1-1-1976

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Emilio Pagoulatos

Angelos Pagoulatos

David L. Debertin

Occasional Paper #765

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The U.S. Petroleum Industry: A Large Scale Econometric Model

Emilio Pagoulatos, Angelos Pagoulatos and David L. Debertin*

In recent years the United States, as well as other nations, have become increasingly concerned with the availability of energy resources to meet increasing energy demands. Energy projections indicate an increasing gap between available supplies and the potential demand for energy resources.

Consumption of energy in the U.S. decreased from a daily average of 205 trillion B.T.U. in 1973 to 200 trillion B.T.U. in 1974. Petroleum provided 42.3 percent of the total energy consumed in 1974, natural gas (dry and liquid) provided 33.9 percent, coal 18 percent, water power 4.2 percent and uranium 1.6 percent. Domestic production of crude petroleum has been decreasing since 1970, while demand for crude petroleum increased through 1973 reaching 4,548 million barrels per year. In 1974, the demand for crude petroleum decreased to 4,439 million barrels per year with domestic production reduced to 3,199 million barrels per year. Consequently, imports of crude petroleum have increased, reaching an annual rate of 1,269 million barrels in 1974 and causing a substantial drain on U.S. balance of payments, (American Petroleum Institute, Risser).

Crude petroleum appears to be the single most important energy source, supplying 42.3 percent of the U.S. total energy needs, (American

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*The authors are repectively: Assistant Professor of Economics at the University of Missouri, St. Louis; Assistant Professor of Agricultural Economics, University of Kentucky, Associate Professor of Agricultural Economics, University of Kentucky.

This paper will be published as Journal Paper No. 76-1-71 of the University of Kentucky Agricultural Experiment Station.

Petroleum Institute). Recent concern over the future availability of imports of crude petroleum and the expected increases in import prices necessitate continued investigation of the petroleum market.

This paper investigates the U.S. structural relationships of the demand and supply of crude petroleum and refined petroleum products. The fundamental equation of the model is an identity which describes an equilibrium condition of the market under investigation:

$$S_t + M_t \times Pop_t - E_t + \Delta_t + NG_t + GA_t = \sum_{i=1}^{10} S_t^i =$$

$$= DISTR_t = \sum_{i=1}^{10} D_t^i \times Pop_t = Dem_t + NG_t + GA_t$$

where (t refers to time):[1]

S_t = is the domestic supply of crude petroleum

M_t = is the imported crude (in per capita terms)

Pop_t = is the U.S. population

E_t = is the exports of crude petroleum

Δ_t = is the change in stocks of crude petroleum

NG = is the amount of natural gas liquids added to crude petroleum for the refining process

NA = is the amount of lease condensate added to crude petroleum for the refining process and the expansion of liquids obtained by the refining process

DISTR = $\sum_{i=1}^{10} S_t^i$ = is the summation of the domestically supplied refined product (net of imports, exports and changes in stocks) which have been divided into ten groups as follows: gasoline, coke, wax, residual fuels, distillate fuels, road oil and asphalt, liquified fuels, still gas and petro-chemical feedstock, kerosene, lubricants.

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[1]Items left out of the indentity constitute less than one per cent of the total amount of crude or refined products. The same applies for E_t and Δ_t.

$\sum_{i=1}^{10} D_t^i$ = is the summation of the domestically demanded refined products (net of imports, exports and changes in stocks) as explained above.

Dem_t = is the total derived demand of crude for domestic uses

The domestic supply of crude, imports of crude, the demands and supplies of refined products, the amounts of natural gas liquids and the processing gain were estimated along with the estimation of reserves of crude petroleum, the price of crude and the profit rate of the petroleum industry by using time series data for the period 1959-1972 (Appendix A contains the data sources and conversions). All equations were specified as linear functions due to the fact that the linear specifications gave overall better results in terms of explaining variation. The complete system consists of ten demand equations for petroleum products, ten supply equations for petroleum products, and 7 equations representing the structural relationships influencing the production of crude oil, and the identity. Many of the endogenous variables are simultaneously determined. Hence, both 2SLS and 3SLS was used to estimate the model. Parameters reported in this paper are 3SLS estimates. In the case of equations with only one endogenous variable, GLS estimates of parameters are generated. The data series was short, and the 3SLS and GLS estimates were usually substantially more efficient than the 2SLS and OLS.

II. The demand for crude petroleum and petroleum refined products.

Crude petroleum is used in the refinery processes, along with natural gas liquids, for the conversion to refined products. Estimation of these subdemands, therefore, can provide the derived demand for crude petroleum which is put into different uses, only after it has been refined.[2]

The following ten demand equations were estimated via GLS:

The per capita demand for gasoline (DGAS) is assumed to be a function of per capita real income (Y) and the following relative prices: the price of gasoline relative to the price of coal chemicals (PG/PCC), the price of middle distillates relative to the price of coal chemicals (PD/PCC) and the price of bituminous and lignite coal relative to the price of coal chemicals (PC/PCC).[3]

The per capita demand for coke (DCOKE) is assumed to be a function of per capita real income (Y) and the price of heavy fuels (used here as a proxy variable) relative to the price of coal chemicals (PH/PCC).

The per capita demand for residual fuel (DRES) is assumed to be a function of per capita real income (Y) and the price of middle distillates (used as a proxy variable) relative to the price of coal chemicals (PD/PCC), the price of gasoline relative to the price of coal chemicals (PG/PCC) and the price of bituminous and lignite relative to the price of coal chemicals (PC/PCC).

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[2]From the summation of the refined products, if the amounts of natural gas, lease condensate and expansion of liquids is subtracted, what remains is the required amounts of crude petroleum (Pagoulatos, 1975).

[3]The ten demands for refined products are specified in terms of relative prices by choosing the prices of products identified as competitive or complementary in the refinery process as well as the prices of coal and coal chemicals which are at a large extent competitive with most refined products.

The per capita demand for wax (DWAX) is assumed to be a function of per capita real income (Y) and the price of retail No. 2 (used here as proxy variable) relative to the price of coal chemicals (PR/PCC).

The per capita demand of distillate fuel (DDIS) is assumed to be a function of per capita real income (Y) and the price of light fuels (used as a proxy variable) relative to the price of coal chemicals (PL/PCC).

The per capita demand for road oil and asphalt (ROA) is assumed to be a function of per capita real income (Y) and the price of road oil and asphalt relative to the price of coal chemicals (PROA/PCC).

The per capita demand for liquified fuel (DLIQ) is assumed to be a function of per capita real income (Y),

the price of bituminous relative to the price of coal chemicals (PC/PCC) and the price of liquified fuel relative to the price of coal chemicals (PLF/PCC).

The per capita demand for still gas and petrochemical feedstock (DSGPT) is assumed to be a function of per capita real income (Y), the price of still gas and petrochemicals relative to the price of coal chemicals (PSP/PCC).

The per capita demand for kerosene is assumed to be a function of per capita real income (Y),

and a proxy representing the average of four prices of refined products relative to the price of coal chemicals (PA/PCC).

The per capita demand for lubricants (DLUB) is assumed to be a function per capita real income (Y), the price of lubricants relative to the price of coal chemicals (PLU/PCC) and a linear time trend (T).

The resulting estimates are as follows:[4]

Demand for Gasoline:

$$\begin{aligned}(1)\quad DGAS &= \underset{(0.81)}{0.81} + \underset{(0.0001)}{0.0013Y} + \underset{(10.4)}{2.9}\ PG/PCC \\ &\quad + \underset{(2.1)}{5.5}\ PD/PCC + \underset{(0.1)}{1.5}\ PC/PCC\end{aligned}$$

Demand for Coke:

$$(2)\quad DCOKE = \underset{(0.06)}{0.16} + \underset{(0.00001)}{0.00006Y} - \underset{(2.69)}{0.65}\ PH/PCC$$

Demand for Residual Fuel:

$$\begin{aligned}(3)\quad DRES &= -\underset{(0.5)}{1.0} + \underset{(0.00009)}{0.0002Y} - \underset{(1.3)}{0.5}\ PD/PCC \\ &\quad + \underset{(7.0)}{17.3}\ PG/PCC + \underset{(0.1)}{1.2}\ PC/PCC\end{aligned}$$

Demand for Wax:

$$(4)\quad DWAX = \underset{(0.01)}{0.04} + \underset{(0.000002)}{0.000003Y} - \underset{(0.24)}{0.73}\ PR/PCC$$

[4]Values in parenthesis represent standard errors.

Demand for Distillate Fuel:

$$\text{(5)} \quad DDIS = \underset{(0.2)}{-\ 1.05} + \underset{(0.0001)}{0.0008Y} - \underset{(0.12)}{0.19}\ PL/PCC$$

Demand for Road Oil and Asphalt:

$$\text{(6)} \quad DROA = \underset{(0.1)}{0.49} + \underset{(0.00001)}{0.0001Y} - \underset{(0.2)}{1.04}\ PROA/PCC$$

Demand for Liquified Fuel:

$$\text{(7)} \quad DLIQ = \underset{(.076)}{.092} + \underset{(0.00002)}{0.00018Y} + .042\ PC/PCC - \underset{(.41)}{.33}\ PLF/PCC$$

Demand for Still Gas and Petrochemical Feedstock:

$$\text{(8)} \quad DSGPT = \underset{(0.7)}{3.7} + \underset{(0.00012)}{0.00074Y} - \underset{(1.9)}{7.3}\ PSP/PCC$$

Demand for Kerosene:

$$\text{(9)} \quad DKERO = \underset{(.19)}{.86} + \underset{(0.00006)}{0.00050Y} - \underset{(0.2)}{1.3}\ PA/PCC$$

Demand for Lubricants:

$$\text{(10)} \quad DLUB = \underset{(.04)}{.15} + \underset{(0.00001)}{0.00004Y} - \underset{(.10)}{.45}\ PLU/PCC - \underset{(.0016)}{.0042T}$$

III. The domestic supply of crude petroleum and the demand for imports of crude petroleum.

The domestic supply of crude petroleum

In formulating a domestic supply of crude petroleum for the U.S., the theory of exhaustible stock resources is utilized in developing the assumptions regarding the responsiveness of joint stock companies that have ready access to the loan market (Adelman, Hotelling, McDonald, Nichols, Solow, Resources for the Future, Nordhaus).

The petroleum industry is assumed to be responding to the difference between the expected net price and the prevailing rate of return in alternative investments. The domestic supply of crude petroleum (S) is then assumed to be a function of a distributed lag: $1.05[.255(PRO_t - INT_t) + 0.205(PRO_{t-1} - INT_{t-1}) + 0.180\ (PRO_{t-2} - INT_{t-2}) + 0.180\ (PRO_{t-3} - INT_{t-3}) + 0.180(PRO_{t-4} - INT_{t-4})]$ where PRO is the profit rate of the petroleum industry and INT the prevailing interest rate. Furthermore, the domestic supply of crude (S) is assumed to be a function of the amount of reserves ($\hat{R}$), the domestic production expenditures in fixed assets (FCE), and the labor inputs (LAB) (Griliches).[5]

The per capita demand for imports of crude petroleum (assuming that the supply of imports is highly elastic at the prevailing prices) is assumed to be a function of the expected profitability (EX), the price of imports (MP), the refining capacity of the U.S. (RC) and the per capita demand for crude (PDC).

The price of crude (P) is assumed to be a function of the amount of reserves ($\hat{R}$), the per capita demand for crude (PDC), the rate of profit of the petroleum industry ($\hat{PRO}$) and the price of bituminous and lignite (PC).

The profit rate of the petroleum industry (PRO) is in turn assumed to be a function of the amount of reserves ($\hat{R}$), the labor input (LAB), the price of crude ($\hat{P}$) and the domestic supply of crude ($\hat{S}$).

The reserves of crude petroleum (R), are assumed to be a function of the price of crude ($\hat{P}$), the drilling activity (DRI) and the costs of drilling (CDRI).[6]

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[5]Reserves affect the domestic supply of crude petroleum through the required reserves production ratio of about eight (by taking into account the relative efficiency of recovery, which ranges from 35 to 40 percent, the ratio takes a value between 24 and 20).

[6]The probability of success of exploration has remained fairly constant over the sample period ranging between 40 and 41 percent.

The processing gain from the refinery process (GA) and the amount of natural gas liquids (NG) added to the crude petroleum base before obtaining the refined products are assumed to be a function of a time trend (T).

The number of exogenous variables in the total system substantially exceeds the number of observations. Predicted (or hat) values used as part of the simultaneous estimation procedure for the crude oil generation submodel were obtained by regressing each dependent variable on all exogenous variables appearing in the crude oil generation submodel. The 3SLS estimates of parameters in the submodel were obtained by applying GLS procedures to the equations of the submodel, using predicted rather than actual values for data on each endogenous variable appearing in the right hand side of the regression equation.

The sub-model is as follows:

Supply of Crude:

$$(11)\quad S = \underset{(64278)}{51974} + \underset{(19192)}{53442}\,EX + \underset{(1168)}{20353}\,FCE + \underset{(10)}{29}\,\hat{R} + \underset{(.69)}{.22}\,LAB$$

Imports of Crude:

$$(12)\quad M = \underset{(1.5)}{1.9} + \underset{(.05)}{.16}\,EX + \underset{(.04)}{.26}\,PDC - \underset{(1.5)}{6.3}\,RC - \underset{(0.4)}{1.1}\,MP$$

Price of Crude:

$$(13)\quad P = \underset{(0.2)}{4.1} + \underset{(.00011)}{.00004}\,\hat{R} - \underset{(.025)}{.035}\,PDC - \underset{(8.6)}{2.3}\,PBL - \underset{(.030)}{.048}\,\hat{PRO}$$

Profit Rate:

$$(14)\quad PRO = \underset{(20)}{52} + \underset{(.001)}{.004}\,\hat{R} + \underset{(.000005)}{.00003}\,LAB - \underset{(.0000013)}{.0000014}\,\hat{S} - \underset{(5.43)}{19.374}\,\hat{P}$$

Reserves:

$$(15)\quad R = \underset{(5132)}{1024} + \underset{(1472)}{1068}\,\hat{P} + \underset{(4.6)}{6.5}\,DRI - \underset{(1.5)}{5.0}\,CDRI$$

Processing Gain:

$$(16)\quad GA = \underset{(31694)}{-57057} + \underset{(3688)}{23816}\,T$$

Natural Gas:

$$(17)\quad NG = \underset{(6894)}{269408} + \underset{(802)}{26887}\,T$$

The crude oil generation submodel is linked to the supply of refined products submodel via the DISTR variable. The total amounts of liquids which occur as a result of the refining process (DISTR) is calculated by

$$(18)\quad DISTR = S + GA + M \times POP + NG$$

where values for S, GA, M and NG are generated from equations 11-17. Predicted (or hat) values for S, GA, M and NG are summed to produce a predicted DISTR. The predicted DISTR is then allocated to alternative products via a third system of equations - the supply of refined products submodel.

IV. The determination of the supply of refined petroleum products.

Ten supply equations, one for each refined product were postulated as a function of the total amount of refined products (i.e. crude petroleum, plus natural gas liquids and the expansion of liquids obtained by the refining processes), and the relative prices of competing product. (Pagoulatos, 1975).

The total amount of refined products is represented in the variable DISTR which is an argument of all the supply equations and the summation of the key coefficients of DISTR is constrained to one.

The supply of gasoline is also a function of the price of gasoline relative to the price of road oil and asphalt (PG/PROA). The supply of coke is also a function of the price of heavy fuel relative to the price of road oil and asphalt (PH/PROA). The supply of residual fuels is also a function of the price of middle distillates relative to the price of lubricants (PD/PLU). The supply of wax is also a function of the price of retail No. 2 relative to the price of lubricants (PR/PLU). The supply of distillate fuels is also a function of the price of light fuels relative to the price of middle distillates (PL/PD) and the average of four prices relative to the price of middle distillates (PA/PD). The supply of road oil and asphalt is also a function of the price of heavy fuel relative to the price of middle distillates (PH/PD) and the price of liquified fuels relative to the price of middle distillates (PL/PD). The supply of liquified fuels is also a function of the price of middle distillates relative to the price of liquified fuels (PD/PLF). The supply of still gas and petrochemical feedstock is also a function of the price of middle distillates relative to the price of light fuels (PD/PL). The supply of kerosene is also a function of the price of light fuels relative to the average of the four prices (PL/PA). The supply of lubricants is also a function of the price of lubricants relative to the price of retail No. 2 (PLU/PR) and the price of middle distillates relative to the price of retail No. 2 (PD/PR).

The resulting estimates are as follows:

$$(19)\quad SGAS = \underset{(65358)}{-\,306053} + \underset{(0.01)}{0.39}\ DISTR + \underset{(5568)}{66994}\ PG/PROA$$

$$(20)\quad SCOKE = \underset{(17556)}{-\,9985} + \underset{(0.002)}{0.013}\ DISTR + \underset{(3456)}{6192}\ PH/PROA$$

$$(21)\quad SRES = \underset{(33212)}{-\,74821} + \underset{(0.01)}{0.14}\ DISTR + \underset{(11208)}{107691}\ PD/PLU$$

$$(22)\quad SWAX = \underset{(1251)}{2172} + \underset{(0.0004)}{0.0006}\ DISTR - \underset{(136)}{93.95}\ PR/PLU$$

$$(23)\quad SDIS = \underset{(205660)}{-\,284708} + \underset{(0.01)}{0.11}\ DISTR + \underset{(2890220)}{2344448}\ PL/PD \underset{(1363965)}{-1210715}\ PA/PD$$

$$(24)\quad SROA = \underset{(8960)}{-\,10633} + \underset{(0.001)}{0.039}\ DISTR + \underset{(7593131)}{63522225}\ PH/PD - \underset{(77589)}{246122}\ PL/PD$$

$$(25)\quad SLIQ = \underset{(11733)}{-\,24697} + \underset{(0.004)}{0.038}\ DISTR - \underset{(9.79)}{9.13}\ PD/PLF$$

$$(26)\quad SSGPT = \underset{(80122)}{-\,26335} + \underset{(0.01)}{0.17}\ DISTR + \underset{(86.64)}{192.02}\ PD/PL$$

$$(27)\quad SKERO = \underset{(38013)}{94793} + \underset{(0.02)}{0.12}\ DISTR - \underset{(723.7)}{3326.7}\ PL/PA$$

$$(28)\quad SLUB = \underset{(1348)}{-\,3836} + \underset{(0.0008)}{0.005}\ DISTR - \underset{(1325.3)}{2884.8}\ PD/PR + \underset{(5864)}{26554}\ PLU/PR$$

Conclusions

We are convinced of the possibility of the econometric approach as a tool for describing the structure of the petroleum industry. Indeed, the bulk of the signs were as expected and the absolute value of each coefficient was usually larger than the corresponding standard error.

The estimated long-run income elasticities of the demands for refined products indicate that the demands for gasoline, coke, residual fuel, wax, road oil and asphalt, still gas and petrochemical feedstock and the demand for lubricants are relatively inelastic with respect to small variations in real income (the income elasticities are respectively: 0.44; 0.57; 0.22; 0.54; 0.69; 0.58; 0.63). The demands for distillate fuels, liquified fuels, and kerosene are relatively elastic with respect to small changes in real income with income elasticities of 2.38, 1.12 and 1.83 respectively.

The estimated long-run price demand elasticities of own prices relative to the price of coal chemicals are fairly small ranging from -0.0007 to -0.4, except in the case of kerosene which has an elasticity of -1.78.

The long-run elasticities of the supplies of refined products with respect to changes in total liquids ran through the refinery, were small, ranging from 0.0007 for still gas and petrochemical feedstock to 0.07 for gasoline and kerosene.

The imports of crude petroleum are relatively elastic to changes in the import price having an elasticity of 1.14. The domestic supply of crude has an elasticity of 0.64 with respect to changes in fixed capital expenditures and 0.03 with respect to changes in the amount of reserves. The reserves of crude petroleum, in turn, have a long-run price elasticity of 0.06.

A computerized quasi simulation model based on the parameters derived from the econometric model is planned which will make it possible to easily obtain projections for endogenous variables based on alternative assumptions with regard to values for exogenous variables.

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APPENDIX

The quantities demanded and 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.

Population figures used to compute per capita magnitudes were taken from the "Statistical Abstract of the United States" published by the U.S. Department of Commerce, U.S. Bureau of the Census.

Income figures were taken from the "Statistical Abstract of the United States" published by the U.S. Department of Commerce, U.S. Bureau of the Census.

Crude petroleum reserves are the proved reserves at the beginning of the year, 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 "Mineral 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 price of lubricants was taken from the "Minerals Yearbook" of the Bureau of Mines. The figures used represent the price of lubricants with 200 viscosity, at 100, 0-10 pour test, 96 V.I. at East Coast.

The refining capacity for crude petroleum was obtained from the "Annual Statistical Review" of the American Petroleum Institute and represents barrels per year of operating and operable capacity.

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[1] The weights assigned from the distributed lag were derived as follows. First the following equation was estimated (Griliches): $Y_t = B_0X_t + B_1X_{t-1} + B_2X_{t-2} + B_3X_{t-3} + B_4X_{t-4} + U_t$ and then the lag was specified as: $Y_t = B[W0Xt + W1Xt-1 + W2Xt-2 + W3Xt-3 = W4Xt-4] + U_t$ where $Wj = Bj/iBi$.

The wholesale price index and the consumer price index were 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 labor input used in the estimation of the supply of crude petroleum represents average hours worked weekly and is reported by the U.S. Department of Labor, Bureau of Labor Statistics, "Employment and Earnings".

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".

The quantities demanded and supplied of the petroleum refined products are expressed in 42 gallon barrels and were taken from the "Minerals Yearbook" of the Bureau of Mines.

The price of coal chemicals was computed as a per unit price from information about the value (f.o.b. mines) and quantity (short-tons) reported in the "Minerals Yearbook" of the Bureau of Mines.

The price of gasoline is the average price of regular grade gasoline (cents per gallon) at the service station including tax. It is reported in "Platt's Oil Price Handbook and Usage" by McGraw Hill, Inc.

The price of heavy fuels is a wholesale price (cents per gallon) and is reported in "Platt's Oil Price Handbook and Usage" by McGraw Hill, Inc.

The price of light fuels are wholesale prices (cents per gallon) and were taken from "Platt's Oil Price Handbook and Usage" which is published by McGraw Hill, Inc.

The price of road oil and asphalt, the price of Retail No. 2 oil, the price of middle distillates and the price of still gas and petrochemical feedstock were computed from "Platt's Oil Gram Price Service" and they represent dollars per barrel.

The price of liquified fuels is in cents per gallon and was taken from the "Mineral's Yearbook" of the Bureau of Mines. The price used is for programs in the New York Harbor/Philadelphia.

The average of four prices refers to the average between motor gasoline, aviation fuel, light fuel and heavy fuel and is expressed in dollars per barrel as reported by the "National Petroleum News Fact Issue".

The drilling activity represents number of wells drilled and the costs of drilling represent average cost per well. The figures are reported in the "Annual Statistical Review" of the American Petroleum Institute.