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Impacts of Selected Price Policies on the Discovery and Extraction of Crude Oil

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Abstract

This paper develops an econometric model of petroleum discovery and extraction. Impacts of three selected price policies for petroleum are analyzed with the model. Higher oil prices do encourage additional domestic oil exploration and extraction.

IMPACTS OF SELECTED PRICE POLICIES ON THE DISCOVERY AND EXTRACTION OF CRUDE OIL

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An examination of the responsiveness to economic incentives of the U.S. petroleum industry is vital if the nation's oil supply is to be maintained or increased. The objective to this paper is to examine the responsiveness to price incentives of petroleum exploration, the generation of proven reserves and the production out of reserves in the United States. An econometric model that represents the decision processes affecting the supply of new discoveries, the increase of proven reserves and the production out of reserves is developed.[1] Parameters are simultaneously determined and are estimated by three-stage least squares. The model is used to determine if adjustments in the pricing mechanism for domestic crude oil will provide the necessary economic incentives to increase the nation's oil supply.

Exploration, Development and Extraction of Crude Oil

The domestic crude oil producing industry is subdivided into three stages: exploration, development, and extraction. Exploration consists of the geological and geophysical analyses which locate potential oil

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[1]A number of other econometric studies of the domestic petroleum supply have appeared recently. Fisher (3) was the first to estimate supply equations for the U.S. petroleum industry. The influence of Fisher's model is evident in subsequent empirical studies. This model has been further utilized and amplified with reference to crude oil supply by Erickson, Millsaps and Spann (2) and Epple (1); and with emphasis on natural gas supply by Khazzoom (4) and MacAvoy and Pindyck (5).

and/or natural gas deposits, and the drilling of exploratory wells. Once oil or gas has been discovered by exploration, development wells are drilled to estimate "proven" reserves. Finally, extraction from existing wells occurs through the utilization of a number of different recovery methods. It thus can be said that petroleum exploration and development create new reserves. The amount of available reserves in turn influences the decisions concerning extracted oil to be refined in petroleum products.

The number of new exploratory wells drilled each year (TED) depends upon the interrelationship between expected returns from oil and gas, risk, and production costs (Equation 1). Since the search for gas and oil is done jointly, new oil discoveries and new gas discoveries are interrelated (Equations 2,3). The probability of finding oil is greater if there has historically been a high ratio of past gas discovereies to oil discoveries. The success ratio (SUC) is defined as the ratio of productive wells to all new wells drilled during the year. The ratio is tied to previous oil and gas discoveries and to the depth at which exploration is being done (Equation 4).

Extensions to reserves of already discovered oil depend on price expectations (Equation 5). Revisions to reserves (RC) do not respond to economic incentives or technology, and can be assumed to be proportional to reserve level changes (Equation 6). Production out of reserves is dependent on the marginal costs associated with the development of reserves, because petroleum producers attempt to balance annual flows with reserve levels. Marginal costs increase as the reserve to production ratio declines, and new production will proceed only if the expected price is high enough to cover costs including a return to investment. Hence, production out of reserves is a function of price expectations and differences between net prices and interest rates.

Crude petroleum imports respond to prices set by OPEC, as well as economic policy in the U.S. (Equation 8). Imports can be thought of as the demand for foreign produced crude. It is the utilization of domestic refining capacity that partically determines import levels, since domestic output played an important role when import quotas were set.

Stochastic equations are also included representing the addition of natural gas liquids to the refining process, and the processing gain occurring as a result of the expansion of fuels due to reforming and cracking (Equations 9,10). The processing gain increases as more crude is run through the refinery, and declines as natural gas liquids are added.

The domestic price of crude is a function of the price of substitutes (imported oil and natural gas) and the degree of refinery capacity utilization (Equation 11). A distributed lag of the sales of refined products represents the substained sales increase that must occur if domestic crude oil prices are to increase.

Three identities close the system. Total new oil discoveries is the product of the average discovery size and the number of new wells drilled (Equation 12). Total reserves is equal to reserves in the previous year plus new discoveries plus extensions and revisions (Equation 13). The total oil for refined products equals the sum of domestic supply, imports, the addition of natural gas liquids and the processing gain.

Model Estimation and Validation

The estimated model consists of 11 stochastic equations and 3 identities. Several of the endogenous variables are simultaneously determined and both two and three stage least squares (3SLS) estimation methods were used. The three stage least squares coefficients had standard errors somewhat lower than the two stage least squares coefficients and are contained in Table 1.

Validation measures were calculated to evaluate the efficacy of the model as a predictive device within the sample period. Comparatively low room mean square errors for all equations suggest that the model could reproduce sample data with a high degree of accuracy. Both the original Theil coefficient (7) and the new Theil coefficient (6) were calculated with similar results. The Theil coefficients were near zero for all equations further substantiating the efficacy of the model within the sample period. Regression coefficients of actual on predicted values were also near one.

Three Policy Simulations

By selecting a set of values of the exogenous variables which reflect median conditions expected to prevail in energy markets in the near future, total additions to reserves, total proven reserves and production out of reserves are simulated for the period 1977 to 1985. The total additions to reserves include the new discoveries, extensions and revisions. Total proven reserves include the 9.6 billion barrels located in Prudhoe Bay, Alaska, discovered in 1968.

Natural gas prices are assumed to increase at a rate of 9 percent per annum in current dollars. Average drilling costs are assumed to increase at 7 percent per annum in keeping with trends over the 1960's and early 1970's. Although the success ratio actually increased at a rate of 0.5 percent per annum over the sample period, the more conservative assumption of a constant success ratio was used to generate the projections. Future consumption of crude petroleum is assumed to increase at the rate of 3.0 percent per annum under constant present prices, 2.8 percent per annum under constant real prices and 2.2 percent per annum under world prices. These consumption estimates do not provide for the Strategic

Petroleum Reserve as required under the Energy Conservation Act. This act requires storage of at least 150 million barrels of petroleum products and crude oil by the end of 1978, and authorizes the storage of up to 1 billion barrels by the end of 1982.

Constant wellhead prices

Constant wellhead prices decrease the number of new exploratory wells drilled, and additions to reserves decline (Table 2). Due to the lack of economic incentives, exploratory drilling and secondary and tertiary recovery stops within five years.

The supply out of reserves decreases even more rapidly than the additions to reserves. Reserve/production ratios remain high because there is little incentive for oil extraction from reserves. Excess demand doubles by 1982 and import levels more than tripple by 1985. Under this scenario, only 26 percent of total U.S. consumption is supplied by domestic oil in 1982.

Constant real wellhead prices

Under the assumption of constant 1976 real prices for domestic crude oil, wellhead prices are hypothesized to be increasing by five percent per annum, the assumed rate of inflation. Import levels would double by 1982, and increase to 4 billion barrels by 1985 (Table 3). Total new additions to reserves increase by 50 percent over the period 1977-85, whereas the supply of domestic crude oil decreases by 60 percent. Although prices are high enough to induce increased exploratory drilling activity, incentives are not sufficient to cause substantially larger amounts of oil to be extracted. Consequently the reserve-production ratio increases to 22.1 in 1985. Domestic crude oil constitutes approximately 50 percent of total U.S. consumption in 1980 but only 21 percent by 1985.

World prices

Under this alternative the 1976 world price for crude oil would be paid to domestic producers. World prices are assumed to increase by 10 percent per year thereafter. These prices provide sufficient incentive for substantially increasing new additions to reserves as well as making more profitable the secondary and tertiary recovery (Table 4). However, because a constant success ratio was assumed, total additions to reserves lag slightly below the supply out of reserves. Crude oil reserves at the end of the year decrease to 24.4 billion barrels in 1982. After 1982 additions to reserves start compensating for the increased rate of extraction.

Conclusions

If our nation's proven reserves of oil are to increase, we must be willing to pay a higher price. Expected higher oil prices, to the extent that they imply expected higher profits, constitute an incentive to increase both exploratory drilling activity and secondary and tertiary recovery of oil. The market mechanism is capable of bringing about the necessary adjustments for increasing domestic crude oil supply.

Constant present prices account for a reduction in the rate of domestic crude oil discovery and extraction. Discovery and extraction stops after six years. Constant 1976 real prices would also provide insufficient incentive to domestic producers. Equalization of the domestic crude oil price with the world price can make the U.S. self sufficient in a six year period after implementation. Although higher prices provide the necessary incentive for domestic producers to increase exploration and development of wells, the reserve-production ratios tend to be low consequently, and the depletion of domestic oil reserves is accelerated.

TABLE I. THREE STAGE LEAST SQUARES ESTIMATE OF U.S. OIL PRODUCTION MODEL, 1959-1972*

New exploratory wells

$$(1)\ TED_t = 77747.5 - 69778.8\ ACW_t - 2581.9\ INT_t + 0.0066\ [4\sigma_0^2\ \hat{ADSZ}_t^2\ (P_{t-1} + P_{t-2} + P_{t-3})^2/9 + 4\sigma_G^2\ \hat{SZNG}_t^2\ (PNG_{t-1} + PNG_{t-2} + PNG_{t-3})^2/9]$$

(3142.4) (6577.0) (562.2) (0.0014)

$$-0.00114\ [\hat{ADSZ}_t\ (P_{t-1} + P_{t-2} + P_{t-3}/3) + \tilde{SZNG}_t\ (PNG_{t-1} + PNG_{t-2} + PNG_{t-3}/3)]$$

(0.00025)

Average discovery size of oil

$$(2)\ \ln ADSZ_t = -74.75 - 0.0815\ \ln ADSZ_{t-1} + 15.30\ \ln SUC_{t-1} - 1.45\ \ln SZNG_{t-1} - 0.441\ \ln \hat{P}_t - 1.31\ \ln PNG_t$$

(12.8) (0.0353) (2.41) (0.08) (0.449) (0.27)

Average discovery size of gas

$$(3)\ \ln SZNG_t = -54.29 - 0.245\ \ln SZNG_{t-1} + 10.08\ \ln SUC_{t-1} - 0.0235\ \ln ADSZ_{t-1} + 0.911\ \ln PNG_t + 1.74\ \ln \hat{P}_t$$

(29.93) (0.176) (5.19) (0.0078) (0.819) (3.84)

Success ratio

$$(4)\ \ln SUC_t = 2.48 - 0.432\ \ln SUC_{t-1} - 0.0148\ \ln ADSZ_{t-1} - 0.0148\ \ln SZNG_{t-1} + 0.610\ \ln DEP_t$$

(0.60) (0.140) (0.0022) (0.0046) (0.043)

Extensions of reserves

$$(5)\ \ln EC_t = 5.82 - 0.0623\ \ln DC_{t-1} - 0.201\ \ln DC_{t-2} + 9.83\ \ln[1.05\ (0.75\ P_{t-1} + 0.2\ P_{t-2} + 0.05\ P_{t-3})]$$

(1.64) (0.0346) (0.035) (1.10)

Revisions of reserves

$$(6)\ RC_t = 1018942.79 + 0.095\ \Delta R_{t-1}$$

(166053.42) (0.033)

Production out of reserves

$$(7)\ S_t = 26796754.3 + 14919181.5\ \ln[1.05\ (0.5\ P_{t-1} + 0.3\ P_{t-2} + 0.2\ P_{t-3})] + 45.05\ \hat{TR} - 1222577.01\ \{1.05\ [0.35\ (PRO_{t-1} - INT_{t-1}) + 0.25\ (PRO_{t-2} - INT_{t-2})$$

(4744257.7) (3783596.7) (5.80) (80744.7)

$$+ 0.2\ (PRO_{t-3} - INT_{t-3}) - 0.2\ (PRO_{t-4} - INT_{t-4})]\}$$

Imports of crude oil

$$(8)\ \ln M_t = -18.58 + 0.95\ \ln M_{t-1} + 1.26\ \ln \hat{S}_t - 0.299\ \ln PM_t - 4.28\ \ln REF_t$$

(2.88) (0.12) (0.30) (0.185) (0.65)

Addition of natural gas liquids

$$(9)\ \ln NG_t = 12.74 - 0.0976\ \ln(\hat{P}_t/PNG_t) + 0.664\ \ln T^2$$

(0.583) (0.0590) (0.026)

Processing Gain

$$(10)\ \ln GA_t = -36.49 - 3.93\ \ln \hat{NG}_t + 6.39\ \ln\ (\hat{S}_t + \hat{M}) + 3.90\ \ln T$$

(32.65) (2.61) (3.66)

Price of crude oil

$$(11)\ \ln P_t = -5.25 + 0.0000013\ \ln PNG_t - 0.120\ \ln REF_{t-1} + 0.0000015\ \ln\ [1.1\ (0.65\ DISTR_{t-1} + 0.35\ DISTR_{t-2})] + 0.702\ \ln PM_t$$

(1.07) (0.0000008) (0.028) (0.00000008) (0.102)

$$(12)\ \hat{DC}_t = \hat{ADSZ}_t \times \hat{TED}_t$$

$$(13)\ \hat{TR}_t = R_{t-1} + \hat{DC}_t + \hat{EC}_t + \hat{RC}_t$$

$$(14)\ DISTR_t = \hat{S}_t + \hat{M}_t + \hat{NG}_t + \hat{GA}_t\ {}^{**}$$

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* (standard errors in parentheses)

** This identity serves as a link of this model with the demands and supplies of refined products.

Table 1 (continued)

TED = number of new exploratory wells drilled (total productive and dry holes drilled each year). Source: (American Petroleum Institute, API).

SUC = success ratio (ratio of productive to total new wells drilled).

ADSZ = average size of new oil discoveries (ratio of new discoveries to total productive and dry holes).

SZNG = average size of new natural gas discoveries (ratio of new discoveries to total productive and dry holes). Source: (API).

DC = new oil discoveries, measured in 42-gallon barrels. Source: (API).

EC = extensions of oil reserves, in 42-gallon barrels. Source: (API).

TR = total reserves, beginning of year (in 42-gallon barrels). Source: (API).

DEP = average depth of new exploratory wells (in feet). Source: (API).

ACW = average cost per exploratory well drilled (in dollars). Source: (API).

R = crude petroleum reserves (proved reserves at the end of the year), measured in 42-gallon barrels. Source: (API).

PNG = price of natural gas liquids at the well head (dollars per barrel). Source: (U.S. Bureau of Mines, USBM).

P = price of crude oil at the well head (dollars per barrel). Source: (USBM).

S = production of crude oil (thousands of 42-gallon barrels). Source: (API).

PRO = profit rate on equity of petroleum industry. Source: (First National City Bank).

INT = interest rate (price of commercial paper 4 to 6 months). Source: (Federal Reserve).

M = imports of crude petroleum (S.I.T.C.: 331.01). Figures converted to thousands of 42-gallon barrels from metric tons. Source: (United Nations).

PM = import unit price (value f.o.b.). Source: (United Nations).

REF = refining capacity utilization. Source: (API).

NG = natural gas liquids added (thousands of 42-gallon barrels.) Source: (API).

GA = processing gain (thousands of 42-gallon barrels). Source: (API).

T = linear time trend.

DISTR = sum of domestically supplied refined products, net of imports, exports and change in petroleum stocks (42-gallon barrels). Source: (USBM).

RC = revisions of established reserves (42-gallon barrels). Source: (API).

Table 2. Impact of constant wellhead prices, 1977-1985.

Year	Total Additions to Reserves	Proved Reserves at end of year	Supply of Production	Excess Demand	Reserve/ Production ratio
1977	1,240	32,440	3,042	1.7	10.6
1978	1,103	30,653	2,890	2.0	10.6
1979	1,081	29,088	2,646	2.3	11.0
1980	920	27,724	2,284	2.7	12.1
1981	708	26,543	1,889	3.4	14.0
1982	--	25,116	1,427	3.8	17.6
1983	--	25,000	--	5.3	--
1984	--	25,000	--	5.4	--
1985	--	25,000	--	5.5	--

Table 3. Impact of constant real prices, 1977-1985.

Year	Total Additions to Reserves[a]	Proved Reserves at end of year[a]	Supply of Production[a]	Excess Demand[b]	Reserve/ Production ratio
1977	1,297	32,500	3,148	1.5	10.3
1978	1,322	30,816	3,006	1.7	10.2
1979	1,387	29,403	2,800	2.0	10.5
1980	1,460	28,497	2,366	2.6	12.0
1981	1,542	27,806	2,233	2.8	12.4
1982	1,660	27,417	2,049	3.0	13.3
1983	1,879	27,455	1,841	3.4	14.9
1984	1,844	27,816	1,483	3.7	18.7
1985	1,832	28,370	1,278	4.0	22.1

[a]Million barrels

[b]Billion barrels

Table 4. Impact of world prices to domestic producers, 1977-1985.

Year	Total Additions to Reserves	Proved Reserves at end of year	Supply	Demand	Reserve Production ratio
1977	1,500	32,800	3,451	1.3	9.5
1978	1,889	30,798	3,891	1.0	7.9
1979	2,719	29,114	4,403	0.6	6.6
1980	2,607	27,283	4,438	0.6	6.1
1981	3,014	25,705	4,592	0.4	5.6
1982	3,814	24,494	5,025	0.1	4.9
1983	5,372	24,406	5,025	-0.2	4.4
1984	6,949	25,372	5,983	-0.7	4.2
1985	7,995	27,290	6,077	-0.7	4.5

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