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Optimal Oil Production in OPEC Members under Macroeconomic Constraints*

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This paper uses a technique of social welfare maximization under marcoeconomic constraints in order to derive the optimal level of oil production in selected members of OPEC. Most of the previous papers use simulation or optimization techniques to solve for optimal solutions, but they ignore the macroeconomic impact of oil production. This paper has attempted to overcome this shortcoming.

The optimal level of oil production is derived under different scenarios. The optimal solutions generally overestimate the actual behaviors. The paper concludes that if economic growth is the main objective of members of OPEC, they should seek ways to expand their revenue beyond the existing levels.

I. Introduction

OPEC and its oil production and pricing policies captures the attention of the public as well as academia in 1975. In those days, OPEC was strong and almost dictated its policies to the rest of the world. Despite its relative monopoly strength, many authors (Kennedy (1974), Levy (1974), Kalymon (1975), Federal Energy Administration (1974), Bohi and Russel (1975)) predicted that OPEC will have substantial surplus capacity by 1985. Following the pioneering work of Hotelling (1931) which provided an extensive treatment of the economics of exhaustible resources, in 1975 a simulation technique was utilized by many economists (Blitzer, et. al. (1975), Kalymon (1975), Abolfathi, et. al. (1977), MacAvoy (1982)) to estimate the supply and demand function for oil and the respective elasticities. Motivated by the oligopolistic power of OPEC in early 1975, many studies (Schmalensee (1976), Salant (1976), Cremer and Weitzman

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economic variables is specified. The process of maximization involves two steps. First, the structure of the economy and the key macroeconomic relationships are estimated. Second, the estimated macro-model is used as a constraint in the process of welfare maximization. This is an open-loop model (Theil (1961), Van Eiyk and Sandee (1959), Chow (1975, 1976)) of welfare maximization which solves for the optimal values of policy variables at the beginning of the planning period.[1] In what follows, a quadratic welfare function is specified which includes a combination of both endogenous and policy variables. The oil policy maker determines the optimal oil production in such a way that minimizes the squared deviation of actual values from the desired values of the target and control variable.[2] Constraints of the model are estimated based on a macro-economic model of selected OPEC states. The macro-model assumes that the economy produces only three goods — namely, oil, imported goods and nontraded goods. Oil is the only export of the economy which is produced by national oil companies. The economy is small and open to international trade. The exchange rate is pegged to a major currency or a basket of major currencies. The price of imported goods and oil is given.[3] The major investor in the economy is government, which uses oil revenue to develop and expand the domestic economy. Fiscal activities of government change the money supply, creating inflation via an excess supply of money over demand for money. There are twelve endogenous and nine exogenous variables. A 2SLS technique was applied to estimate the macro-model using pooled data for Indonesia, Iran, Kuwait, Nigeria, Saudi Arabia, and Venezuela. The estimation results of the macro-model are presented in Appendix 1.[4] The period of study is 1973-1986. The period before 1973 was omitted, first because some countries included in this study did not have full control over their oil industry before early 1975. Second, major structural changes took place between the two oil price hikes of 1973 and 1979. The data were mostly taken from various issues of

1 Instead of an open-loop model, one may use a closed loop optimal control model which specifies the policy variables as a function of future observations (Chow 1975)).

2 A major shortcoming of a quadratic function is that it penalizes both positive and negative deviations equally, but it has many nice mathematical properties. For example, one can obtain optimal solutions by applying the certainty equivalence theorem (Simon (1956)) to the linear econometric model with an additive random disturbance used in the present study (Chow 1975)).

3 OPEC as a whole may exert some impact on the international price of oil, but individual countries are price takers.

4 A covariance model of pooled-data estimation is employed which requires to include (N–1) + (T–1) dummy variables to account for the possibility of variations in intercepts over time and over cross-sections. N and T stand for the number of cross-sections and time series respectively. The significan dummies are reported in the appendix.

G	=	Total Government Expenditures
R	=	Government Revenue
L^s	=	Money Supply
L^d	=	Money Demand
PN	=	Price of Nontraded Goods
P	=	Price Level
π	=	Expected Price

Exogenous Variables

PO	=	Price of Oil
B	=	Monetary Base
PM	=	Price of Imports
M	=	Money Multpilier
X^s	=	Quantity of Oil Produced
e	=	Exchange Rate
YF	=	Income of Industrial Countries
t	=	Time
E	=	Monetary Variable
DIR	=	Dummy Variable for Iran
DIN	=	Dummy Variable for Indonesia
DS	=	Dummy Variable for Saudi Arabia
DV	=	Dummy Variable for Venzuela
DK	=	Dummy Variable for Kuwait

III. Optimal Oil Policy

Table 2 reports optimal oil production in the six selected OPEC members. These results were obtained under three different scenarios (A, B, C). The vector Y contains all or some of the endogenous variables of the macro-model. The target values (desired values) in vector Y^0 are set to grow at 5%, starting from their 1973 values. This is based on the assumption that a higher growth rate is not realistic and a lower rate is not desirable. The matrix E includes the weights given to each policy objective. In scenario A, all endogenous variables were included in the social welfare function and were assumed to be equally important to policy makers, which results in the matrix F becoming an identity matrix. Scenario B assumes that economic growth is twice as important as other variables, and it carries a weight equal to two. Finally, in scenario C all endogenous variables were dropped from the welfare function except the national income. In the studies cited before (Van den Bogard and Theil (1959), etc.), the vector Z includes traditional policy variables such as government expenditures and money supply. Here, based on institutional arrangements in oil exporting countries (e.g. the oil ministry functions in-

Table 2 (continued)

(Million Barrels)

Year	Kuwait Actual	Kuwait Optimal A	Kuwait Optimal B	Kuwait Optimal C	Nigeria Actual	Nigeria Optimal A	Nigeria Optimal B	Nigeria Optimal C
1974	929.3	1,283.5	1,442.2	1,283.1	823.1	760.9	690.4	760.4
1975	760.7	925.4	902.4	924.9	650.9	839.5	821.0	838.4
1976	785.2	805.8	835.8	805.9	756.5	661.9	623.1	661.5
1977	718.7	812.7	824.8	813.0	761.1	772.6	781.2	772.2
1978	778.0	740.2	747.2	740.0	692.4	775.1	782.7	776.8
1979	912.6	951.8	1,110.1	951.9	840.3	704.6	678.1	704.6
1980	608.9	949.0	967.0	948.9	753.2	852.5	785.0	852.9
1981	412.3	568.4	515.7	568.3	525.5	770.2	799.3	770.1
1982	243.0	280.7	225.0	280.6	476.6	503.2	509.7	503.1
1983	328.3	237.3	226.8	237.3	443.5	488.0	519.7	488.1
1984	333.0	319.7	304.8	319.9	509.0	453.4	471.6	453.5
1985	294.6	308.8	277.9	308.8	520.4	518.4	501.5	518.1

Year	Saudi Arabia Actual	Saudi Arabia Optimal A	Saudi Arabia Optimal B	Saudi Arabia Optimal C	Venezuela Actual	Venezuela Optimal A	Venezuela Optimal B	Venezuela Optimal C
1974	3,095.1	2,672.2	2,563.2	2,695.5	1,086.4	1,722.5	1,949.5	1,550.1
1975	2,582.5	2,960.1	2,993.6	3,074.5	956.4	1,095.4	965.2	1,036.6
1976	3,139.3	2,618.4	2,558.8	2,596.6	839.7	938.5	883.4	878.4
1977	3,358.0	3,091.0	3,074.9	3,138.2	816.8	1,077.3	1,050.6	953.4
1978	3,029.9	3,366.2	3,342.9	3,383.9	790.4	929.4	957.1	895.3
1979	3,479.3	3,011.9	3,062.9	3,076.3	860.1	910.1	1,081.0	943.7
1980	3,623.6	3,441.1	3,340.8	3,444.5	792.4	1,034.6	1,077.1	977.1
1981	3,579.9	3,607.3	3,520.2	3,605.2	769.5	1,021.2	892.2	849.9
1982	2,334.2	3,491.2	3,608.9	3,571.7	657.4	732.8	737.6	761.3
1983	1,753.9	2,521.2	2,628.1	2,504.6	644.8	533.1	568.8	619.8
1984	1,636.2	1,887.2	1,932.3	1,860.8	620.6	115.4	483.5	370.0
1985	1,186.3	1,761.3	1,799.9	1,734.6	600.8	559.3	507.8	570.0

less than optimal under scenarios B and C. Solution B requires more production than the other two solutions. In Iran, actual and optimal results are very close up to 1979. Scenarios A and B involve less error before 1979, but after this year the actual pattern of production (ups and downs in proinevitable. If data were available for individual countries, it would have been desirable to consider the differences among these nations and estimate the model for each country separately. Also, a study of the impact of oil revenue on the components of government expenditures rather than the aggregate level can be very helpful. A comparison of macroeconomic optimal solutions (Hotelling rule) with the results of this study could shed light on the merits of this macroeconomic approach.

$R^2 = 0.78 \quad \bar{R}^2 = 0.75 \quad D.W. = 1.82$
$RHO = 0.50 \quad F = 24.24 \quad SER = 8{,}015.3$

$$P_t = 71.74 + 0.081\,PM_t + 0.01\,L_t^s - 0.005\,L_t^d + 0.468\pi_t$$
$$(0.48) \quad (0.081) \quad (2.68) \quad (-1.09) \quad (1.19)$$

$R^2 = 0.75 \quad \bar{R}^2 = 0.71 \quad D.W. = 1.93$
$RHO = 0.22 \quad F = 17.67 \quad SER = 55.42$

$$\pi_t = 0.60\,P_t + 0.4\pi_{t-1}$$
$$(6.49) \quad (4.58)$$

$R^2 = 0.68 \quad \bar{R}^2 = 0.67 \quad D.W. = 2.42$
$RHO = -0.29 \quad F = 71.58 \quad SER = 58.59$

$$PN_t = 425.64 + 0.417\,PM_t + 0.018\,Y_t - 0.029\,PN_{t-1}$$
$$(2.69) \quad (0.41) \quad (1.70) \quad (-0.17)$$
$$-\,324.58\,DIR - 405.88\,DIN - 550.95\,DS$$
$$(-3.88) \quad (-6.38) \quad (-4.56)$$
$$-\,325.51\,DV - 327.29\,DK$$
$$(-2.96) \quad (-3.21)$$

$R^2 = 0.82 \quad \bar{R}^2 = 0.79 \quad D.W. = 1.7$
$RHO = 0.86 \quad F = 30.12 \quad SER = 52.43$

$$Y_t = -10{,}683.82 + 961.87\,PO_t + 13.05\,X_t^s + 0.56\,Y_t$$
$$(-0.58) \quad (0.88) \quad (2.14) \quad (2.23)$$

$R^2 = 0.72 \quad \bar{R}^2 = 0.71 \quad D.W. = 2.01$
$RHO = 0.23 \quad F = 43.89 \quad SER = 20{,}418.4$

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