THE SUPPLY OF NEW DISCOVERIES OF CRUDE OIL, PRODUCTION OUT OF RESERVES, AND DETERMINATION OF TOTAL REFINERY OUTPUT IN THE UNITED STATES

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RESEARCH REPORT 28: February 1977

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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 possibly increased. Government policy toward the petroleum industry might include price ceilings, import quotas, depletion allowances and other tax breaks, restrictions on gasoline comsumption, and antitrust suits. Little is known with respect to how each of these government policies ultimately affect the prices and availability of oil and oil products to the consumer.

In this paper an econometric model designed to represent the economic relationships governing the petroleum industry is presented. The identification of crucial variables that regulate the flow of petroleum to refineries can provide some insight as to the impacts of alternative petroleum policies on the generation of reserves. Production out of reserves determines the flow of petroleum to the refineries. An examination of the responsiveness to economic incentives of petroleum exploration is vital if the nation's proven reserves are to be increased.

Imports of crude petroleum will be explicitely taken into consideration. All liquids that go into the process used to produce refined petroleum products will be modeled. Equations representing the supply of new discoveries to increase proven reserves and the production out of reserves are specified. Since crude petroleum is a nonrenewable asset special attention is paid to the issue of exhaustibility.

A number of econometric studies of the domestic petroleum supply have appeared recently. Fisher's [7] 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. Erickson, Millsaps and Spann [6], specified a model of crude oil reserves stocks. Khazzoom [11] dealt with the oil discovery problem. Epple's study [5] dealt with petroleum discoveries and the decisions of the oil exploring firms. Adams and Griffin [1] concentrated only on the petroleum refining industry. They estimated the supply of refined products with a linear programming model. The Federal Energy Administration's Project Independence Report is being revised to forecast oil and natural gas supply and energy demand. Haussman discussed potential biases identified with the FEA's model [9]. McAvoy and Pindyck are the first to have attempted a intergrated model of all aspects of the natural gas industry. They dealt with regulatory policies for the natural gas shortage [13].

A model explaining exploration, reserves determination, production out of reserves and total liquids to be refined will be developed and estimated.

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A Theoretical Framework

Crude Oil Reserves

Reserves available in any time period influence petroleum industry's decisions with respect to the quantity of extracted oil to be refined in petroleum products.

The sector of the petroleum industry most difficult to capture is the supply of new proven reserves. Actual additions to reserves through new discoveries occur by a complicated process involving a large number of technological factors. Structural equations can be formulated to link economic and technological variables that are important in crude oil additions.

In geophysical exploration, as the major structures (oil pools) are discovered and tested, the search must increasingly turn to more subtle structural features (in terms of difficulty of drilling, thickness of the productive stratum and permeability of the formation). Oil deposits occurring in such features are likely to produce less oil than those previously found in more favorable structures.

Assuming that an adequate incentive exists to encourage an intensified exploration effort, there is a physical limit to the amount of exploration that can be accomplished within a given period of time. The limit is determined largely by the number of drilling rigs available and the rate at which the drilling can be done. Progress has been made in increasing drilling speed and lowering drilling costs. Further improvements can speed the rate of exploration and development of sites as well as to make economic some of the sites that previously did not warrant such development.

Fisher's [7] study of wildcat drilling and discovery has shown that for economic as well as geologic reasons, small prospects considered by operators tend to be relatively certain and the big prospects relatively risky. This is so because large prospects, by offering larger returns on investment, attract operators at higher levels of risk than do small prospects.

Economic incentives influence the amount of exploration that occurs and determine exploration characteristics. An increase in economic incentives leads to more wildcat drilling. This wildcat drilling takes place on prospects poorer than those which would be drilled at a lower incentive level. Fisher suggests that the underlying size distribution of prospects is highly skewed, for risk tends to be reduced by information-gathering activity before drilling is seriously considered. Further, operators may prefer to drill smaller, less risky prospects as prices increase. Fisher explains that there tends to accumulate a set of undrilled prospects about which some information is known. This set consists principally of relatively small, relatively certain prospects. Hence, an increase in price induces a decrease in average size of the prospect which is drilled.

This partially offsets the increase in risk which would otherwise occur. The effect is short-run and is restricted to price increases. Furthermore, although higher oil prices would be expected to result in more drilling activity, over time the size of discovery decreases owing to the depletion of a finite stock of the resource. However, the discovery of large prospects is also tied to the amount of research effort geared toward the identification of large oil pools. This process involves substantial costs which are sustained over several years. As the amounts invested in identification and exploration processes continue over time, on the average, larger pools of oil are likely to be discovered. Such is the case of oil found in the Outer Continential Shelf.

Measures such as average size of discovery or the success ratio (the ratio of productive to total wildcats) are functions not only of the distribution of petroleum prospects found in nature but also of the risk attitudes of operators in the industry. For example, the success ratio cannot be taken as a measure of the probability of discovery. An increase in the success ratio tends to be associated with a decreased probability of discovery in the following year.

The search for oil and gas is carried out jointly. For a given probability of finding either oil or gas, the higher the ratio of past gas discoveries to past oil discoveries, the higher will be the probability of finding oil. The discovery of large gas fields may act as an incentive for the drilling of large structures.

The major component of new reserve additions is the drilling of new wells. Some are successful crude oil wells, some are successful natural gas wells, and some are unsuccessful (dry holes). The drilling of wells depends largely on economic incentives. In our model, drilling is assumed to be dependent on average drilling costs, the price of crude oil at the wellhead, the success of discovery in the previous period (i.e. the proportion of productive to total number of wells drilled), and the average discovery size of natural gas in the previous time period.

The rate of exhaustion of potentially productive oil-bearing land is not solely determined by the oil-prospecting firm. The oil prospecting firm buys or rents inputs (exploratory wells and oil-bearing land) and produces outputs in the form of information about the locate of crude oil deposits. Therefore, it is the owner of the mineral rights to land who determines the rate at which exhaustion occurs. This is done through the decision to permit exploration to proceed or to withhold the land from exploration.[1] An increase in the unit-rent on oil- bearing land of a given quality will lead to an increase in the amount of land supplied. This is because the land is bid away from other uses and because landowners who were withholding land from exploration in the expectation of an increase in rents will be induced to make their land available.

The average size of discovery of crude oil is a function of the average discovery size of crude oil of the previous time period. Average discovery size in the previous period depicts the depletion effect for large prospects. In addition, the average size of discovery of crude is dependent on the size of discovery of natural gas in the previous time period, the success ratio of the previous time period, a distributed lag of costs sustained for identification and exploration, and the price of crude oil at the wellhead. Equations determining the success ratio and the average size of discovery of natural gas are specified in accordance with the foregoing relations (including secondary and tertiary recovery).

Extension of crude oil reserves depends on both economic incentives and amounts of crude previously discovered through exploratory drilling. Economic incentives account for the use of either new technologies or making present tertiary recovery methods economic. Furthermore, if discoveries at any point in time are small, an incentive exists for the recovery of oil from already existing reservoirs by recovery from greater depths.

The revisions of established reserve levels do not seem to respond to any specific economic or technological variable. In our model, revisions are assumed to be proportional to prior discoveries and reserve levels.[2]

For any time period t, total proven reserves of crude oil in the U.S. are given by the identity:

$$R_t = R_{t-1} + DC_t + EC_t + RC_t - S_t$$

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[1]See Epple [5, pp. 66-69].

[2]The disaggregation of revisions and extensions follows the example of the work of McAvoy and Pindyck [13] for natural gas.

where extensions (EC_t), revisions (RC_t) and new discoveries (DC_t) are combined to form additions to reserves. The amounts of crude oil extracted (S_t) are the only major subtraction from reserves.

Total Refinery Output

Crude oil and lease condensate are the primary inputs for the refining process which yield the refined petroleum products. The aggregate supply of refined products ($DISTR_t$) is calculated by the following identity for any time period t:

$$DISTR_t = S_t + M_t + NG_t + GA_t$$

The amount of crude oil and lease condensate (S_t), imports (M_t), the amount of natural gas liquids added for the refining process (NG_t), and the processing gain (GA_t) realized in the refineries sums to the total amount of refined products.[3]

Production out of Reserves

The supply of production is simply the marginal cost (in the short-run) of developing existing reserves so that a particular level of annual flow can be achieved. Marginal production costs will depend on reserve levels relative to production, and as the reserve to production ratio becomes small marginal costs would be expected to rise sharply.[4]

In oil production, a reserve-production ratio of about 8:1 is required. Hence, an increase in eight units of recoverable reserves is needed to maintain a one-unit increase in production. However, present technology recovers only about 40 percent of total reserves. About 20 units of oil would, therefore, need to be discovered to increase production by one unit.

If economic means were to become available for recovering oil that is currently identified but not recoverable, proved reserves would immediately be increased. This would come about through new technology or price increases, sufficient to make present tertiary recovery methods economic.[5]

Although price would be expected to be positively related to production out of reserves, if reserve production ratios are lower than 8:1, current prices may have little impact on extraction decisions.

Since crude oil is an exhaustible nonrenewable stock resource, oil industry decisions regarding extraction rates refer to the entire planning horizon which coincides with the depletion of the resource.

The equilibrium path that the price of nonrenewable resources should follow to the point of exhaustion has been derived by both Hotelling and Solow. The equilibrium price changes over time so that market price (net of extraction costs) is increasing exponentially at a rate corresponding to the interest rate. As a result, extractors will be indifferent

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[3]Items left out of the identity, such as exports of crude petroleum, change in stocks, ets., constitute less than one percent of the total amount of crude or refined products.

[4]This argument was first made by McAvoy and Pindyck [13] regarding natural gas production. The same underlying assumptions seem to be holding in the case of crude oil production.

[5]See Adelman [2, 3] and McAvoy and Pindyck [13].

between extracting and holding [12, 15, 18].

Firms in the petroleum industry are composed of joint stock companies. The assets of these firms can be easily exchanged. Furthermore, the industry has a ready access to the loan market.

As long as expected profits from the refining and marketing operations are higher than the rate of return from alternative investments crude oil will come to the refineries.[6] A positive difference between profit rate and interest rate over future periods would bring forth an increase in supply out of reserves. This is because of the possibility of investing present profits so to yield an additional return. The larger the difference between expected profits and expected interest rate in the present and near future periods, the larger the forthcoming supply of crude oil. Capital intensity characterizes the petroleum industry. Hence, production expenditures in fixed assets would then be expected to be highly correlated with supply of production out of reserves in every time period.

Epple [5] refutes the common belief that the price of an exhaustible resource will rise at the rate of interest. While this is true when the initial resource endowment is fixed and marginal production costs are zero, this is not generally the case. If technical progress in extraction is sufficiently rapid, it is possible that the resource price may remain constant or even decline for a time. One would expect that a price increase would call forth an increased supply of the resource unless the increase in price caused expectations of future price increases. For a given price a decrease over time in the quantity of the resource produced is expected because of the effect of cumulative extractions in increasing the costs of production. Technical progress could offset this effect.

Imports, Natural Gas Liquids and Processing Gain

Imports of crude petroleum can be assumed to respond to domestic economic influences as well as the price of imported crude oil [4]. The price of imports can be taken as given since it is fixed by the Organization of the Oil Producing and Exporting Countries. Imports can be thought of as a demand for foreign crude oil. It is hypothesized that current imports are a function of imported crude oil in the previous time period, the price of imports, the domestic supply of crude and the utilization of domestic refining capacity (which acts as a capacity constraint).

As the amount of crude oil that is refined increases and the utilized capacity approaches the total refining capacity, imports may not increase so rapidly.

The refinery processes not only uses crude oil and lease condensate but also natural gas liquids. The amount of natural gas liquids added to the liquids to be refined has been steadily increasing. Both economic and technological factors have been responsible for this. The quantity of natural gas liquids depends on the price of crude relative to the price of natural gas liquids and a linear time trend.

The processing gain is the final component needed to determine the total amount of liquids from the refinery process. This is the summation of the quantities of all refined products produced ($DISTR_t$). The processing gain represents the expansion of fuels owing to some of the refining processes such as reforming and cracking. The equation for the processing gain contains the amount of natural gas liquids added for refining, the amounts of crude oil and lease condensate run through stills, and a linear time trend.

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[6] The steady flow of the supply of crude petroleum can be viewed as a minimum amount of output which will be produced each year because the industry is confronted with a down sloping demand curve for the product which is increasing over time. Large decreases in the level of output will allow substitutes to take over the market.

Structure and Estimation of the Model

The organization of the model is described in simplified form in Figure 1. The model consists of 11 stochastic equations and 3 identities. Both linear and log linear versions of the model were estimated using time series data for the period 1959-72. Two-stage least squares estimation was used since several of the endogenous variables are simultaneously determined. Ordinary least squares estimates were also obtained for comparison. The logarithmic specification was preferred because of the higher coefficients of determination associated with the estimated equations and lower overall standard errors. Data source and transformations and the symbols used are summarized below.

t = subscript denoting year.

TED = number of new exploratory wells drilled. These are the total productive and dry holes drilled each year, and they are published in the "Annual Statistical Review" by the American Petroleum Institute.

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

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

SZNG = average size of new natural gas discoveries is the ratio of new discoveries to total productive and dry holes, and they are published in the "Annual Statistical Review" by the American Petroleum Institute.

DC = new oil discoveries measured in 42-gallon barrels. The figures are found in "Petroleum Facts and Figures" of the American Petroleum Institute.

EC = extensions of oil reserves measured in 42-gallon barrels. The figures are found in "Petroleum Facts and Figures" of the American Petroleum Institute.

TR = total reserves at the beginning of the year. The figures are in 42-gallon barrels and are published in "Petroleum Facts and Figures" of the American Petroleum Institute.

DEP = average depth of new exploratory wells. The figures are in feet, and they are found in the "Annual Statistical Review" of the American Petroleum Institute.

EX = expenditures for exploration and drilling. The figures are computed from the "Annual Statistical Review" of the American Petroleum Institute.

ACW = average cost per exploratory well drilled. The figures are in dollars, and they are published in the "Annual Statistical Review" of the American Petroleum Institute.

R = crude petroleum reserves are the proved reserves at the end of the year. The figures are in 42-gallon barrels and are published in "Petroleum Facts and Figures" of the American Petroleum Institute.

PNG = price of natural gas liquids at the well head (dollars per barrel). The figures are reported in the "Minerals Yearbook" of the Bureau of Mines.

P = price of crude oil at the well head (dollars per barrel). The figures are reported in the "Mineral Yearbook" of the Bureau of Mines and they were deflated within the wholesale price index.

S = production of crude oil (in thousands of 42-gallon barrels, from the "Annual Statistical Review" of the American Petroleum Institute).

PRO = profit rate on equity of the petroleum industry. The figures are the rate of return on book net assets and is reported in the "Monthly Letter" of the First National City Bank, New York.

INT = interest rate. The figures represent the price of commercial paper 4 to 6 months reported by the Board of Governors in the "Federal Reserve Bulletin."

K = production expenditures in fixed assets of the petroleum industry. These figures are published in "Financial Analysis of a Group of Petroleum Companies" by the Energy Economics Division of the Chase Manhattan Bank, New York, and they were indexed with 1960 as the base year.

M = imports of crude petroleum. The figures are reported in the "Yearbook of International Trade Statistics" by the United Nations. The Standard International Trade Classification number is 331.01, and the figures are converted to thousands of 42-gallon barrels from metric tons.

PM = average import price. The figures are computed as a per unit price from the value (f.o.b.) and quantity figures reported in the "Yearbook of International Trade Statistics" of the United Nations.

REF = refining capacity utilization (as percent of total). Total capacity for refining is reported in thousands of 42-gallon barrels, and it is found in the "Annual Statistical Review" of the American Petroleum Institute.

NG = natural gas liquids added, in thousands of 42-gallon barrels, from the "Annual Statistical Review" of the American Petroleum Institute.

GA = processing gain in thousands of 42-gallon barrels from the "Annual Statistical Review" of the American Petroleum Institute.

PBL = price of bituminous and lignite. The figures are computed as a per unit price from value and quantity (short-ton) figures reported in the "Minerals Yearbook" of the Bureau of Mines.

T = linear time trend.

DISTR = sum of domestically supplied refined product (net of imports, exports and change in petroleum stocks). The figures are in 42-gallon barrels and are reported in the "Minerals Yearbook" of the Bureau of Mines.

P/PNG = price of crude relative to the price of natural gas at the wellhead.

RC = revisions. The figures are in 42-gallon barrels and are published in "Petroleum Facts and Figures" of the American Petroleum Institute.

The resulting estimates are*:

New exploratory wells

(1) $\ln TED_t = 3.09 - 1.21 \ln ACW_t - 1.20 \ln SUC_{t-1} + 0.359 \ln \hat{P}_t +$

(7.29) (0.24) (1.16) (1.17)

$1.39 \ln SZNG_{t-1}$

(0.99)

Average discovery size of oil

(2) $\ln ADSZ_t = -95.02 - 0.162 \ln ADSZ_{t-1} + 1.30 \ln[1.1(0.42 EX_{t-1} +$

(48.15) (0.08) (2.10)

$0.32 EX_{t-2} + 0.26 EX_{t-3})] + 15.01 \ln SUC_{t-1} + 1.27 \ln SZNG_{t-1} -$

(6.07) (0.19)

$1.52 \ln \hat{P}_t$

(4.67)

Success ratio

(3) $\ln SUC_t = 2.34 - 0.298 \ln SUC_{t-1} - 0.013 \ln ADSZ_{t-1} - 0.018 \ln SZNG_{t-1} +$

(1.12) (0.27) (0.004) (0.008)

$0.547 \ln DEP_t$

(0.09)

Average discovery size of gas

(4) $\ln SZNG_t - 42.43 - 0.185 \ln SZNG_{t-1} + 0.040 \ln ADSZ_{t-1} + 9.05 \ln SUC_{t-1} +$

(54.09) (0.16) (0.11) (10.93)

$0.365 \ln PNG_t$

(1.71)

***Values in parenthesis are standard errors.**

Extensions of reserves

$$(5)\quad \ln EC_t = 2.88 - 0.761\ \ln EC_{t-1} + 1.99\ \ln TED_{t-1} - 0.009\ \ln \hat{DC}_t +$$

(1.70) (0.23) (0.31) (0.03)

$$0.498\ \ln \hat{P}_t$$

(1.46)

Revisions of reserves

$$(6)\quad \ln RC_t = 7.18 + 0.462\ \ln \Delta RT_{t-1}$$

(2.48) (0.16)

Production out of reserves

$$(7)\quad \ln S - 9.42 + 0.235\ \ln [\![1.05\ [0.255(PRO_t - INT_t) + 0.205\ (PRO_{t-1}) +$$

(1.09) (0.06)

$$0.18\ (PRO_{t-2} - INT_{t-2}) + 0.18\ (PRO_{t-3} - INT_{t-3}) - 0.18$$

$$(PRO_{t-4} - INT_{t-4})]\ ]\!] + 0.259\ \ln \hat{P}_t + 0.158\ \ln \hat{TR}_t + 0.674\ \ln K_t$$

(0.28) (0.06) (0.08)

Imports of crude oil

$$(8)\quad \ln M_t = -14.73 + 1.12\ \ln M_{t-1} + 0.905\ \ln \hat{S}_t - 0.069\ \ln PM_t - 2.95\ \ln REF_t$$

(5.71) (0.29) (0.66) (0.40) (0.43)

Addition of natural gas liquids

$$(9)\quad \ln NG_t = 12.49 + 0.004\ \ln(\hat{P}_t/PNG_t) + 0.156\ \ln T^2$$

(1.32) (0.05) (0.02)

Processing Gain

$$(10)\quad \ln GA_t = -67.55 - 10.52\ \ln \hat{NG}_t + 14.11\ \ln \hat{S}_t + 1.47\ \ln T^2$$

(59.40) (8.01) (9.51) (0.76)

Price of crude oil

$$(11)\quad \ln P_t = 8.04 + 0.029\ \ln PBL_t - 0.099\ \ln \hat{TR}_t + 0.209\ \ln PNG_t - 0.488\ \ln S_{t-1} -$$

(3.02) (0.13) (0.16) (0.09) (0.15)

$$0.460\ \ln P_{t-1}$$

(0.29)

Identities

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

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

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

Statistical Results and their Interpretation

Coefficients for most parameters estimated via 2SLS were substantially larger than the respective standard errors, and signs agreed with hypothesized results throughout the model.

New Additions to Reserves

The elasticity of exploratory drilling with respect to the price of crude is about + 0.35 [equation (1)]. The elasticity of the average size of discovery with respect to the crude price is about -1.52 [equation (2)]. The elasticity of the extensions of proven reserves with respect to price of crude is about + 0.49 [equation (5)].

Although prices do not have coefficients substantially larger than the standard errors, signs support theoretical arguments. There is little evidence to suggest that price incentives stimulate exploratory drilling activity but cause a deterioration of discovery size.[7] Furthermore, price incentives induce more extensions of proven reserves by making economic new technology for recovering additional oil from already drilled oil wells.

The number of exploratory wells drilled (TED) at time t is negatively related to the average drilling cost per well (ACW) and the success ratio of the previous time period (SUC_{t-1}). The negative coefficient of the success ratio implies that, when relatively small and certain prospects tend to accumulate during a year, the success ratio is higher than usual during that year and the accumulated incentory of such prospects is being depleted at a faster than usual rate. The following year there are fewer prospects to be drilled at a profitable rate. Consequently, the number of prospects drilled would be expected to decrease in time t + 1. Fisher [7] argues that the effect of inventory depletion is to reduce the number of small prospects that would otherwise be drilled so that the average discovery size increases. Finally, a rise in SUC_{t-1} is accompanied by a fall in SUC_t. The effect of SUC_{t-1} in equation 3 is negative, because of the inventory depletion effect, and positive in equation 4 because of the "incentive-toward-larger-prospects effect."[8] The success ratio (SUC) furthermore is positively related with depth in that the deeper the exploratory wells are dug the larger the expected success ratio tends to be.

The average discovery size of crude oil (ADSZ) is positively related to the amount of money spent for exploration over past periods. It usually takes a substantial exploratory effort before new large reserves can be discovered.[9]

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[7]This same conclusion was first reached by Fisher [7] and subsequently by Erickson and Spann [6] in their work on natural gas and oil supply. Epple [5] concludes "...the analysis was motivated by the suspicion that earlier estimates resulting in the assertion of a highly elastic supply curve for crude oil were based on an incomplete model of supply. The analysis of Chapter 3 demonstrated that this was in fact, is the case, and the results indicated that the assertion of a highly elastic supply curve was warranted." p. 104.

[8]This point comes more clearly across in this study, because of the district-distinguishing effects, involved in Fisher's study [7].

[9]Such is the case of offshore prospects in the recent past.

The clear implication of the above-mentioned facts is that the sensitivity of new oil discoveries to economic incentives is substantially less than that for wildcat drilling. This is primarily caused by the discovery size deterioration which comes about when small prospects are made attractive by a price increase. The average size of natural gas discoveries (SZNG) becomes important in crude oil exploration because the two products are jointly produced. Prior discoveries of natural gas ($SZNG_{t-1}$) indicate possibility of finding crude oil.[10] Large natural gas discoveries suggest large structures of undiscovered crude oil. This makes the elasticities in equations (1) and (2) positive. Since large prospects and certainty tend to be inversely related, $SZNG_{t-1}$ must be positively related to the success ratio in equation (3). But because of inventory depletion the average size of natural gas discoveries decreases over time. Equation (4) suggests that SZNG has an elasticity with respect to $SZNG_{t-1}$ of -0.18. Furthermore the price of natural gas has a positive effect on the average discovery size of natural gas, which is consistent with the McAvory and Pindyck findings [13].

Extensions of crude oil reserves (EC) depend on previous extensions (EC_{t-1}) and total exploratory wells drilled (TED_{t-1}). The short-run depletion effect of extensions in equation (5) is given by the elasticity -0.76 with respect to EC_{t-1}. Total exploratory drilling (TED_{t-1}) has a positive effect on extensions. Finally, small discoveries of new oil will induce the pumping of oil out of old wells from greater depths, as indicated by the elasticity of -0.008 of variable $\hat{DC}$ in equation (5).

The revision of crude oil reserves (RC) (equation (6),) responds to the change of previous year's reserves. The elasticity of 0.46 implies that one barrel increase in the stock of reserves generates about 0.46 barrels of increase in the crude oil reserves revisions one year later.

Increased crude oil prices do not necessarily act as an incentive to exploration and discoveries of new oil reserves. Rather, prices interact with variables such as (a) investments on identifying reservoirs (b) exhaustion effects stemming from the average discovery size, (c) the success ratio and (d) extensions that affect the willingness of the industry to intensify the exploration effort. Discovery diminishes size when small, but certain prospects become attractive as prices increase. Hence, it is difficult to determine the net impacts of a price of increase. However, the depletion effects suggest the need for moderate increases in price to maintain a steady exploratory effort.

Determination of total Refinery Liquids

The domestic production out of reserves was estimated. Price does not contribute to explained variation, as expected. Remaining variables had coefficients substantially larger than the respective standard errors. The distributed lag of the difference between expected profits and prevailing interest rate (PRO-INT) is positively related to the amount of crude oil and lease condensate extracted (5). Furthermore, total reserves (TR) and fixed production expenditures of fixed assets (K) are positively related to the production of crude oil out of reserves. Elasticities were estimated at + 0.15 and + 0.67, respectively (equation (7)).

Imports of crude oil (M) are positively associated with imports in the previous period (M_{t-1}) and with domestic production out of reserves ($\hat{S}$). The positive relationship between imports and domestic supply seems reasonable in that increases in expected prices signal increased demands. This reduces both domestic reserves production and imported crude oil

[10] Previous studies have obtained negative coefficients for this same variables, because natural gas became a valuable by product only after the mid-fifties.

quantities.

As expected, imports of crude petroleum are negatively associated with the prevailing import price having an elasticity of -0.69 from equation (8). Furthermore, refining capacity (REF) contraints imported crude. Imports decrease as refining capacity utilization approaches full capacity.

Natural gas liquids (NG) added to crude petroleum lease condensate in refining and directly related to the price of crude price of natural gas ratio. The time trend variable depicts technology. Natural gas liquids additions increase if the crude prices increase by more than the price of natural gas liquids and *vice versa* (equation (9)).

The processing gain (GA) is, as expected, negatively associated with the amount of natural gas liquids, positively associated with the amount of crude oil and lease condensate, and positively associated with the trend squared (equation (10)).

The price equation (P) reveals a positive relationship between the price of crude oil, bituminous and lignite prices (PBL) and natural gas liquids (PNG). Furthermore, as total reserves ($\hat{TR}$) increase, a lower price would be required to bring forth an increased production out of reserves and to provide a stimulus to exploratory drilling. Exploratory drilling apparently faces a high success ratio as well as a high discovery size.

Equation (11) explains the price of crude petroleum (P). The price of crude in time t is negatively related to the price of crude in previous time periods. This is because the real price of crude was falling over the sample period. Price of crude petroleum is negatively related to the supply of reserves in the previous period (S_{t-1}). This is consistent with the arguments made earlier. A low level of supply out of reserves in one time period leads to expectations of a forthcoming higher price in the following.

These results suggest that the industry is indeed capital intensive. Decisions regarding the extraction of crude oil are based on present and prospective profitability. Price increases have only a modest effect in the extraction of oil from the ground (the elasticity is + 0.259). Rather, it is expectations regarding future profits that count. A policy of incentives with present ceiling prices could be sufficient to stimulate future production out of reserves.

The insensitivity of import levels to prices set by the Arab nations suggests that tariffs would not be successful in controlling imports. Import quotas would seem to be a more effective alternative in curtailing import increases. Quotas could be used in conjunction with domestic policies designed to stimulate the comparative profitability of the oil industry.

Conclusion

A model of the supply of crude oil reserves, production out of reserves and the determination of total liquids from the refinery process for the transformation to refined petroleum products was constructed and estimated.

Principal conclusions include the following. Economic incentives influence both the amount and characteristics of exploratory drilling. As expected, the elasticity of production out of reserves with respect to price are low. Although price increases lead to more exploratory drilling, prospects considered were smaller and more risky. The extensions of reserves of crude oil respond weakly to price. If in a particular year new oil discoveries are low, an incentive exists to extend reserves the following year.

Domestic production out of reserves responds very little to increased prices. Domestic production rather reacts to expectations about future net prices. Future expected profitability becomes a key variable in the decisions of how much to pump out of the ground at any time period. The above-mentioned conclusions imply that increased prices will not necessarily lead to increased reserves and increased production out of reserves. Rather, the interaction of price incentives with policies which make oil industry profitable will increase the flow of crude petroleum to the refineries. Moderate prices increases are needed to offset the depletion effect of an exhaustible stock resource.

The input mix of liquids that goes into the refined petroleum product transformation does not react to changes in the relative price of crude oil and natural gas liquids. Finally, the amount of imported crude oil is not sensitive to the prevailing average import price and, therefore, a policy of tariffs would be ineffective. Import quotas then remain as the reasonable alternative.

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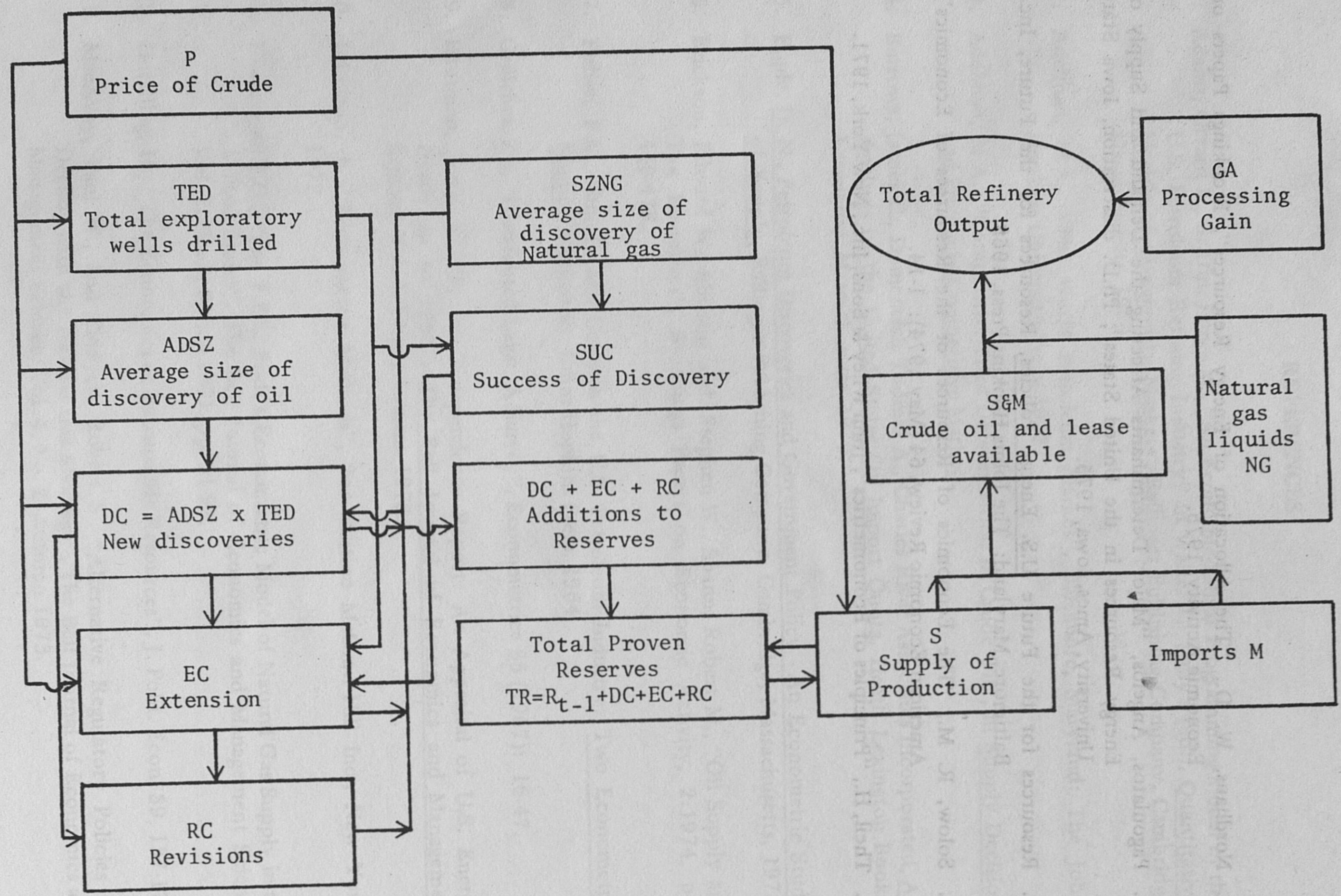

Figure 1.--Simplified structure of the Petroleum and Refined Petroleum Products Model