopoly price.

Appendix

In this appendix we present the cost data for our preferred specification.

Reserves

Total recoverable reserves are assumed equal to twice time-proven recoverable reserves as given in BP statistical review of the world oil industry, 1974. For the Persian Gulf and North Africa 943.4 bbl (billion barrels); for Western Europe 52.6 bbl; for the U.S. 81.2 bbl; for the rest of the world 363.6 bbl.

Capital costs

Capital costs for one barrel daily capacity were taken to be: U.S. and Western Europe $7,000, Persian Gulf and North Africa $500, rest of the world $1,500. If we assume that the decline rate is 8% and the discount rate 5% for OPEC and 8% for other parts of the world, this corresponds to a steady state capital cost per barrel of $3.07 in the U.S. and in Western Europe, $0.18 in the Persian Gulf and North Africa, $0.66 in the rest of the world. These figures are taken as initial costs; they increase according to formula (10) as reserves are depleted.

Transportation and current costs

Transportation costs were taken to be $0.85 from the Persian Gulf and North Africa, $0.05 from Western Europe, $0.40 from the U.S. and $0.85 from the rest of the world.

Current costs were taken equal to $0.12 in the OPEC countries, $0.75 in Western Europe, $0.55 in the U.S. and $0.70 in the rest of the world.

Note that from the point of view of our analysis, current costs and transportation costs play the same role.

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