Government Price Policies and the Availability of Crude Oil

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This study examines the effects of price incentives on the availability of petroleum. Expected sustained higher crude oil prices to domestic producers constitute an incentive to increase both exploratory drilling and secondary and tertiary recovery of oil as well as production out of reserves. Reserve-production ratios tend to fall under high prices. Equalization of the domestic price to the real world price would make the U.S. self sufficient within a six year period. Constant prices result in no new additions to reserves after a five year period and very low production levels. Imports reach sixty-five percent of domestic consumption.

While agricultural economists have already been concerned with the effects of increased energy costs on the availability of fuels and chemicals, on the mix of crops produced, and on shifts in producer and consumer welfare, they have not dealt with the more general problem of the effect of government policy on the petroleum extraction system [Adams; King and Johnston; Heady and Dvoskin, Carter and Youde; and Klepper et. al.]. In an effort to delineate areas of energy research for agricultural economists, Whittlesey and Butcher argue for research dealing not only with impacts of the changing energy situation on agriculture but for more involvement by agricultural economists in the national situation of supply, demand and policy for energy resources.

This study presents a model useful for examining the effects of selected price policies by the federal government on petroleum production. We attempt to determine if adjustments in the pricing mechanism for domestic crude oil will improve the demand-supply situation for oil in the U.S. Price policies examined include: (a) equalization of the domestic wellhead price for crude oil at the world price, (b) constant money wellhead prices for crude oil, (c) constant real wellhead prices, and (d) equalization of domestic wellhead prices with the 1976 world price with increases thereafter equal to the change in the domestic wholesale price index.

Studies by Epple, Khazzoom, Carter and Youde, Fisher, Adams and Griffin, and Erickson, Millsaps and Spann, have all dealt with the oil discovery problem. However, these studies have not analyzed the impact of economic policy on the total oil production system, but rather focused on specific facets of the industry. MacAvoy and Pindyck did develop an integrated economic model, but their study was designed to assess the effects of alternative regulatory policies on the natural gas, not the crude oil industry.

Model Structure

A theoretical model that captures the total system regulating the generation and extraction of crude oil is developed and estimated. The model is explicitly designed to test the responsiveness to price incentives of petroleum exploration, reserves generation and

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extraction. Figure 1 illustrates the conceptual relationships comprising the structure of the model. The model consists of three major components: (a) a petroleum exploration submodel, (b) a reserves generation submodel, and (c) a submodel generating oil for refined products.

Petroleum Exploration

The petroleum exploration component of the model consists of four stochastic equations and one identity (Table 1). The supply of new domestic oil is determined by the product of the number of exploratory wells drilled (TED) and the average discovery size (ADSZ) per well (Equation 1).[1] The number of exploratory wells drilled (TED) depends upon the interrelationship between expected returns from oil and gas, costs of production and risk (Equation 2). Because of the time-lag between investment outlays and the accrual of revenues, the interest rate is included.

The search for oil and gas is carried out jointly, and new oil discoveries (ADSZ) are

[1] For the derivation of the estimated equations, see Pagoulatos, Pagoulatos and Debertin.

TABLE 1. Petroleum Exploration[a]

New oil discoveries

(1) $DC = ADSZ \times TED$

New exploratory wells

(2)
$$TED_t = \underset{(31242.4)}{77747.5} - \underset{(6577.0)}{69778.8}\, ACW_t - \underset{(562.2)}{2581.9}\, INT_t + \underset{(0.0014)}{0.0066}\, [4\sigma_0^2\, \widehat{ADSZ}_t^2\, (P_{t-1} + P_{t-2} + P_{t-3})^2/9 + 4\sigma_G^2\, \widehat{SZNG}_t^2\, (PNG_{t-1} + PNG_{t-2} + PNG_{t-3})^2/9] - \underset{(0.00025)}{0.00114}\, [\widehat{ADSZ}_t\, (P_{t-1} + P_{t-2} + P_{t-3}/3) + \widehat{SZNG}_t\, (PNG_{t-1} + PNG_{t-2} + PNG_{t-3}/3]$$

Average discovery size of oil

(3)
$$ln ADSZ_t = \underset{(12.8)}{-74.75} - \underset{(0.0353)}{0.0815}\, ln ADSZ_{t-1} + \underset{(2.41)}{15.30}\, ln SUC_{t-1} - \underset{(0.08)}{1.45}\, ln SZNG_{t-1} - \underset{(0.449)}{0.441}\, ln \hat{P}_t - \underset{(0.27)}{1.31}\, ln PNG_t$$

Average discovery size of gas

(4)
$$ln SZNG_t = \underset{(29.93)}{-54.29} - \underset{(0.176)}{0.245}\, ln SZNG_{t-1} + \underset{(5.19)}{10.08}\, ln SUC_{t-1} - \underset{(0.0078)}{0.0235}\, ln ADSZ_{t-1} + \underset{(0.819)}{0.911}\, ln PNG_t + \underset{(3.84)}{1.74}\, ln \hat{P}_t$$

Success ratio

(5)
$$ln SUC_t = \underset{(0.60)}{2.48} - \underset{(0.140)}{0.432}\, ln SUC_{t-1} - \underset{(0.0022)}{0.0148}\, ln ADSZ_{t-1} - \underset{(0.0046)}{0.0148}\, ln SZNG_{t-1} + \underset{(0.043)}{0.610}\, ln DEP_t$$

Price of crude oil

(6)
$$ln P_t = \underset{(1.07)}{-5.25} + \underset{(0.0000008)}{0.0000013}\, ln PNG_t - \underset{(0.028)}{0.120}\, ln REF_{t-1} + \underset{(0.00000008)}{0.0000015}\, ln [1.1\, (0.65\, DISTR_{t-1} + 0.35\, DISTR_{t-2})] + \underset{(0.102)}{0.702}\, ln PM_t$$

Definition of variables

DC = new oil discoveries, measured in 42-gallon barrels. Source: (American Petroleum Institute, API).
TED = number of new exploratory wells drilled (total productive and dry holes drilled each year). Source: (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).
ACW = average cost per exploratory well drilled (in dollars). Source: (API).
INT = interest rate (price of commercial paper 1 to 6 months). Source: (Federal Reserve).
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).
DEP = average depth of new exploratory wells (in feet). Source: (API).
REF = refining capacity utilization. Source: (API).
DISTR = sum of domestically supplied refined products, net of imports, exports and change in petroleum stocks (42-gallon barrels). Source: (USBM).

[a] (Standard errors are in parentheses).

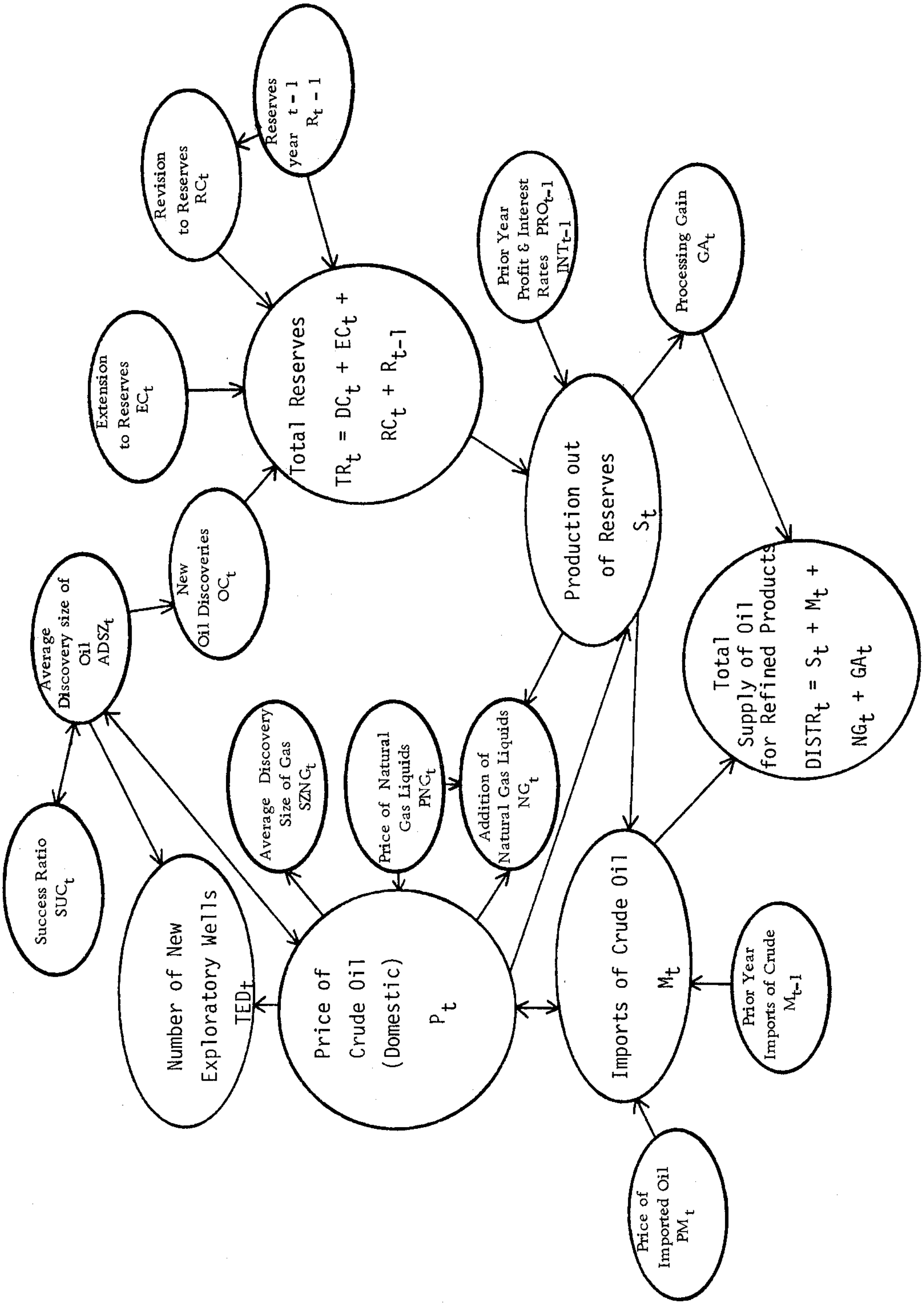

Figure 1. Causal flow diagram of the petroleum model

associated with discoveries (SZNG) of natural gas (Equations 3-4). The probability of finding oil is greater as the ratio of past gas discoveries to past oil discoveries increases. However, as Fisher points out, there are many more small, less risky, petroleum prospects still to be discovered than there are large, more risky prospects. Hence, the average discovery size will be reduced as the finite stock of oil and gas is depleted. The success ratio (SUC), defined as the ratio of productive to total new wells drilled, is a function of previous discoveries of oil and gas and the depth at which exploration is taking place (Equation 5).

The price of crude oil (P) is a function of the price of close substitutes (natural gas and imported crude oil) and the extent of refinery capacity utilization (Equation 6). A distributed lag of the sales of refined products rather than actual sales is used, because a sustained increase in sales of refined products must occur if the price of crude oil is to increase.

Reserves Generation

The reserves generation component of the model consists of two stochastic equations and one identity (Table 2). Total proven reserves of crude oil (TR) are equal to the sum of reserves remaining in the previous period, (R_{t-1}), new discoveries (DC), new extensions of reserves (EC) and revisions to existing reserves (RC) for any time period (Equation 7).[2]

Extensions of previously discovered oil (EC) depend upon expected prices, which are given by a distributed lag [see Griliches], as well as the amounts of crude previously discovered (Equation 8). Economic incentives result in the adoption of new technologies in extraction and make possible the use of secondary and tertiary recovery methods. Revisions of established reserve levels (RC) do not respond to economic or technological variables and are assumed to be proportional to changes in reserve levels (Equation 9).

Oil for Refined Products

The final submodel focuses on oil for refined products (Table 3). The primary inputs

[2]Proven reserves according to the American Petroleum Institute are the estimated quantities of crude oil which geological and engineering data demonstrate with reasonable certainty to be recoverable from known reservoirs under existing economic and operating conditions. Although proven reserves are known with a probability of one at any given time, indicated and inferred reserves can be considered given lower probabilities. Also, the percentage of oil recovered from any given deposit has been increasing with cumulative recovery efficiency rising from 25 percent in 1955 to 33 in the 1970's. Secondary and tertiary recovery with expectations for higher prices as they become more economical will be increasing the cumulative recovery efficiency, thus increasing the extensions of proven reserves as well as the revisions. About 50 percent of the oil from reservoirs discovered to date is still in the ground [Risser].

TABLE 2. Reserves generation

Total reserves

$$(7)\ \hat{TR}_t = R_{t-1} + \hat{DC}_t + \hat{EC}_t + \hat{RC}_t$$

Extensions of reserves

$$(8)\ \ln EC_t = \underset{(1.64)}{5.82} - \underset{(0.0346)}{0.0623}\ \ln DC_{t-1} - \underset{(0.035)}{0.201}\ \ln DC_{t-2} + \underset{(1.10)}{9.83}\ \ln[1.05\,(0.75\,P_{t-1} + 0.2\,P_{t-2} + 0.05\,P_{t-3})]$$

Revisions of reserves

$$(9)\ RC_t = \underset{(166043.42)}{1018942.79} + \underset{(0.033)}{0.095}\ \Delta R_{t-1}$$

Definition of variables

TR = total reserves, beginning of year (in 42-gallon barrels). Source: (API).
R = crude petroleum reserves (proved reserves at the end of the year), measured in 42-gallon barrels. Source: (API).
EC = extensions of oil reserves, in 42-gallon barrels. Source: (API).
RC = revisions of established reserves (42-gallon barrels). Source: (API).

to the petroleum refining industry are domestic crude oil and lease condensate (S), natural gas liquids (NG) and oil imports (M). To arrive at the total quantity of products from the refinery, (DISTR), the processing gain realized in the refineries (GA) is also included (Equation 10).

Because petroleum producers attempt to balance annual flows with reserve levels, the supply of domestic production (S) is determined by the marginal cost of developing existing reserves (Equation 11). Hence, marginal production costs will depend on reserve levels relative to domestic production. As the reserve to production ratio declines, marginal costs rise exponentially. Development of new production sites will be undertaken only if the expected price of oil covers all costs including a normal return on investment and a risk allowance. A short-term glut may send current prices down. If the glut was expected to be temporary, and long-run price expectations were high enough, development might continue even at low current prices.

Price expectations and the opportunity cost of investing in petroleum production are expressed as distributed lags of past prices and the difference between net price and the rate of interest.[3]

Imports of crude petroleum are assumed to respond to domestic economic policy as well as the price of imported crude oil [Burrows and Domencich, Adelman]. Current imports (M) are viewed as demand for foreign crude oil and respond to the price of imports and the domestic supply of crude. This is because import quotas were set on the basis of domestic output and the utilization of domestic refining capacity acts as a constraint (Equation 12).

[3]The equilibrium path that the price of a nonrenewable resource should follow to the point of exhaustion is such that net price is increasing exponentially at a rate corresponding to the interest rate, unless technological progress affects production [Adelman, Epple, Hotelling, Nordhaus, and Solow].

TABLE 3. Oil for Refined Products

Total refined liquids

$$(10)\ DISTR_t = \hat{S}_t + \hat{M}_t + \hat{NG}_t + \hat{GA}_t$$

Production out of reserves

$$(11)\ S_t = \underset{(4744257.7)}{26796754.3} + \underset{(3783596.7)}{14919184.5}\ ln[0.5\ P_{t-1} + 0.3\ P_{t-2} + 0.2\ P_{t-3})] + \underset{(5.80)}{45.05}\ \hat{TR}$$
$$- \underset{(80744.7)}{1222577.01}\{1.05[0.35\ (PRO_{t-1} - INT_{t-1}) + 0.25\ (PRO_{t-2} - INT_{t-2})$$
$$+ 0.2\ (PRO_{t-3} - INT_{t-3}) - 0.2\ (PRO_{t-4} - INT_{t-4})]\}$$

Imports of crude oil

$$(12)\ lnM_t = \underset{(2.88)}{18.58} + \underset{(0.12)}{0.95}\ lnM_{t-1} + \underset{(0.30)}{1.26}\ lnS_t - \underset{(0.185)}{0.299}\ lnPM_t - \underset{(0.65)}{4.28}\ lnREF_t$$

Addition of natural gas liquids

$$(13)\ lnNG_t = \underset{(0.583)}{12.74} - \underset{(0.0590)}{0.0976}\ ln(\hat{P}_t/PNG_t) + \underset{(0.026)}{0.332}\ lnT^2$$

Processing Gain

$$(14)\ lnGA_t = \underset{(32.65)}{-36.49} - \underset{(2.61)}{3.93}\ ln\hat{NG}_t + \underset{(3.66)}{6.39}\ ln(\hat{S}_t + \hat{M}) + \underset{(0.46)}{1.95}\ lnT^2$$

Definition of variables

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).
M = imports of crude petroleum (S.I.T.C.: 334.01). 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).
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.

The amount of natural gas liquids (NG) added in the refinery process, because of economic and technological factors, has been steadily increasing over time (Equation 13). Natural gas liquids have been a relatively small proportion of total inputs (averaging about 14 percent of total supply over the period 1959-1972) and have been directly related to the price ratio of crude to natural gas liquids.

The processing gain (GA) represents the expansion of fuels due to some refining processes such as reforming and cracking, and is the final component of the total amount of refined liquids.[4] The quantity of processing gain increases in direct proportion to the amount of crude oil and lease condensate run through stills, and declines in proportion to the amount of natural gas liquids added for refining (Equation 14).

Estimation and Validation

The complete econometric model consists of 11 stochastic equations and 3 identities. Some parameters of the structural relationships are simultaneously determined. Two stage least squares and three stage least squares were used to estimate model parameters. Estimates obtained via the three stage least squares method were somewhat more efficient than the two stage least squares estimates. Three stage least squares results are presented in Tables 1-3. Estimates were obtained using time series data from 1959 to 1972.

A major effort was devoted to the validation of the model using quantitative measures suggested in Theil [1966]. The model was first validated with respect to its ability to predict endogenous variables within the range of the data over the time period 1959 to 1972. Predicted values for endogenous variables were obtained for reduced forms from the first stage of estimation (the Unrestricted Reduced Form or URF estimates). Predicted values generated from both the structural equations of both the second and third stage (the Restricted Reduced Form or RRF estimates) of the model were also generated. The predicted values from each of the three estimation methods (URF, two stage RRF, and three stage RRF) were used in conjunction with actual data to calculate Theil coefficients, correlations between actual and predicted values, root mean square errors, and error decomposition measures [Theil, 1966]. None of the prediction methods were found to be clearly superior to the others based on these validation measures [Steckler]. Table 4 summarizes calculated values for the validation measures using predictions obtained from the structural equations of the third stage. Calculated values suggest that the model largely does an adequate job of predicting endogenous variables within the range of the actual data.

Old Theil coefficients based on predicted and realized changes in endogenous variables ranged from .164 to .793 while new Theil coefficients ranged from .248 to 1.063. Simple correlations between actual and predicted values were above .88 except for the equation generating the average size of natural gas discoveries. Regression coefficients of actual data on predicted values were all near one. Root mean square errors are all low relative to the magnitude of raw data values.

To further scrutinize the model's efficacy as a predictive device, predictions for endogenous variables were calculated for the years, 1973, 1974, 1975 and 1976 using actual data for predetermined variables for those years. Comparison of actually observed values of endogenous variables for 1973, 1974, 1975 and 1976 with values obtained from the equations based on the 1959 to 1972 data provide a very critical test of the ability of the model to predict beyond the range of the sample data. Results using the RRF three stage least squares parameter estimates are presented in Table 5. Predicted values for

[4]The processing gain represents approximately 3 percent of the total supply of refined products over the 1959-1972 period.

TABLE 4. Summary of Selected Validation Measures for the Econometric Model.

Variable Name	Old Theil Coefficient[ab]	New Theil Coefficient[ac]	Correlation between Actual and Predicted	Regression Coefficient of Actual on Predicted	RMS Error[d]	Fraction of Error Due to[d]: Unequal Central Tendency U_m	Unequal Variation U_s	Imperfect Covariation U_c	Wrong Slope U_r	Non Zero Disturbances U_d
New Exploratory Wells	.501	0.976	.939	0.942	3164 wells/year	.0149	.0028	.9822	.5594	.4256
Average Discovery Size of Oil	.128	0.248	.975	0.987	1476 barrels/well drilled/year	.0003	.0615	.9381	.0153	.9843
Average Discovery Size of Gas	.793	0.983	.334	0.933	2.151 trillion cu. ft./year	.0032	.6065	.3903	.0016	.9952
Success Ratio	.336	0.609	.912	0.918	10.18 percent/year	.0000	.0966	.9034	.0015	.9985
Price of Crude Oil	.164	0.336	.981	1.000	1.02 dollars/year	.0000	.0241	.9758	.1000	.9000
Extensions of Reserves	.560	0.921	.924	0.951	1271 barrels/year	.0001	.1901	.8097	.0833	.9167
Revisions of Reserves	.457	0.905	.622	0.835	1439 barrels/year	.0009	.0004	.9987	.1966	.8025
Production out of Reserves	.443	1.063	.969	1.0119	103.6 million barrels/year	.0033	.1870	.8090	.6377	.3590
Imports of Crude	.446	0.867	.947	0.981	1109 barrels/year	.0020	.0024	.9957	.2399	.7581
Addition of Natural Gas Liquids	.229	0.497	.966	0.969	1040 barrels/year	.0134	.1787	.8079	.4801	.5065
Processing Gain	.683	1.033	.888	0.999	2449 barrels/year	.0000	.0241	.9759	.1002	.8998

[a] Theil Coefficients calculated on the basis of predicted and realized changes in endogenous variables, not actual values

[b] $[\Sigma(P_i - P_i)^2/n]^{1/2} / [\Sigma P_i^2/n)^{1/2} + (\Sigma A_i^2/n)^{1/2}]$

[c] $[\Sigma(P_i - A_i)^2/\Sigma A_i^2]^{1/2}$

[d] Calculated on the basis of predicted and realized changes in endogenous variables.

TABLE 5. **Actual and Simulated Values of Selected Variables, 1959 to 1976**

	Total Additions to Reserves[a]		Total Reserves[a]		Supply of Production[a]		Reserve Production Ratio	
Year	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated
1959	3,666	3,427	31,719	31,411	2,574	2,417	12.3	12.9
1960	3,365	2,340	31,613	31,369	2,574	2,581	12.2	12.1
1961	2,657	2,527	31,758	31,954	2,621	2,529	12.1	12.6
1962	2,180	2,320	31,389	31,275	2,676	2,641	11.7	11.8
1963	2,174	2,343	30,969	31,439	2,752	2,662	11.2	11.8
1964	2,664	2,434	30,990	30,901	2,786	2,972	11.1	10.4
1965	3,048	3,272	31,352	31,100	2,848	3,074	11.0	10.1
1966	2,964	3,162	31,452	31,193	3,027	3,169	10.4	9.8
1967	2,962	2,951	31,376	30,964	3,215	3,179	9.7	9.7
1968	2,454	2,282	30,707	30,556	3,329	3,178	9.2	9.6
1969	2,120	2,258	29,631	29,320	3,371	3,494	8.7	8.4
1970	12,688	10,163	39,001	36,196	3,517	3,387	11.0	10.7
1971	2,317	2,277	38,062	35,056	3,453	3,417	11.0	10.3
1972	1,557	1,459	36,399	33,068	3,459	3,447	10.5	9.6
1973[b]	2,145	2,100	35,299	31,808	3,360	3,287	10.5	9.6
1974[b]	1,993	2,000	34,249	30,595	3,202	3,213	10.6	9.5
1975[b]	1,318	1,312	32,682	28,719	3,052	3,188	10.7	9.0
1976[b]	3,094	3,121	32,400	29,008	2,825	2,832	11.4	10.2

[a] Figures are ten thousand barrels.
[b] Simulated values are projections using coefficients derived from the 1959-72 sample data.

the years 1973-1976 all track very closely historical data for the same time period (see Figures 2-4).

Using the Oil Model in a Policy Setting

The demand conditions of the 1980's can be described in a number of ways, varying from quite expansive (continued increases in petroleum product demands due to strict regulation of crude oil prices) to quite restrictive (because of higher crude oil prices and new coal and solar energy technologies).

The approach taken here is not to choose an extreme set of values of the exogenous variables to be inserted into the model. Rather, a set of values was chosen that follows from "median" conditions likely to prevail in energy markets in the near future. Demand for crude petroleum is expected to increase at the rate of 2.2 percent per annum under constant present prices and at the rate of 2.0 percent per annum under world prices.[5] These figures are based on historical demand increases. It is expected that natural gas prices will increase at a rate of 9 percent per annum in current dollar terms and that the average drilling cost will increase at 7 percent per annum.[6] These values were then inserted into the econometric model to produce simulated values of additions to reserves, total proven reserves and production out of reserves for the time period, 1977 to 1985. Impacts of the four price policies on additions to reserves, proven reserves and production out of reserves are summarized in Figure 2-4.

Domestic production and reserves under world prices

Domestic price increases to the world price would have only a slight impact on new

[5] The Energy Policy and Conservation Act provides for a Strategic Petroleum Reserve in order to reduce the impact of disruptions in supplies of petroleum products. The Act requires storage of at least 150 million barrels of petroleum products and crude oil by December 22, 1978, and authorizes storage of up to 1 billion barrels by December 22, 1982. These amounts of crude oil will have to be added in our calculations of demand.

[6] The assumption of a decreasing success ratio is conservative in that despite the past trend, future offshore leasing may stimulate larger average discovery sizes per well drilled. Furthermore, over the sample period the success ratio increased at a rate of 0.5 percent per annum.

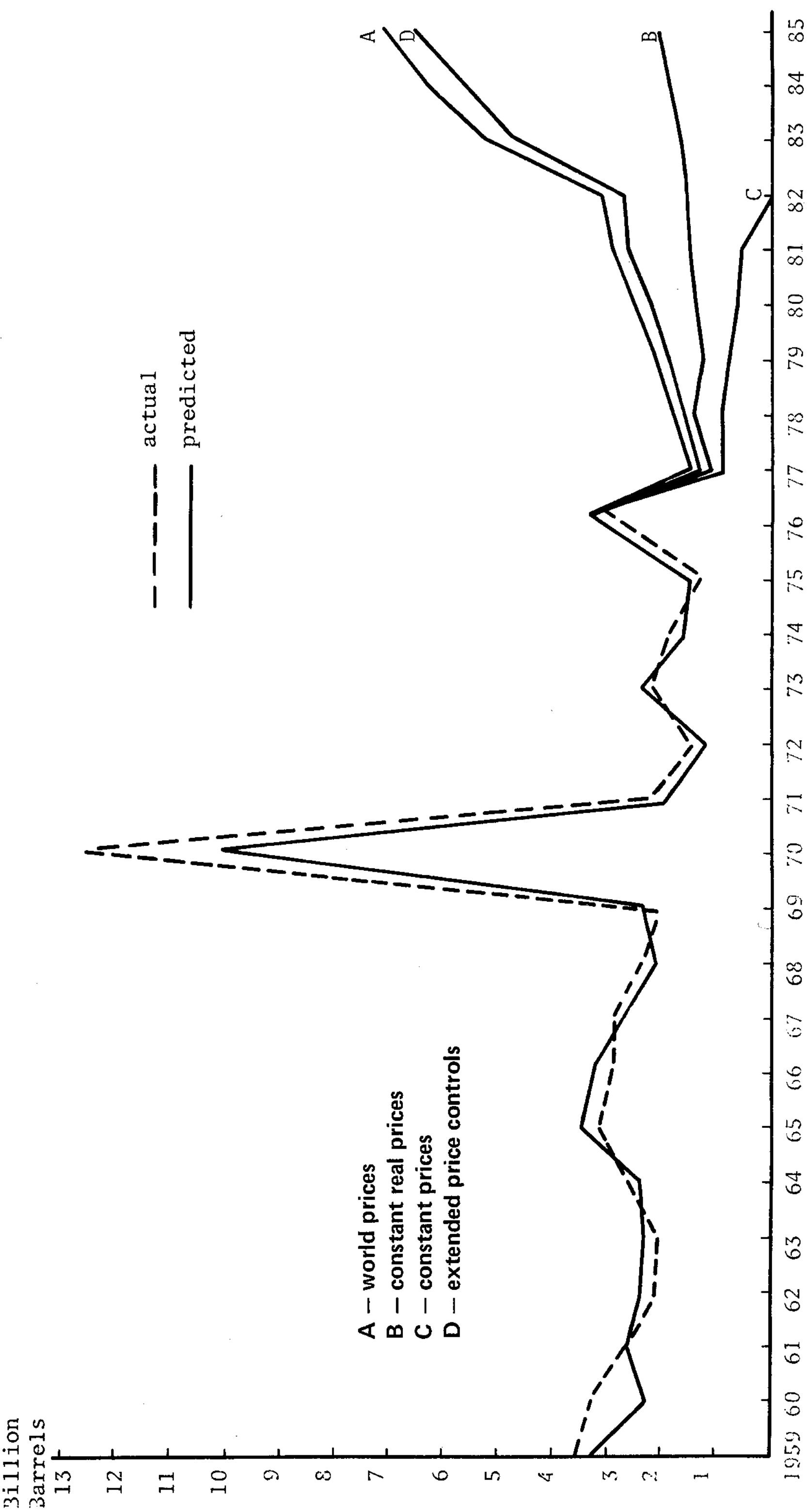

Figure 2. Impact of alternative price policies on additions to reserves

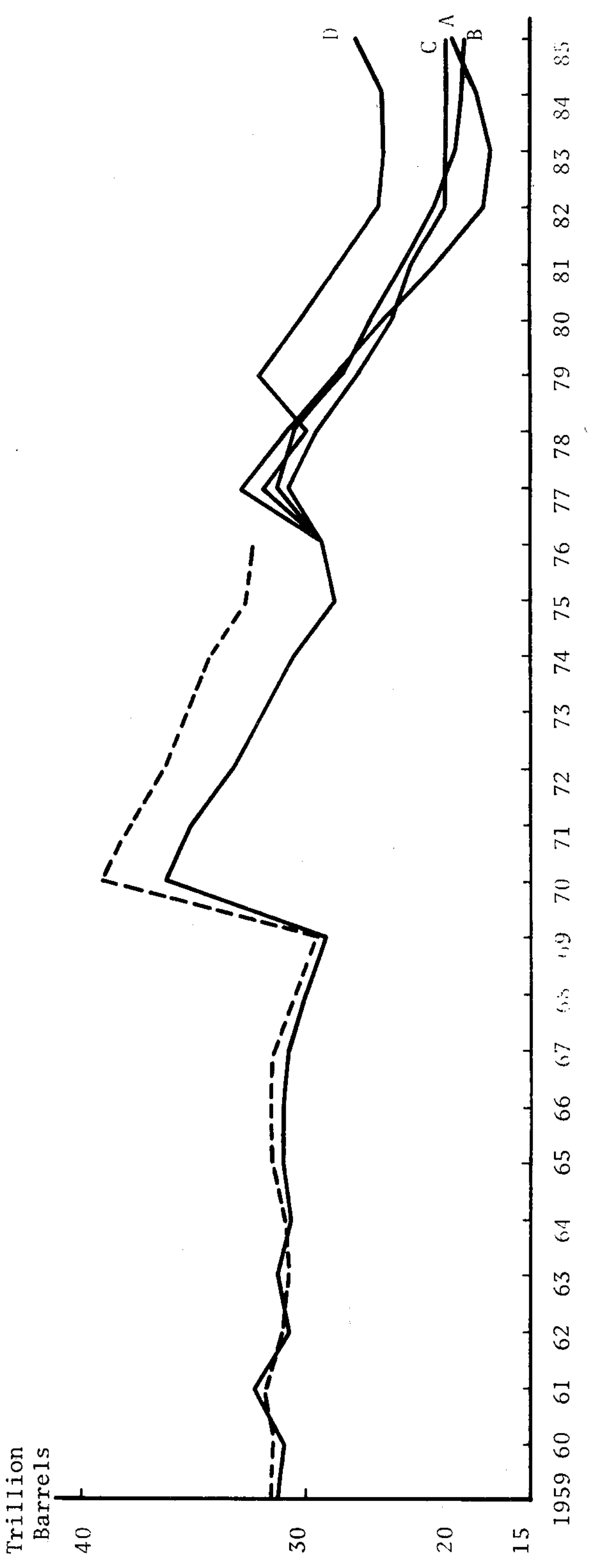

Figure 3. Impact of alternative price policies on reserves

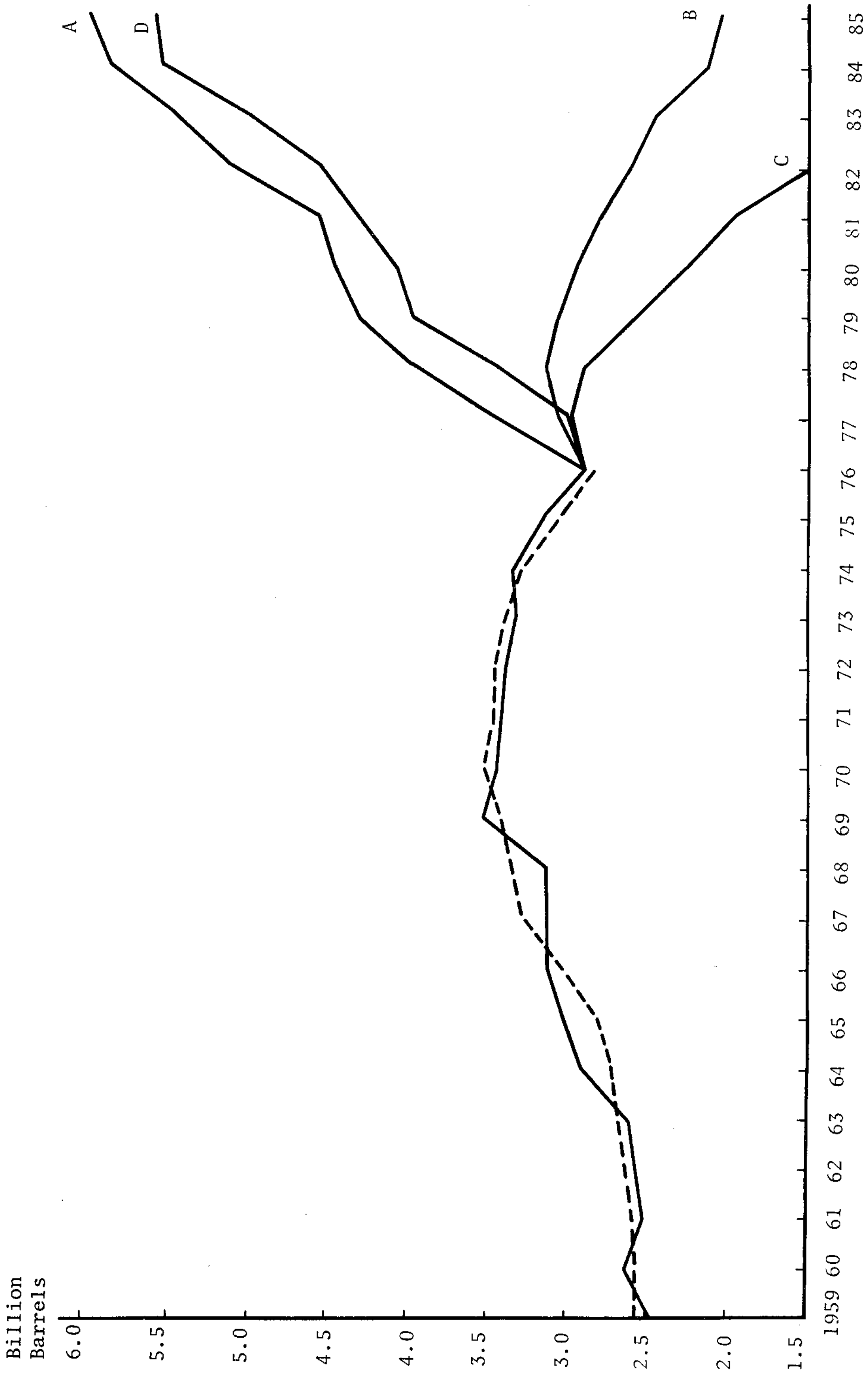

Figure 4. Impact of alternative price policies on production out of reserves

discoveries of reserves over the 1977 to 1979 period.[7] This impact is due to the assumption of a decreasing success ratio and to the lagged response of exploration to economic incentives. However, world prices provide a significant incentive for new discoveries of oil, thereafter. Total additions to reserves increase by 25 percent in 1978 over 1977 and surpass 3 billion barrels in 1982 (Table 6). Total additions to reserves (Figure 2) do not necessarily track closely the level of reserves (Figure 3) due to the increased production levels over the 1977 to 1982 period.[8]

Price incentives in exploration coupled with a decreasing success ratio yield total additions to reserves which are lower than the amounts of extracted oil at these prices. Total additions to reserves reach 7 billion barrels a year by 1985 which is approximately 5.5 billion barrels greater than the new additions to reserves for 1977, expected prior to the series of price increases.

Higher crude oil prices at the wellhead would make it profitable to increase production by more than 2 billion barrels during the period 1978 to 1985. The increased production out of reserves reduces the reserve-production ratio from 9:1 in 1977 to 3:7 in 1985 as a larger proportion of existing reserves is removed in response to the price incentive.

The result of a deregulated domestic price is to substantially increase domestic production and greatly reduce the magnitude of the crude oil shortage. Domestic supply is sufficient to meet 88 percent of expected U.S. consumption by 1980. The domestic production shortage is eliminated and an excess supply results by 1985. Excess supplies occurring after 1983 may lead to rebuilding of the reserves base, possibly some exports and to some price softening on new field contracts.

Constant Real Wellhead Prices

The average price of crude oil at the wellhead is hypothesized to be increasing at an average rate of 5 percent per annum corresponding to the expected inflation. The annual total additions to reserves are shown in Table 7. The supply of production out of reserves is steadily decreasing after 1978 with a doubling of the excess demand by the year 1985. A constant real wellhead price does not provide enough incentive for a substantial increase in exploration and production out of reserves. These price incentives coupled with the decreasing success ratio account for lower additions to reserves compared to the amounts extracted, with reserves decreasing to 23 billion barrels in 1985.

Imports increase by 29 percent by 1980, and domestic crude oil constitutes only 50

[7]World prices are assumed to increase at an average rate of 10 percent per year. More recent moderate stands taken by OPEC cast some doubt on the likelihood of this scenario.

[8]The figures include the 9.6 billion barrels located in Prudhoe Bay, Alaska, in 1968.

TABLE 6. Impact of Raising Domestic Crude Oil Prices at the Wellhead to World Prices, 1977-1985

Year	Total additions[a] to Reserves	Total Reserves[a]	Supply of Production[a]	Excess[b] Demand	Reserves Production Ratio
1977	1,497	32,797	3,450	1.3	9.5
1978	1,876	30,783	3,890	1.0	7.9
1979	2,103	28,570	4,317	0.6	6.6
1980	2,530	26,665	4,435	0.6	6.0
1981	2,922	24,017	4,590	0.4	5.2
1982	3,100	22,101	5,018	0.1	4.4
1983	5,256	21,910	5,447	−0.2	4.0
1984	6,370	22,315	5,965	−0.7	3.7
1985	7,106	23,393	6,028	−0.7	3.9

[a]Million barrels.
[b]Billion barrels.

TABLE 7. Impact of Raising Wellhead Prices Five Percent Per Year, 1977-1985.

Year	Total additions to Reserves	Total Reserves	Supply of Production	Excess Demand	Reserve Production Ratio
1977	1,195	31,996	3,050	1.7	10.5
1978	1,365	30,258	3,103	1.7	9.7
1979	1,238	28,473	3,023	1.9	9.4
1980	1,303	26,877	2,899	2.2	9.2
1981	1,372	25,462	2,787	2.4	9.1
1982	1,475	24,300	2,637	2.6	9.2
1983	1,692	23,509	2,483	2.8	9.4
1984	1,853	23,176	2,186	3.2	10.6
1985	2,065	23,185	2,056	3.5	11.2

percent of the total U.S. consumption. Because of the relatively lower profitability, the reserve-production ratio remains higher than before. Proven reserves decrease to 23.1 billion barrels and production out of reserves to 2 billion barrels in 1985.

Constant Wellhead Prices

Under the assumption of constant wellhead prices, additions to reserves decline very rapidly with no new oil being discovered after a 5 year period (1977-1982). Import levels would increase by 62 percent by 1980, and only 45 percent of total U.S. consumption would be supplied by domestic oil. The supply out of reserves also decreases, due to the lack of economic incentives. Excess demand reaches 5.5 billion barrels in the year 1985. As expected, the reserve-production ratio increases as more oil is kept in the ground (Table 8).

Blended Price Controls

Under this plan, price controls on the price of crude petroleum at the wellhead are to change as follows: 1) the price of newly discovered oil will be allowed to rise over a 3 year period to the 1976 world price, adjusted thereafter for domestic general level price increases; b) the current $5.5 and $11.28 price ceilings for previously discovered oil will be allowed to rise at the rate of domestic price inflation; c) incremental tertiary recovery from old fields would receive the world price. Finally, a crude oil equalization tax equal to the difference between the controlled domestic crude oil price and the world price would be used to raise the price of domestically consumed oil to the world price.

This scheme of pricing domestic oil at the wellhead provides adequate economic incentives for increased efforts in exploration and extraction of crude oil (Table 9). Total additions to reserves double within a five year period (1977-1981) and supply out of reserves increases by about 40 percent over the

TABLE 8. Impact of Constant Wellhead Prices, 1977-1985

Year	Total additions to Reserves	Total Reserves	Supply of Production	Excess Demand	Reserve Production Ratio
1977	1,129	31,300	3,013	1.7	10.4
1978	1,077	29,512	2,865	2.0	10.3
1979	933	27,838	2,607	2.3	10.6
1980	809	26,369	2,278	2.7	11.5
1981	703	25,193	1,879	3.4	13.4
1982	–	23,774	1,419	3.8	16.7
1983	–	23,700	–	5.3	–
1984	–	23,700	–	5.4	–
1985	–	23,700	–	5.5	–

TABLE 9. Impact of Extended Price Controls, 1977-1985

Year	Total additions to Reserves	Total Reserves	Supply of Production	Excess Demand	Reserve Production Ratio
1977	1,385	31,996	3,150	1.7	10.4
1978	1,650	30,156	3,490	1.5	8.6
1979	1,890	32,046	3,995	0.9	8.0
1980	2,410	30,273	4,183	0.9	7.2
1981	2,708	28,617	4,364	0.6	6.6
1982	2,887	26,825	4,679	0.4	5.7
1983	4,950	26,605	5,170	–	5.1
1984	5,700	26,670	5,635	–0.3	4.7
1985	6,780	27,800	5,650	–0.3	4.9

same period.[9] Domestic production by 1980 would constitute 82 percent of total domestic consumption. Imports would be cut by one half compared with current levels. Excess demand reduces to zero by 1983 (within a 6 year period) and reserve-production ratios are fairly low. Although the reserve-production ratios are higher than the ratios under world prices for domestic producers, the incentives for extracting oil are substantial.

Conclusions

We have developed an econometric model which examines the responsiveness of petroleum exploration to prevailing oil prices. The model consisted of 11 stochastic equations and 3 identities. The model was estimated via three stage least squares and validated with a variety of numerical measures. The behavior of the model beyond the sample period appears to be quite good. Statistical results suggest that producers respond to expected sustained price increases and that if our nation's proven reserves of oil are to increase, we must be willing to pay a higher price.

Preliminary indications from the simulations of this study indicate that rising crude oil prices provide the necessary incentive to the U.S. petroleum industry for intensifying the exploration effort. Higher prices increase the number of new exploratory wells drilled and the use of the secondary and tertiary recovery methods. Although a time lag exists between the exploration stage and the development of wells, higher prices also induce more production out of reserves. Consequently, the market mechanism by itself appears to be capable of bringing about the necessary adjustments in the domestic reserves of crude oil as well as the supply of domestic crude to the refineries. However, high prices tend to induce comparatively lower reserve to production ratios as the amounts extracted from the ground are larger than the additions to reserves, given the assumption of a decreasing success ratio in exploration.

Equalization of the domestic price of crude oil at the wellhead with the world price provides enough incentive to domestic producers to increase exploration and extraction. Although under this policy the U.S. could become self sufficient in a period of six years after implementation, sizeable windfall profits would be secured by the producers. A constant price or constant real price with base year 1976 would provide insufficient incentive for domestic producers. But a policy of constant real 1976 world price for the domestic producers would result in sufficient incentives for an increased oil flow, which eventually would make the U.S. self-sufficient within a seven year period.

[9]Our calculations are based on the 1976 world price and an increase thereafter of 6 percent per year.

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