1-1-1978

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Occasional Paper #789
July 1978

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AN ECONOMETRIC STUDY OF THE RELATIONSHIP BETWEEN REFINED PRODUCT PRICES AND THE PRICE OF DOMESTIC AND IMPORTED CRUDE OIL

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This study describes the relationship between demand and supply of refined products and the demand for crude petroleum. Despite the growing importance of joint product industries, econometric attempts to characterize these technologies have met with only limited success (Vinod, Christensen, Jorgenson, Lau, and Griffin).

A few studies have provided econometric estimates for selected refined petroleum product categories. In this study all of the refined petroleum product categories are taken into consideration. Demands and supplies will be econometrically estimated. Adams and Griffin were the first to have attempted the estimation of the refining process through linear programming methods that were adapted to reflect the jointness in production. In this study the demand for crude oil is linked to the demands for refined products through a set of technological relationships and the price equations for each refined product is used to derive estimates of elasticities with respect to quantity supplied, price of domestic crude oil and price of imports.

Parameters of the structural relationships are estimated by two stage least squares, given the simultaneous framework within which all relationships were specified and the sample period performance and predictability of models are evaluated. The study is part of a larger model which is presented in Figure 1 with explanations of the variables in Table 1.

The Demand for Crude Petroleum

Crude petroleum is used in the refinery process, along with natural gas liquids, in order to produce refined products. The amounts of crude petroleum demanded can be derived from the estimation of the demands for refined products. Estimation of these demands is also important in determining the necessary mix of products to be refined at any given period of time. The following equation represents the technical relationship between crude and 10 major refined product categories:

$$\sum_{n=1}^{10} C_{nt} - NG_t - GA_t = D_t$$

where: C_t is the demand for each refined product category

NG_t is the amount of natural gas liquids used in the refining process

GA_t is the processing gain obtained from the expansion of fuels owing to such processes as reforming and cracking

D_t is the amount of crude petroleum demanded.

The processing gain represents the expansion of fuels owing to some refining processes such as reforming and cracking, and is the final component needed to determine the total amount of refined liquids. The quantity of processing gain (GA) increases in direct proportion to the amount of crude oil and lease condensate run through stills (S), and declines in proportion to the amount of natural gas liquids added for refining (NG). A nonlinear time trend (T^2) has been added to the estimating equation:

$$GA_t = f(NG_t, S_t, T^2)$$

The refinery process utilizes not only curde oil and lease condensate but also natural gas liquids. The amount of natural gas liquids added, because of economic and technological factors, has been steadily increasing over time. The quantity of natural gas liquids (NG) is positively related to the price of crude relative to the price of natural gas liquids (P/PNG) and a time trend (T^4):

$$NG_t = f(P_t/PNG_t, T^4)$$

The price of crude oil (P) is assumed to be positively related to the sales of refined products and the price of crude imports (PM), and negatively related to the price of natural gas (PNG) and the extent of refinery capacity utilization (REF). A distributed lag of the sales of refined products (C) rather than actual sales are used, because a sustained increase in sales of refined products must occur if the price of crude petroleum is to increase. Hence, the price equation of the model is:

$$P_t = f(PNG_t, PM_t, REF_t, C_t)$$

Demands for Refined Products

The demands for refined products (C_{nt}), are a function of their own prices (P_{nt}), and per capita real income (Y_t). In the demand for residual fuel, wax, road oil, asphalt, still gas and petrochemical feedstock, the price used is the relative price with respect to the price of coal chemicals (PCC_t), which constitute an important substitute. The number of oil burners ($OILB_t$), is directly related to the demand for distillate fuels; the average miles flown (MF_t), to the demand for kerosine; the output of the chemical industry ($CHEM_t$), to the demand for liquified fuels; the number, use and efficiency of cars, trubks, and fuses (AGV_t), to the demand for gasoline; and, the miles of paved roads (MUU_t), to the demand for road oil and asphalt.

Because of the sizeable sensitivity of heating uses to temperature, the petroleum industry's heating degree days variable (DD_t), was added in the demands for residual fuel, distillate fuel, kerosine, and liquified fuel.[1]

The available stock of oil consuming equipment is a principal determinant of the demand for any given petroleum product because it is generally not possible to substitute alternative fuels in machines designed to run on a specific fuel. Substitutions between fuels takes place in the long-run, as when equipment is put in place. In the short-run, economic factors determine the intensity with which equipment will be used. Therefore, short-run elasticities are expected to be less than long-run elasticities (in absolute value) because complete adjustment of consumer demand to changes in income and/or prices often takes years. To capture these elasticities the lagged dependent variable was introduced as an exogenous variable in the equation.

Import and End of the Year Stock Equations

Demands for imports were specified for those refined products for which imported amounts were more than 5 percent of the total supply. These products are the residual fuel and distillate fuel.[2] The import equations were specified as a function of the degree of utilization of domestic refining capacity (REF_t), the stocks at the end of the year (ST_t), and the domestic supply of the product.

Stocks equations were estimated for the residual fuel, distillate fuel, lubricants and kerosine. Stocks for these products constituted at least 3 percent of the total supply. Stocks at the end of the year (ST_t), are a function of the price of the product, the imported amounts and the domestic amounts of the product demanded during the year.

The Price of Refined Product

The price equation for each refined product is a function of the wellhead domestic price of crude petroleum (P_t), the price of imported crude (PM_t), the degree of domestic refining capacity utilization (REF_t), and the amount of the product refined domestically.

For the products for which stocks at the end of the year were estimated, they were also included in the respective price equations. An examination of the concentration ratios (CON_t) of the industry indicated that inclusion of this variable would be of importance in the kerosine price equations.[3]

All of the outputs are substitutes in production for each other given the jointness in the production function. However, the substitution responses are much stronger between some products than others (Griffin). Gasoline is a strong substitute with respect to distillate and petrochemical feedstocks because the raw material for gasoline, the light and heavy gas oils, can be either run through the catalytic cracking process to make gasoline or blended directly to produce distillate oil. Strong substitution between gasoline and petrochemical feedstocks is also to be expected since light naphthas, which are a feedstock to the catalytic reformer for gasoline production, are also a primary petrochemical feedstock.

The substitution channels between kerosine and other outputs are ones where all outputs exhibit fairly similar substitution responses. This phenomeon is due to the distillation property of kerosine which is between the gasoline and distillate cuts from the distillation unit, with a part, but not all of the kerosine serving as input in the manufacture of the two adjacent products.

Estimation and Validation of the Model

The econometric model consists of 10 demand equations for refined petroleum products, 10 price equations, 4 stock adjustment equations, 2 import equations, and 3 technological equations. The parameters of the structural relationships are simultaneously determined and are estimated by two-stage least squares.

The estimates of the parameters obtained are presented in Tables 2-6. The predictive ability was tested with favorable results. Theil coefficients were near zero and few turning points were missed.

Interpretation of Results

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

The fastest growing demands for refined products are for wax, liquified fuel, still gas and petrochemical feedstock followed by gasoline, coke and road oil and asphalt. The short-run price elasticities of demand were found to be lower than the long-run elasticities as it can be seen from Table 7. All of the short-run price elasticities of demand were low except for the still-gas and petrochemicals which was elastic. Due to the uses of the fuels and substitutability the demands for wax and kerosine become elastic in the long-run.

From the sign of the coefficients depicting the jointness in the production of refined products it can be seen that prolonged controls on gasoline prices would imply greater output of distillates and petrochemical feedstock. The same relationship would exist for kerosine and residual fuels.

Table 7 also presents the short and long run elasticities of the prices of domestically refined petroleum prices and the price of domestic and imported crude petroleum. It can be seen that increases in the domestic price of crude oil have had a larger effect on the prices of refined products than what increases in prices of imported crude have.

FOOTNOTES

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[1]Distillate fuel is primarily used for heating and is closely related to the number of oil burners in use and the weather. Residual fuel is used for heating and by public utilities in the production of electricity. Kerosine is used for heating (there is a decreasing use of kerosine for heating), as an industrial fuel and as fuel in commercial jet aircraft. Lubricating oil used for automotive consumption (about half) and the remainder is used in industry. Technological change over time has reduced the lubrication oil requirements.

[2]The imports of residual fuel are on the average about 12 percent of total supply and the imports of distillate fuel are about 7 percent.

FOOTNOTES cont.

[3] High concentrations ratios were found for kerosine, road oil and asphalt, coke and lubricants. However, only the concentration ratio for kerosine was varying over time.

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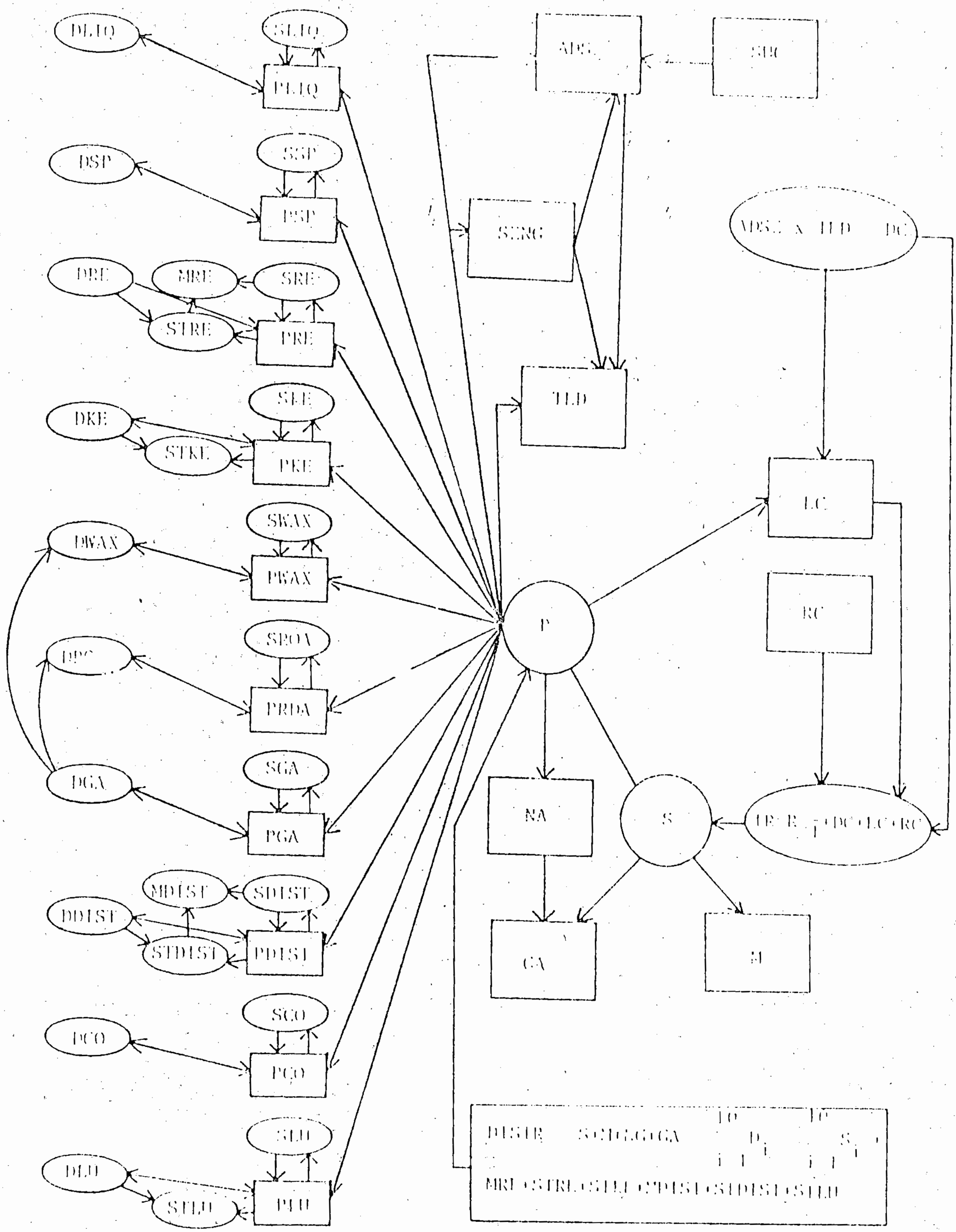

Figure 1. Simplified causal diagram of the model.

Table 1. List of variables

TED = number of new exploratory wells drilled (total productive and dry holes drilled each year).

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).

DC = new oil discoveries, measured in 42-gallon barrels.

EC = extensions of oil reserves, in 42-gallon barrels.

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

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

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

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

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

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

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

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

DGA = gasoline demanded (in thousands of 42-gallon barrels).

SGA = gasoline supplied (in thousands of 42-gallon barrels).

Table 1. -- continued.

PGA = price of gasoline (is the average price of regular grade gasoline, in cents per gallon at the service station including tax).

DCO = coke demanded (in thousands of 42-gallon barrels).

SCO = coke supplied (in thousands of 42-gallon barrels).

PCO = price of heavy fuel used as a proxy for the price of coke (a wholesale price in cents per gallon).

DRE = fuel demanded (in thousands of 42-gallon barrels).

SRE = residual fuel supplied (in thousands of 42-gallon barrels).

PRE = the price of residual fuel (in dollars per barrel) reported.

STRE = stocks at the end of the year (in thousands of 42-gallon barrels).

MRE = imports (in thousands of 42-gallon barrels).

DWAX = wax demanded (in thousands of 42-gallon barrels).

SWAX = wax supplied (in thousands of 42-gallon barrels).

PWAX = price of retail No. 2 oil used as a proxy for the price of wax (in dollars per barrel).

DDIST = distillate oils demanded (in thousands of 42-gallons barrels).

SDIST = distillate oils supplied (in thousands of 42 gallon barrels).

PDIST = price of light fuels used as a proxy for the price of distillate oils (is a wholesale price in cents per gallon).

Table 1. -- continued.

STDIST = stocks at the end of the year (in thousands of 42-gallon barrels).

MDIST = imports (in thousands fo 42-gallon barrels).

DROA = road oil and asphalt demanded (in thousands of 42-gallon barrels).

SROA = road oil and asphalt supplied (in thousands of 42-gallon barrels).

PROA = price of road oil and asphalt (in dollars per barrel).

DLIQ = liquified fuels demanded (in thousands of 42 gallon barrels).

Table 2. Two stage least squares estimates for the price of crude oil, the processing gain and the addition to national gas liquids.[a]

ADDITION OF NATURAL GAS LIQUIDS: $lnNG_t = 12.74 - 0.0976\ ln(P_t/PNG_t) + 0.332\ lnT^2$

$(0.583)\ (0.590)\qquad (0.026)$

PROCESSING GAIN: $lnGA_t = -36.49 - 3.93\ lnNG_t + 6.39\ lnS_t + 1.95\ lnT^2$

$(32.65)\ (2.61)\qquad (3.66)\qquad (0.46)$

PRICE OF CRUDE OIL: $P_t = -5.25 - 0.0000013\ PNG_t - 0.120\ REF_{t-1} + 0.0000015\ [1.1\ (0.65\ DISTR_{t-1}$

$(1.07)\ (0.0000008)\qquad (0.028)\qquad (0.00000008)$

$+0.35\ DISTR_{t-2})] + 0.702\ PM_t$

(0.102)

[a]Values in parenthesis are standard errors.

Table 3. Two Stage Least Squares Results for Distillate Fuels and Gasoline.

DEMAND FOR DISTILLATE FUELS --

$$DDIST = 0.592 - 0.764\ \widehat{PDIST} + 0.00011\ OILB - 0.00038DD + 0.730\ DDIST_{t-1}$$

(1.338) (0.327) (0.00008) (0.00015) (0.570)

IMPORTS OF DISTILLATE FUELS --

$$MDIST = 10{,}214.930 - 243{,}736.578\ REF + 0.681\ \widehat{STDIST} + 0.199\ \widehat{SDIST}$$

(69,965.558) (96,182.294) (0.188) (0.040)

PRICE OF DISTILLATE FUELS --

$$PDIST = -2.249 + 0.511\ \hat{P} + 0.542\ MPDIST + 0.472\ REF - 0.0000014\ \widehat{MDIST}$$

(2.287) (0.498) (0.512) (1.748) (0.0000035)

$$- 0.00000010\ \widehat{STDIST} + 0.00000060\ \widehat{SDIST} + 0.864\ PDIST_{t-1}$$

(0.00000037) (0.00000021) (0.725)

$$- 0.0000002\ \widehat{SKE} - 0.00000009\ \widehat{SGAS}$$

(0.0000002) (0.00000008)

STOCKS OF DISTILLATE FUELS --

$$STDIST = 851{,}816.802 - 393{,}196.128\ \widehat{PDIST} - 75{,}398.235\ \widehat{DDIST} + 1.033\ \widehat{MDIST}$$

(508,995.908) (311,163.294) (49,007.296) (0.467)

$$- 0.439\ STDIST_{t-1}$$

(0.108)

DEMAND FOR GASOLINE --

$$DGA = 4.724 - 1.17\ \widehat{PGA} + 0.0090\ AGV + 0.00065\ Y + 0.350\ DGA_{t-1}$$

(3.139) (1.05) (0.0042) (0.00018) (0.214)

PRICE OF GASOLINE --

$$PGA = -0.018 + 0.0088\ \hat{P} + 0.0000023\ PM - 0.010\ REF + 0.0000000012\ \widehat{SGA}$$

(0.202) (0.0043) (0.0000017) (0.163) (0.0000000003)

$$+ 1.049\ PGA_{t-1} - 0.00000001\ \widehat{SDIST} - 0.00000018\ \widehat{SP}$$

(0.176) (0.00000001) (0.00000007)

Table 4. Two-stage Least Squares Results for Still Gas, Petrochemical Feedstock, Kerosine and Coke.

DEMAND FOR STILL GAS-PETROCHEMICAL FEEDSTOCK --

$$DSP = -\ 0.25 - \underset{(0.496)}{0.637}\ \widehat{PSP}/PCC + \underset{(0.00032)}{0.00071}\ Y + \underset{(0.233)}{0.251}\ DSP_{t-1}$$

PRICE OF STILL GAS-PETROCHEMICAL FEEDSTOCK --

$$PSP = -\ \underset{(3.584)}{8.760} + \underset{(0.660)}{1.174}\ \hat{P} + \underset{(0.000049)}{0.000055}\ PM + \underset{(2.026)}{5.948}\ REF - \underset{(0.00000123)}{0.00000063}\ SSP + \underset{(0.320)}{0.862}\ PSP_{t-1} - \underset{(0.0000039)}{0.0000076}\ \widehat{SGAS}$$

DEMAND FOR KEROSINE --

$$DKE = \underset{(0.678)}{0.742} - \underset{(0.149)}{0.137}\ \widehat{PKE} + \underset{(0.0000073)}{0.0000081}\ MF - \underset{(0.00014)}{0.00043}DD + \underset{(0.348)}{0.774}\ DKE_{t-1}$$

PRICE OF KEROSINE --

$$PKE = -\ \underset{(6.780)}{9.322} + \underset{(1.247)}{1.611}\ \hat{P} + \underset{(0.000074)}{0.000044}\ PM + \underset{(3.678)}{4.415}\ REF + \underset{(0.052)}{0.135}\ CONKE - \underset{(0.000016)}{0.000024}\ \widehat{STKE} + \underset{(0.0000005)}{0.00000026}\ \widehat{SKE} - \underset{(0.454)}{0.221}\ PKE_{t-1} - \underset{(0.0000021)}{0.0000082}\ \widehat{SRE} - \underset{(0.0000001)}{0.0000009}\ \widehat{SDIST}$$

STOCKS OF KEROSINE --

$$STKE = \underset{(21{,}225.944)}{59{,}132.240} - \underset{(3{,}764.281)}{8{,}176.576}\ \widehat{PKE} - \underset{(7{,}200.885)}{11{,}391.853}\ \widehat{DKE} + \underset{(0.259)}{0.408}\ STKE_{t-1}$$

DEMAND FOR COKE --

$$DCO = \underset{(0.083)}{0.077} - \underset{(0.158)}{0.328}\ \widehat{PCO} + \underset{(0.000023)}{0.000033}\ Y + \underset{(0.289)}{0.460}\ DCO_{t-1}$$

PRICE OF COKE --

$$PCO = \underset{(15.221)}{4.139} + \underset{(3.001)}{3.033}\ \hat{P} + \underset{(0.000016)}{0.000092}\ PM - \underset{(7.180)}{12.174}\ REF + \underset{(0.00002)}{0.00012}\ \widehat{SCO} + \underset{(0.183)}{0.208}\ PCO_{t-1}$$

Table 5. Two Stage Least Squares Results for Residual Fuel Sand Lubricants.

DEMAND FOR RESIDUAL FUELS -- $DRE = -\ 0.736 - 0.763\ \hat{PRE}/PCC + 0.00021\ Y - 0.00013DD + 0.860\ DRE_{t-1}$

(0.734) (0,366) (0.00011) (0.00011) (0.180)

IMPORTS OF RESIDUAL FUELS -- $MRE = -\ 816{,}316.671 + 1{,}362{,}759.018\ REF + 2.497\ STRE - 0.697\ \hat{SRE}$

(2,418,314.329)(2,524,859.110) (1.896) (0.171)

PRICE OF RESIDUAL -- $PRE = 216.824 - 34.228\ \hat{P} + 0.0032\ PM - 39.704\ REF + 0.000036\ MRE + 0.00057\ ST\hat{RE}$

(102.547) (18.284) (0.0017) (57.597) (0.000018) (0.00016)

$+\ 0.000065\ \hat{SRE} - 0.725\ PRE_{t-1} - 0.000059\ \hat{SKE}$

(0.000059) (0.277) (0.000048)

STOCKS OF RESIDUAL FUELS --$STRE = -\ 21{,}923.917 + 1{,}148.521\ \hat{PRE} - 25{,}277.129\ \hat{DRE} - 0.032\ \hat{MRE} - 0.352\ STRE_{t-1}$

(46,370.296) (638.967) (9,738.202) (0.018) (0.255)

DEMAND FOR LUBRICANTS -- $DLU = 0.194 - 0.094\ \hat{PLU} + 0.000033\ Y - 0.0028\ T + 0.274\ DLU_{t-1}$

(0.116) (0.081) (0.000014) (0.0015) (0.083)

PRICE OF LUBRICANTS -- $PLU = 47.955 - 11.034\ \hat{P} + 11.725\ PM - 17.900\ REF + 0.00052\ \hat{SLU}$

(36.301) (8.001) (6.418) (21.545) (0.00031)

$-\ 17.079\ PLU_{t-1}$

(10.006)

STOCKS OF LUBRICANTS --$STLU = 33{,}281.469 - 2{,}014.095\ \hat{PLU} - 131{,}070.238\ DLU + 0.902\ STLU_{t-1}$

(7,073.896) (1,654.830) (27,013.144) (0.102)

Table 6. Two-stage Least Squares Results for Liquified Fuels, Wax, Road Oil, and Asphalt.

DEMAND OF LIQUIFIED FUELS -- $DLIQ = \underset{(0.145)}{0.256} - \underset{(0.011)}{0.013}\ PL\hat{I}Q + \underset{(0.00067)}{0.00075}\ CHEM - \underset{(0.000053)}{0.000063} DD + \underset{(0.260)}{0.617}\ DLIQ_{t-1}$

PRICE OF LIQUIFIED -- $PLIQ = -\underset{(0.2839)}{0.0081} + \underset{(0.0600)}{0.0028}\ \hat{P} + \underset{(0.0000022)}{0.0000015}\ PM + \underset{(0.123)}{0.114}\ REF - \underset{(0.00000025)}{0.00000044}\ SL\hat{I}Q + \underset{(2.026)}{0.113}\ PLIQ_{t-1}$

DEMAND FOR WAX -- $DWAX = \underset{(0.0134)}{0.0048} - \underset{(0.209)}{0.228}\ PWAX/PCC + \underset{(0.0006)}{0.0013}\ D\hat{G}A + \underset{(0.178)}{0.737}\ DWAX_{t-1}$

PRICE OF WAX -- $PWAX = -\underset{(14.496)}{10.844} - \underset{(0.780)}{0.825}\ \hat{P} + \underset{(0.00023)}{0.00010}\ PM + \underset{(3.336)}{7.720}\ REF - \underset{(0.00017)}{0.00021}\ SW\hat{A}X + \underset{(0.165)}{0.0990}\ PWAX_{t-1}$

DEMAND FOR ROAD OIL & ASPHALT -- $DROA = -\underset{(0.379)}{1.232} - \underset{(0.304)}{0.116}\ PR\hat{O}A/PCC + \underset{(0.00011)}{0.00041}\ MUU + \underset{(0.014)}{0.054}\ D\hat{G}A + \underset{(0.159)}{0.831}\ DROA_{t-1}$

PRICE OF ROAD OIL & ASPHALT -- $PROA = -\underset{(1.474)}{2.238} + \underset{(0.282)}{0.576}\ \hat{P} - \underset{(0.0000155)}{0.0000020}\ PM + \underset{(0.541)}{0.841}\ REF + \underset{(0.00000016)}{0.00000040}\ S\hat{R}OA + \underset{(0.318)}{0.699}\ PROA_{t-1}$