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by

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INTRODUCTION

Various facets of petroleum policy in the United States - price ceilings, import quotas, percentage depletion, restrictions affecting gasoline consumption, breaking the industry intergration - rest on the issue of the sensitivity of petroleum exploration, production out of reserves and demand to economic incentives. An examination of the responsiveness to economic incentives of petroleum exploration is vital if the nation's proven reserves are to be increased. Production out of reserves determines the flow of petroleum to the refineries. The identification of crucial variables that regulate the flow can provide some insight as to the impacts of alternative petroleum policies on the generation of reserves and the flow of crude oil of the sensitivity to economic incentives of exploration and production out of reserves.

Imports of crude petroleum will be explicitely taken into consideration as well as all liquids that go into the refinery process to produce the refined petroleum products, constituting the final food for consumption. In particular decisions affecting the supply of new discoveries to increase proven reserves and the production out of reserves are differentiated. Special attention is paid to the issue of exhaustibility since crude petroleum is a nonrenewable asset.

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Several econometric studies of various aspects of domestic petroleum supply have appeared in recent years. Fisher's model [7] is the first attempt to econometrically estimate supply equations for the U.S. petroleum industry. The influence of his model is clearly evident in all subsequent empirical studies dealing with the volume of crude oil discovered. Fisher deals only with the petroleum discoveries as do Erickson, Millshaps and Spann [6], who specified a model of crude oil reserves stocks. Khazzoom [11] at the Federal Power Commission, has dealt with the oil discovery aspect of the petroleum industry. Epple's work [5], rested also with petroleum discoveries and the decisions of the oil - prospecting firm, with no reference to the issue of exhaustibility; whereas Adams and Griffin [1], concentrated only on the petroleum refining industry and estimated the supply of refined products with a linear programming model. Presently, the Federal Energy Administrations Project Independence Report is being revised to forecast oil and natural gas supply and energy demand. The potential biases identified with the FEA's model are discussed by Haussman [9]. McAvoy and Pindyck are the first to have attempted in intergrated model of all aspects of the natural gas industry in dealing with regulatory policies for the natural gas shortage, [13].

In the sections which follow the theoretical undepinnings of a model explaining exploration, reserves determination, production out of reserves and total liquids to be refined, will be developed and estimated.

Crude Oil Reserves

The amounts of reserves available at any point in time influence the

decisions concerning extracted oil to be refined in petroleum products.

Additions to reserves come from new discoveries and from extensions of previous discoveries or revisions of earlier estimates of previous discoveries. New oil discoveries are in turn associated with natural gas discoveries because of their common occurrence.

Probably the sector of the petroleum industry most difficult to capture in a conceptual model is the supply of new proved reserves. Since actual additions to reserves through new discoveries are realized by a complicated process involving a large number of technological factors, it may seem naive to try to model the process by using a set of simple econometric relationships. However, 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 are discovered and tested, the search must increasingly turn to more subtle structural features. Deposits occurring in such features, are in general likely to be less prolific producers than previously found fields in more favorable structures.

Assuming that adequate incentive exists to encourage an intensified exporation effort, there is still 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 that are available and the rate at which the drilling can be done. Considerable progress has been made in increasing drilling speed and lowering drilling costs. Further improvements can not only speed up the rate

of exploration and development of sites but also make economic some of the sites that previously did not warrant such development.

As Fisher's [7] study of wildcat drilling and discovery has shown, regarding the shape of the distribution of prospects considered in any one year, it seems that both for economic as well as possibly for geologic reasons, the small prospects considered by operators tend to be realtively certain and the big prospects relatively risky. This is so if only because big prospects, by offering larger returns on investment, attract operators at higher levels of risk than do small prospects.

It follows that economic incentives influence the amount of exploration that occurs; economic incentives also determine exploration characteristics. Thus, an increase in economic incentives leads to more wildcat drilling but this takes place on prospects poorer than those which would be drilled at a lower incentive level. As Fisher indicates, it seems plausible to suppose that the underlying size distribution of prospects is highly skewed toward small ones so that a small price change greatly changes the number of small prospects which are deemed worth drilling. On the other hand, the distribution of risk over prospects seems less likely to be so skewed, for risk tends to be reduced by information-gathering activity before drilling is seriously considered. Further, operators may prefer a reduction of size to an increase of risk when price rises. Finally as Fisher explains, theretends to accumulate a set of undrilled prospects about which some informationis known. This set consists principally of realtively small, relatively certain prospects. It follows that an increase in price induces a decrease in average size associated with

an increase in certainty partially offseting 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 would be expected to decrease due to the depletion of a finite stock of the resource. However, it apears that 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, it would be expected that 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 of average results, 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, it follows that the success ratio cannot be taken as a measure of the probability of discovery in that generally an increase in the success ratio tends to be associated with a decreased probability of discovery in the following year, ceteris paribus.

Because the search for oil and gas is carried out jointly, given the probability of finding either oil or gas, usually the higher the ratio of past gas discoveries to past oil discoveries, the higher will be the probability of finding oil in a given area. It follows that the

discovery of large gas fields may be acting as an incentive for the drilling of large structures.

The major component of new reserve additions is the drilling of new wells, of which some are successful crude oil wells, some are successful natural gas wells and some are unseccessful (dry holes). The drilling of wells depends largely on economic incentives. In our model, drilling is dependent upon average drilling costs, the price of crude oil at the well head, 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 location of crude oil deposits. Therefore, it is rather the owner of the mineral rights to land, who determines the rate at which exhaustion occurs by his decision either to permit exploration to proceed or to withhold the land from exploration.[1] At a given point in time 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 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 the land available.

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[1] See Epple's remarks on this subject [5 pp. 66-69].

The average size of discovery of crude oil is in turn a function of the average discovery size of crude oil of the previous time period which depicts the depletion effect for large prospects, the average 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. The specification of the equations for the success ratio and the average size of discovery of natural gas is in accordance with the above specified relations.

Extension of crude oil reserves depend upon 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, rather revisions are assumed to be proportional to prior discoveries and reserve levels.[2]

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

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

where extensions (EC_t), revisions (RC_t) and new discoveries (DC_t) are combined to form additions to reserves. The amounts of crude oil

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

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), the amount of natural gas liquids added for the refining processes (NG_t) and the processing gain (GA_t) realized in the refineries add up to the total amount of refined products.[3]

Production out of Reserves

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

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[3]Items left out of the identity, such as exports of crude petroleum, change in stocks, etc., constitute less than one per cent 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 prodctuion.

In oil production, where a reserve-production ratio of about eight is required, the addition of eight units of recoverable reserves would be needed to maintain the one-unit increase in production. However, because present technology recovers only about 40 units of the oil, identification of about 20 units of oil in the ground would be required to sustain production at a higher than present level.

If economic means were to become available for recovering oil that is currently identified but not recoverable, the effect would be an immediate large increase in proved reserves. This would come about through new technology or a sufficiently large parice increase, to make some present tertiary recovery methods economic.[5]

However although price would be expected to have an exponential relationship to the supply of production out of reserves (setting price equal to marginal cost) for small values of reserve production ratios the price of the current period may only partly influence extraction decisions.

Given that crude oil is an exhaustible nonrenewable stock resource the profit maximizing decision of the oil industry refers not only to individual time periods but also 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 and it turns out to be that the price should be changing over time so that market price net of extraction costs be increasing

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

exponentially at a rate corresponding to the interest rate so that extractors will be indifferent between extracting and holding [12, 15, 18].

In the case of the petroleum industry which is composed of joint stock companies the assets of these firms can be easily exchanged and furthermore the industry has a ready access to the loan market.

As long as expected profits from the operations of refining and maketing of petroleum products are higher then the rate of return from alternative investments a steady flow of crude oil will be coming to the refineries.[6] A constant difference between profit rate and interest rate over future periods would bring forth an increase in supply out of reserves in the present period because of the possibility of investing present profits so that they can 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 supply of crude oil forthcoming. Because of the capital intensity which characterizes the petroleum industry, production expenditures in fixed assets would then be expected to be highly correlated for the supply of production out reserves in every time period.

As Epple [5] points out, a common misconception is that the price of an exhaustible resource will rise at the rate of interest. While this

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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.

is true for the special case in which the initial endowment of the resource is fixed and marginal production cost is zero, this will not in general be true. If technical progress in extraction is sufficiently rapid, it is possible that the price of the resource may remain constant or even decline for a time. One would expect that, at a given point in time, a price increase would call forth a increased supply of the resource unless the increase in price resulted in the expectation of additional price increases in the future. For a given price one would also expect a decrease over time in the quantity of the resource produced because of the effect of cumulative extractions in increasing the costs of production, though 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 influecnes 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 Countires. Viewing imports as a demand for foreign crude oil it is hypothenzied that imports respond to 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 amounts of crude oil run through the refineries increase and the utilized capacity approaches the total capacity of refining, a slowing down of increases in imports would be expected.

What goes into the refinery processes is not only crude oil and lease condensate but also natural gas liquids. The amount of

natural liquids added to the liquids to be refined has been steadily increasing due to both economic and technological reasons including output mix of refined products. The estimated equation therefore depends upon 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 that come out of the refinery process, or the summation of the quantities of all refined products produced ($DISTR_t$). The processing gain represents the expansion of fuels due to some of the refinering 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.

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 1959-1972. Two stage least squares estimation was the method since several of the endogenous variables are simultanously determined. Ordinary least squares estimates were also abtained 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 sources and transformations are reponded in Appendix . For convenience, the symbols used are summarized below.

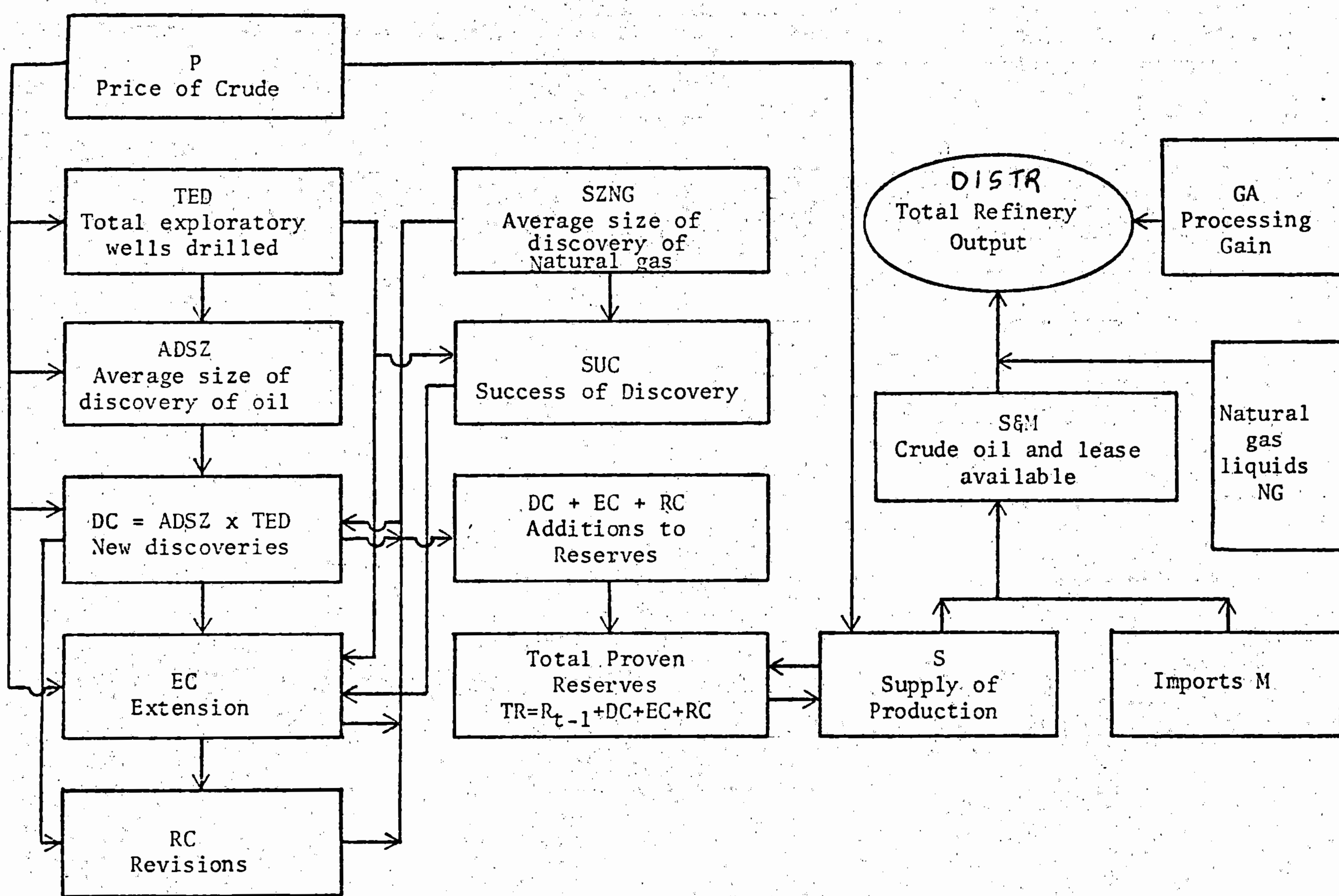

Figure 1. Structure of the Petroleum and Refined Petroleum Products Model

t = subscript denoting year

TED = no. of new exploratory wells drilled

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

ADSZ = avg size of new oil discoveries

SZNG = avg size of new natural gas discoveries

DC = new oil discoveries

EC = extensions of oil reserves

TR = total reserves at the end of the year (beginning)

DEP = avg depts of new exploratory wells

COST = cost of exploration and drilling

ACW = avg cost per exploratory well drilled

ΔR = change in stock of oil reserves

PNG = price of natural gas at the well head

P = price of crude oil at the well head

S = production of crude oil

PRO = profit rate on equity of the petroleum industry

INT = interest rate

K = production expenditures in fixed assets of the petroleum industry

L = production labor costs

M = imports of crude petroleum

Pm = avg import price

REF = refining capacity utilization

NG = natural gas liquids added

GA = processing gain

PBL = price of bituminous & lignite

T = linear time trend

DISTR = sum of domestically supplied refined product (net of imports, exports and change in petroleum stocks)

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

RC = Revisions

The resulting estimates are*:

New exploratory wells

(1) $\ln TED_t = \underset{(7.29)}{3.09} - \underset{(0.24)}{1.21} \ln AGW_t - \underset{(1.16)}{1.20} \ln SUC_{t-1} +$

$\underset{(1.17)}{0.359} \ln \hat{P}_t + \underset{(0.99)}{1.39} \ln SZNG_{t-1}$

Average discovery size of oil

(2) $\ln ADSZ_t = \underset{(48.15)}{-95.02} - \underset{(0.08)}{0.162} \ln ADSZ_{t-1} + \underset{(2.10)}{1.30} \ln[1.1(0.42COST_{t-1} +$

$0.32COST_{t-2} + 0.26COST_{t-3})] + \underset{(6.07)}{15.01} \ln SUC_{t-1} +$

$\underset{(0.19)}{1.27} \ln SZNG_{t-1} - \underset{(4.67)}{1.52} \ln \hat{P}_t$

Success ratio

(3) $\ln SUC_t = \underset{(1.12)}{2.34} - \underset{(0.27)}{0.298} \ln SUC_{t-1} - \underset{(0.004)}{0.013} \ln ADSZ_{t-1} - \underset{(0.008)}{0.018} \ln SZNG_{t-1} +$

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*Values in parenthesis are standard errors.

$$+\ 0.547\ln DEP_t$$

(0.09)

<u>Average discovery size of gas</u>

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

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

$$0.365\ln PNG_t$$

(1.71)

<u>Extensions of reserves</u>

$$(5)\quad \ln EC_t = 2.88 - 0.761\ln EC_{t-1} + 1.99\ln TED_{t-1} - 0.008\ln \hat{DC}_t +$$

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

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

(1.46)

<u>Revisions of reserves</u>

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

(2.48) (0.16)

<u>Production out of reserves</u>

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

(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)

<u>Imports of crude oil</u>

$$(8)\quad \ln M_t = -14.73 + 1.121\ln M_{t-1} + 0.905\ln \hat{S}_t - 0.069\ln PM_t - 2.95\ln REF_t$$

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

Addition of natural gas liquids

$$(9)\ \ln NG_t = 12.49 + 0.004\ln(\hat{P}_t/PNG_t) + 0.156\ln T^2$$
$$(1.32)\quad (0.05)\qquad\qquad (0.02)$$

Processing Gain

$$(10)\ \ln GA_t = -67.55 - 10.52\ln \hat{NG}_t + 14.11\ln \hat{S}_t + 1.47\ln T^2$$
$$(59.40)\quad (8.01)\qquad (9.51)\qquad (0.76)$$

Price of crude oil

$$(11)\ \ln P_t = 8.04 + 0.029\ln PBL_t - 0.099\ln \hat{TR}_t + 0.208\ln PNG_t - 0.488\ln S_{t-1} -$$
$$(3.02)\quad (0.13)\qquad (0.16)\qquad (0.09)\qquad (0.15)$$
$$0.460\ln P_{t-1}$$
$$(0.29)$$

Identities

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

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

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

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 price of crude is about

- 1.52 [equation (2)] and 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, suggesting that price incentives may stimulate exploratory drilling activity but cause a deterioration of discovery size.[6] 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 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 inventory 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. As Fisher has suggested , the effect inventory depletion is to reduce the number of small prospects that would otherwise be drilled so that the average size of discovery of oil increase.

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[6]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.

Finally, a rise in SUC_{t-1} is accompanied by a fall in SUC_t *ceteris paribus* and 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."[7] The success ration (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 further positively related with the amounts of money spent for explanation over past periods of time, in that most times it takes a substantial exploratory effort before new large reserves can be discovered.[8]

The clear implication of the above is that the sensitivity of new oil discoveries to economic incentives is substantially less than the similar sensitivity of wildcat drilling. This is primarily caused by the deterioration of discovery size 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 of the jointness in the supply of the two products. Past, large discoveries of natural gas ($SZNG_{t-1}$) can be taken as an indication of the possibility of

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

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

the possibility of finding crude oil and inparticular large structures of crude oil. This makes the elasticities in equations (1) and (2) positive. In turn, since large prospects and certainty tend to move in opposite directions, it follows that $SZNG_{t-1}$ must be positively related to the success ratio in equation (3). But, in ventory - depletion accounts for a decreasing average size of natural gas discoveries overtime, although very small as it can be seen from equation (4) where 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 in line with the result obtained by McAvory and Pindyck [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 elasticty -0.76 with respect to EC_{t-1}. Total exploratory drilling (TED_{t-1}) has a positive effect on extensions as do economic incentives through price increases. Finally, low discoveries of new oil will induce the pumping of oil from greater depths as indicated by the elasticity of -0.008 of the variable $\hat{DC}$ in equation (5).

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

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

A policy of increased prices as an incentive to exploration and discoveries of new oil reserves will not neccessarily accomplish that result. It is rather the interaction of prices with variables such as long-term investments in the identification of new large reservoirs and exhaustion effects stemming from the average discovery size, success ratio and extensions that affect the willingness of the industry to intensify the exploration effort. The deterioration of discovery size, when small but more certain prospects become attractive by a price increase, accounts mainly for the inconclusiveness regarding the effect of economic incentives. However, the depletion effects would 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 estimated, although it shows that price does not contribute to explain 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) has a positive relation with the amount of crude oil and lease condensate extracted (5). Further more total reserves (TR) and fixed production expenditures of fixed assets (K) are positively associated with the production of crude oil out of reserves, the elasticities being + 0.15 and + 0.67 respectively from equation (7).

Imports of crude oil (M) are positively associated with imports in the previous period (M_{t-1}) and with the domestic production of the

U.S. out of reserves ($\hat{S}$). The positive relation between imports and domestic supply seems reasonable in that increases in expected prices signal increased demands which reduces both domestic production out of reserves as well as imported crude oil.

As expected, the imports of crude petroluem are negatively associated with the prevailing import price having an elasticity of -0.69 from equation (8). Furthermore, refining capacity (REF) acts as a contraint to imported crude, which decreases as the refining capacity utilization increases toward the full capacity.

The natural gas liquids (NG) added to the crude petrol m and lease condenate for the refinery process depend positively upon the relative price of crude with respect to the price of natural gas liquids and time trend squared depicting technology. The addition of natural gas liquids increases as the price of crude increases by more than the price of natural gas liquids and **vice versa**, **from** equation (9).

The processing gain (GA) obtained in the determination of total refinery liquids 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 with the time trend squared depicting the technological trend, from equation (10).

The price equation (P), shows that there is a positive relation between the price of crude oil and the prices of bituminous and lignite (PBL) and natural gas liquids (PNG). Furthermore, as total reserves

become larger ($\hat{TR}$), a smaller price is necessary to be established in order to bring forth both an increased production out of reserves as well as to provide a stimulus to exploratory drilling. Exploratory drilling then apparently is facing a high success ratio as well as a high discovery size.

From equation (11), which explains the price of crude petroluem (P), it can be further seen that prices of successive periods are negatively associated due to the fact that over the ample period (1959-1972) the real price of crude has been falling. Finally the price of crude petroleum is negatively associated with the supply of reserves in the previous period (S_{t-1}) in accordance with the arguments made earlier that a low level of supply out of reserves in one time period implies the expectation of a forthcoming higher price in the next period.

The above results suggest that the industry is indeed capital intensive and that decisions regarding extraction of crude oil from the ground are made 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). It is rather the expectations regarding future net prices (or profitability of the industry) that count. A policy of incentives with present ceiling prices could be sufficient to stimulate future production out of reserves.

With regard to the imported crude oil, the insensitivity of imports to prices set by the Arab nations suggests that tariffs would not be successful in controlling imports. Import quotas, rather seem to be the alternative in curtailing increases in imporst along with domestic policies to stimulate the comparative profitability of the oil industry.

CONCLUSIONS

The purpose of this paper was to construct a model of the supply of crude oil reserves, production out of reserves and the determination of total liquids in the refinery process. The empirical results indicate that economic incentives influence the amount of exploratory drilling and its character. The crude oil reserve supply elasticity and the production out of reserves are not very sensitive to economic incentives. Although price incentives lead to more exploratory drilling, the prospects considered are poorer than those that would have been considered at a lower incentive level. Crude oil reserve extensions respond partially to economic incentives, but mainly to low levels of new oil discovered, providing incentives for deeper pumping in existing wells.

Domestic reserve production sluggishly responds to increased prices, but does react to future net price expectations. Expected future profitability becomes a key variable in deciding how much ground oil to pump in any time period. These conclusions imply that a policy of increasing prices to both enhance reserves and production of crude oil will not be effective. Rather, it is the price incentives interacting with other policies favoring a comparative profitability that will increase the flow of crude petroleum to the refineries. Moderate price increases, however, are needed to offset the exhaustible stock resource depletion effect.

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APPENDIX

The quantities supplied of crude petroleum as well as the natural gas liquids and lease condensate, and the processing gain were taken from the "Annual Statistical Review" published by the Division of Statistics and Economics of the American Petroleum Institute. The respective quantities are reported in thousands of 42 gallon barrels.

The number of exploratory wells drilled are the total productive and dry holes drilled each year and the average size of discovery is the ratio of new discoveries to total productive and dry holes. Similarily, the average size of 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.

Crude petroleum reserves are the proved reserves at the beginning of the year, which along with the revisions and extensions are published in "Petroleum Facts and Figures" of the American Petroleum Institute. The figures are reported in 42 gallon barrels.

Capital expenditures of the petroleum industry were represented by Domestic Production Expenditures in fixed assets. The figures were computed and indexed with 1960 as the base year, from the publication "Financial Analysis of a Group of Petroleum Companies" of the Energy Economics Division of the Chase Manhattan Bank.

Imports of crude petroleum were compiled from the "Yearbook of International Trade Statistics" of the United Nations. The S.I.T.C. (Standard International Trade Classification) number used was 331.01 and the figures were converted to 42 gallon barrels from the original metric tons.

The price of imports of crude petroleum was computed as a per unit price from the value (f.o.b.) and quantity figures reported in the "Yearbook of International Trade Statistics".

The domestic price of crude petroleum represents the price at the well (dollars per barrel). The price figures were taken from the "Minerals Yearbook" published by the Bureau of Mines.

The interest rate was used in the estimation of the supply of crude petroleum. The figures used are the price of commercial paper 4 to 6 months reported by the Board of Governors of the Federal Reserve System in the "Federal Reserve Bulletin."[1]

The price of natural gas is the value at the wellhead and was computed from the "Minerals Yearbook" published by the Bureau of Mines.

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

The wholesale price index was computed from the "Statistical Abstract of the United States" published by the Bureau of the Census by converting the Figures to 1960 base year. They were used in the deflation of prices.

The rate of profit of the petroleum industry represents the rate of return on book net assets as reported by the First National City Bank "Monthly Letter".

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[1]The weights assigned from the distributed lag were derived as follows: First the following equation was estimated (Griliches): $Y_t = B_o X_t + B_1 X_t - 1 + B_2 X_t - 2 + B_3 X_t - 3 + B_4 X_t - 4 + U_t$ and then the lag was specified as: $Y_t = B[W0Xt + W1Xt-1 + W2Xt-2 + W3Xt-3 = W4Xt-4] + U_t$ where $Wj = Bj/Bi$. [7]

The amounts of natural gas liquids, the processing gain and the total amount of liquids transfered in the refineries is reported by the American Petroleum Institute in the "Annual Statistical Review," in thousands of 42 gallon barrels.

The average cost per well and the average depth (feet) of new oil wells are found in the "Annual Statistical Review" of the American Petroleum Institute. The total cost sustained each year for exploration is obtained by the multiplication of the average cost per well and the number of productive and dry holes drilled each year.