THE U.S. DEMAND FOR FOREIGN CRUDE OIL: A TRANSLOG APPROACH

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During the 1970s, the composition of U.S. imports of crude oil by country of origin changed substantially. Table 1 shows the value shares of the six major suppliers to the United States: Saudi Arabia, Iran, Libya, Nigeria, Indonesia, and Venezuela. Perhaps the most significant change is the large increase in the share of Middle East oil during the 1970s. Middle East oil has not always dominated U.S. imports; Saudi crude came to prevail during this period and Libya's share in total oil imports also rose significantly. The decline in the significance of Venezuelan crude is spectacular: in 1971 Venezuelan crude constituted 42 percent of total U.S. oil imports; this share had fallen to less than 6 percent by 1977. (Note that Mexico did not become a significant supplier to the United States until the 1980s.)

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The Journal of Energy and Development, Vol. 11, No. 2
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Table 1

U.S. IMPORTS OF CRUDE OIL: VALUE SHARES FOR THE SIX MAJOR OPEC SUPPLIERS, SELECTED YEARS 1971-1979
(in percent)

	1971	1973	1975	1977	1979
Middle East	32.15	37.31	42.87	55.52	54.50
Saudi Arabia	12.48	19.47	23.58	28.20	30.53
Iran	11.15	8.99	9.34	10.97	7.20
Libya	8.52	8.84	9.96	16.34	16.78
Other OPEC suppliers[a]	67.85	62.69	57.13	44.48	45.50
Nigeria	14.42	27.77	26.46	27.28	29.09
Indonesia	11.41	15.15	13.97	11.39	8.99
Venezuela	42.02	19.77	16.70	5.80	7.42

[a]OPEC = Organization of the Petroleum Exporting Countries.

Undoubtedly, these fluctuations in shares reflect changes in world demand and supply conditions. Oil production levels have varied greatly throughout the 1970s, both in absolute and in relative terms. Saudi output, for instance, more than doubled between 1971 and 1979, and that of Indonesia increased by over three-quarters. Venezuelan production, on the other hand, fell by one-third, and both Libyan and Iranian outputs declined by about one-quarter. There are important changes on the demand side as well. Most significantly, the U.S. share in world crude-oil imports almost trebled during the 1970s, while the European Economic Community's (EEC) share fell by about one-third; Japan's share increased for most of the period.[1]

Not surprisingly, these changes in world market conditions have led to significant changes in relative crude-oil prices. The absolute and relative price (relative to Saudi oil as the benchmark) of each crude is reported for selected years in table 2. All prices rose dramatically during the period, but not without substantial variations in relative prices. Libyan crude was consistently the most expensive Middle East oil. This reflects its low gravity and sulfur content and the proximity of Libyan fields to U.S. and European markets. Note, however, that the relative price of Libyan crude decreased during the 1970s. Other observable

[1]United Nations, *1979 Yearbook of International Trade Statistics* (New York: United Nations, 1980), table 331.

Table 2

CRUDE-OIL PRICES OF SIX MAJOR OPEC SUPPLIERS, SELECTED YEARS 1971-1979[a]
(in U.S. dollars per barrel)

	1971	1973	1975	1977	1979
Middle East					
Saudi Arabia	2.19	3.27	11.53	12.39	17.26
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
Iran	2.13	3.22	11.51	12.49	18.48
	(.97)	(.98)	(1.00)	1.01	1.07
Libya	3.23	5.15	15.32	14.00	19.91
	(1.47)	(1.57)	(1.33)	(1.13)	(1.15)
Other OPEC suppliers[b]					
Nigeria	3.05	4.80	12.17	14.56	20.72
	(1.39)	(1.47)	(1.06)	(1.18)	(1.20)
Indonesia	2.09	5.87	12.65	13.55	18.03
	(.95)	(1.80)	1.10	1.09	1.04
Venezuela	2.80	4.45	14.50	13.99	19.30
	(1.28)	(1.36)	(1.26)	(1.13)	(1.12)

[a]The numbers in parentheses are the prices relative to the price of Saudi crude.
[b]OPEC = Organization of the Petroleum Exporting Countries.

changes are the decrease in the relative price of Nigerian crude from the early to late 1970s, the steady increase in the relative price of Iranian crude, the decline in the relative price of Venezuelan crude in the late 1970s, and the significant variations in the price of Indonesian oil.

There is little doubt that the relative crude-oil prices to which American importers were subjected are a major factor in explaining the changing composition of U.S. oil imports.[2] It is, however, beyond the scope of this article

[2]An implicit assumption, not uncommon in demand theory, is that the differences in the characteristics of the oil across countries are reflected in the prices of the different crudes. Some of the important characteristics of crude oil are its gravity, sulfur content, pour point (temperature at which it flows), paraffin content, and where it is located (shipping distance from export point to the U.S. market). These characteristics do vary from country to country and across fields but are quite stable over time. K. S. Cuddington, "High Sulfur Content Associated with Largest Petroleum Reserves," *Oil and Gas Journal*, March 24, 1980, pp. 95-6. See T. Rifai, *The Pricing of Crude Oil: Economic and Strategic Guidelines for an International Energy Policy* (New York: Praeger Publishers, 1975) for a discussion of how prices reflect the different characteristics of the crudes.

to probe these price movements. Instead, assuming that U.S. oil importers are cost minimizers, we intend to explain the U.S. response to the observed price changes. More specifically, the purpose of this paper is to present a formal model of the U.S. demand for foreign crude oil by country of origin. We are particularly interested in determining the size of the price elasticities of U.S. demand for foreign crude by region of origin. Large elasticities would obviously go a long way in explaining the changing composition of U.S. imports when confronted with changes in relative prices. Although the focus of the article is on demand and we assume that U.S. importers act as price takers, allowance is made in our econometric work for the endogeneity of prices due to the simultaneity of demand and supply.

All of our estimates are derived in a system framework, i.e., all demand functions are specified simultaneously and estimated jointly using a system estimation technique. There are many advantages to a system approach: the demand functions are consistent with and derived from an underlying theoretical model; all the demand functions are consistent with one another; and the procedure yields coeffiencient estimates that are statistically more efficient than those obtained estimating the demand equations separately.[3] The paper also serves as an illustration of how multiple-stage budgeting can be applied in empirical work to facilitate the estimation of large demand systems. After presenting the model, empirical implementation will be discussed, followed by reporting and interpretation of estimation results, and closing with brief conclusions.

The Model

In this section we develop a simple model to explain the demand for foreign oil by country of origin. We assume that imports of crude can be consistently aggregated, and we specify the following aggregate demand function for foreign crude:

[3]Most authors who have estimated import demand functions by country of origin have specified and estimated all the demand equations independently of one another; see, for instance, H. S. Houthakker and S. P, Nagee, "Income and Price Elasticities in World Trade," *Review of Economics and Statistics*, 1969, pp. 111-25, and G. M. Grossman, "Import Competition from Developed and Developing Countries," *Review of Economics and Statistics*, 1982, pp. 271-80. For examples of a system approach to general import demand by country of origin, see U. R. Kohli, "Simultaneous Technologies and Demand and Supply Conditions in International Trade," *Empirical Economics*, 1979, pp. 235-46 and "U.S. Imports by Origin: A Systems Approach," *Weltwirtschaftliches Archiv*, 1985, pp. 741-55.

$$q = h(p/p_y, q_y) \tag{1}$$

where q and p are, respectively, the quantity and the price of aggregate imports of oil from the six major suppliers, p_y is the price of a domestic substitute, and q_y is a domestic activity variable. The partial derivative of $h(\cdot)$ with respect to the relative price is assumed negative, and the partial with respect to the activity variable assumed positive. Equation (1) can easily be derived from production theory if one views imported oil as an intermediate product in the domestic production process.[4]

The aggregate own price elasticity of demand for foreign oil (ε) is

$$\varepsilon \equiv \partial ln q/\partial ln p \,|\, dq_y = 0 \tag{2}$$

The slope properties of $h(\cdot)$ imply that $\varepsilon<0$.

The assumption that imports of oil can be aggregated implies that the domestic technology is separable between inputs of foreign oil and other domestic and foreign inputs. Assume that the demand for foreign oil is determined in several steps. First, the aggregate demand for foreign oil is determined; this step is described by equation (1). Next, the demand for oil from region i is determined conditional on aggregate imports of oil. Rather than trying to determine the demand for imports from all six countries simultaneously, we make the simplifying assumption that aggregate imports of oil can be disaggregated in two steps.[5] Importers first choose between two regions, the "Middle East" (Saudi Arabia, Iran, Libya) and the "Rest of the World" (Nigeria, Indonesia, Venezuela). It is only when the region of origin has been chosen that importers select the country where the oil is purchased (figure 1). This assumption is made partially for convenience since we found it impractical to estimate a system of six simultaneous and interdependent demand equations. Multicollinarity of the price variables would be a serious problem in a system of that size. The curvature conditions would almost certainly be violated, and the system would be too large to impose them.

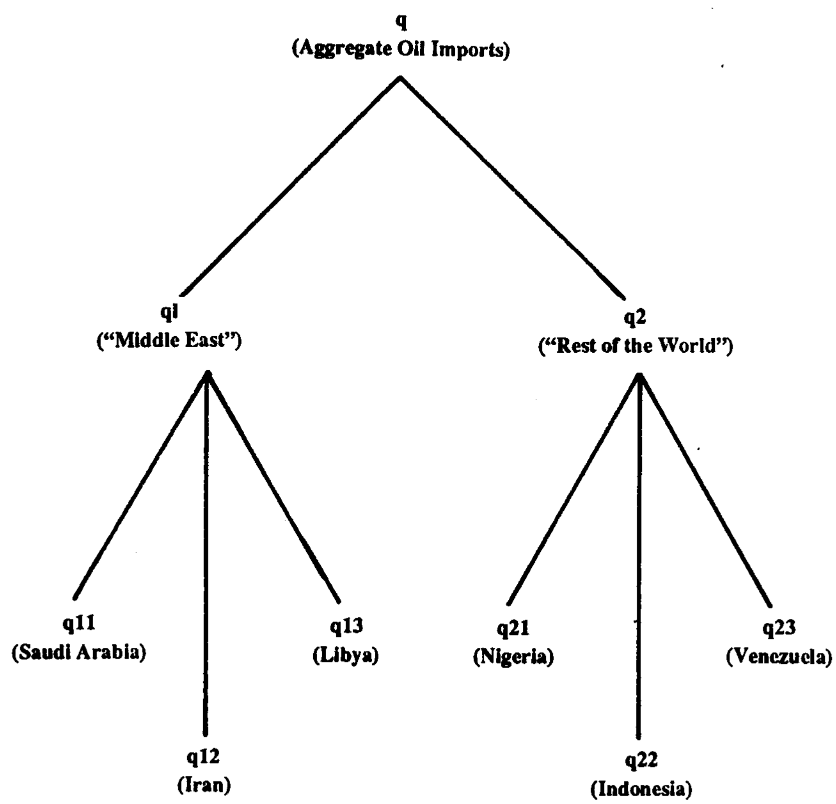
The separability assumption also has factual appeal. There are some fundamental differences in the physical characteristics of the crudes from the two regions. Middle East oil is generally higher in sulfur content and tends to be

4See U. R. Kohli, "U.S. Imports by Origin: A Systems Approach," for details.

5The general use of separability assumptions to simplify demand estimation is considered by I. F. Pearce, *A Contribution to Demand Analysis* (Oxford: Oxford University Press, 1964). For an application, see M. A. Fuss, "The Demand for Energy in Canadian Manufacturing," *Journal of Econometrics*, 1977, pp. 89-116.

Figure 1

DISAGGREGATION SCHEME



heavier.[6] The relative political instability of the Middle East during our sample period (e.g., the 1973 Arab-Israeli war and the revolution in Iran) also provides justification for differential treatment.

Let aggregate imports of oil be given by the following aggregation relationship:

$$q = f(q_1, q_2) \tag{3}$$

[6]For more details on the characteristics of different crudes, see K. S. Cuddington, op. cit.; T. Rifai, op. cit.; and J. C. McCaslin, editor, *International Petroleum Encyclopedia* (Tulsa: The Petroleum Publishing Co., 1976).

where q_i is the quantity index for oil imports from region i (i=1, 2; region 1 is the Middle East, and region 2 is the Rest of the World). The variable q is the quantity index for foreign oil imports. The function f(·) is assumed to be monotonically increasing, linearly homogeneous, and concave. Assuming cost minimization, the aggregation relationship can also be described by the following cost function:

$$C(p_1,p_2,q) \equiv \min_{q_1,q_2} \{p_1q_1 + p_2q_2 : f(q_1, q_2)\geq q;\ q_1q_2\geq 0\} \qquad (4)$$

for p_1, $p_2>0$, and $q\geq 0$; where p_i is the price index for oil from region i(i=1, 2). Given the properties of f(·), then C(·) is nondecreasing, linearly homogeneous, and concave in prices.[7] It is also monotonically increasing and linearly homogeneous in the quantity of aggregate imports of oil. This last property implies that C(·) can be written:

$$C(p_1,p_2,q) = c(p_1,p_2)q \qquad (5)$$

where c(·) is a unit cost function and is equal to p, the price index for foreign oil. The function c(·) is nondecreasing, linearly homogeneous, and concave.

The cost minimizing demand for imports from region i (i=1, 2) can be obtained by differentiation of equation (5), a result known as Shephard's lemma:[8]

$$q_i = \partial C(\cdot)/\partial p_i = q\partial c(\cdot)/\partial p_i \qquad (6)$$

These demand functions are conditional on q, the quantity of aggregate oil imports.

The elasticity of demand for oil from region i with respect to the price of oil from region j (i,j=1,2), conditional on q, is therefore:

$$\varepsilon^i_j \equiv \partial \ln q_i/\partial \ln p \Big|_{dq=0} = s_j \frac{c(\cdot)_{ij}}{c_i\, c_j} \qquad i,j=1,2 \qquad (7)$$

where $c_i = \partial c(\cdot)/\partial p_i$, $c_{ij} = \partial^2 c(\cdot)/(\partial p_i \partial p_j)$, and s_j is the share of imports of oil from region j in total imports. The derivation of equation (7) involves the repeated use of Shephard's lemma, equation (6).

[7]See W. E. Diewert, "Applications of Duality Theory," in *Frontiers of Quantitative Economics 2*, eds. Intriligator and Kendrick (Amsterdam: North Holland, 1974).

[8]R. W. Shepherd, *Cost and Production Functions* (Princeton: Princeton University Press, 1953).

ε^i_j is a conditional elasticity since it is defined for a given q. Total price effects (conditional on q_y) are given by:

$$\varepsilon^i_j{}^* = \varepsilon^i_j + s_j \varepsilon \qquad (8)$$

The concavity of c(·) implies that $\varepsilon^i_i \leq 0$; furthermore, given that $\varepsilon<0$ by assumption, it can be seen from equation (8) that $\varepsilon^i_i{}^* < \varepsilon^i_i$, hence $|\varepsilon^i_i{}^*| > |\varepsilon^i_i$ (i = 1,2). That is, the own price elasticity of a region is greater when there are more opportunities to substitute away from foreign oil.

Let the aggregation function for each region be:

$$q_i = f^i(q_{i1}, q_{i2}, q_{i3}) \qquad i=1,2 \qquad (9)$$

where q_{ih} (i=1,2; h=1,2,3) is imports from country h in region i. Countries are labeled as follows: Saudi Arabia (11), Iran (12), Libya (13), Nigeria (21), Indonesia (22), and Venezuela (23). The variable q_i is again the quantity index for imports of oil from region i. The f^i(·)'s are assumed monotonically increasing, linearly homogeneous, and concave. Assuming cost minimization, the aggregation relationships can be described by the following cost functions:

$$C^i(p_{i1},p_{i2},p_{i3},q_i) \equiv \min_{q_{i\cdot}} \{\sum_{h=1}^{3} p_{ih}q_{ih}: f^i(q_{i\cdot}) \geq q_i, q_{i\cdot} \geq 0\} \qquad i=1,2 \qquad (10)$$

where p_{ih} is the price of oil from country h in region i, and $q_{i\cdot} = (q_{i1}\ q_{i2}\ q_{i3})'$. Given the properties of f^i(·), C^i(·) is nondecreasing, linearly homogeneous, and concave in prices. Furthermore, it is linearly homogenous in q_i; hence it can be written:

$$C^i(p_{i1},p_{i2},p_{i3},q_i) = c^i(p_{i1},p_{i2},p_{i3})q_i \qquad i=1,2 \qquad (11)$$

The function c^i(·) is the unit cost function and is equal to p_i, the price index for oil from region i. It is nondecreasing, linearly homogeneous, and concave in the prices of the crudes from that region's countries.

The cost-minimizing demand for oil from country (i,h) can be obtained by differentiation (i.e., Shephard's lemma).

$$q_{ih} = \partial C^i(\cdot)/\partial p_{ih} = q_i \partial c^i(\cdot)/\partial p_{ih} \qquad i=1,2 \quad h=1,2,3 \qquad (12)$$

The elasticity of demand for oil from country (i,h) with respect to the price of oil from country (i,k), conditional on qi is therefore,

$$\varepsilon^{ih}_{ik} \equiv \partial ln q_{ih}/\partial ln p_{ik}\Big|_{dq_i=0} = s_{ik}\frac{c^i(\cdot)\, c^i_{hk}}{c^i_h\, c^i_k} \qquad i=1,2 \quad h,k=1,2,3 \qquad (13)$$

where s_{ik} is the share of imports of oil from country k in total imports of oil from region i, $c^i_h = \partial c^i(\cdot)/\partial p_{ih}$, and $c^i_{hk} = \partial^2 c^i(.)/\partial p_{ih}\partial p_{ik}$).

Each elasticity ε^{ih}_{ik} is a partial elasticity since it is defined for a given q_i (i=1,2). Note also that these elasticities are only defined for countries in the same region. For instance, a change in the price of Nigerian crude will have no affect on the demand for Saudi crude if imports from the Middle East are held constant.

It is, of course, of interest to get estimates of each country's total price elasticity and estimates of country elasticities across regions. If q_i (i=1,2) and q are allowed to vary, the total elasticities, conditional on domestic activity (q_y) can be obtained by totally differentiating equation (12), and making use of (2) and (6):

$$\varepsilon^{ih}_{jk}{}^{*} = \partial ln q_{ih}/\partial ln p_{jk}\Big|_{dq_y=0} = \varepsilon^{ih}_{jk} + s_{jk}\,\varepsilon^{i}_{j} + s_{jk}s_j\varepsilon = \varepsilon^{ih}_{jk} + s_{jk}\varepsilon^{i}_{j}{}^{*} \qquad (14)$$

$$i,j=1,2;\ h,k=1,2,3$$

where $\varepsilon^{ih}_{jk} = 0$ for $i \neq j$. The concavity of $c^i(\cdot)$ implies that $\varepsilon^{ih}_{ih} \leq 0$. Given this, equation (14) implies that $|\varepsilon^{ih}_{ih}{}^{*}| > |\varepsilon^{ih}_{ih}|$.

Once functional forms are specified for C(.) and $C^i(.)$, the demand functions, equations (6 and (12), can be derived. The data can then be used to jointly estimate each system of demand equations subject to the restrictions suggested by theory: homogeneity, symmetry, and additivity. The resulting empirical estimates of the cost functions can then be used to get estimates of the partial [equation (7) - equation (8)] and total [equation (13) - equation (14)] price elasticities of demand.

Empirical Implementation

We now need functional forms for the unit cost functions, equations (5) and (11). Forms are needed that are flexible enough to not constrain *a priori* the signs or the magnitudes of the price elasticities. One such functional form is the Translog.[9] In the case of equation (5) the Translog is

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[9]L. R. Christensen, D. W. Jorgenson, and L. J. Lau, "Transcendental Logarithmic Production Frontiers," *Review of Economics and Statistics*, 1973, pp. 28-45.

$$ln\, c = \alpha_0 + \Sigma_i \alpha_i ln p_i + 1/2 \Sigma_i \Sigma_j \gamma_{ij} ln p_i, ln p_j \qquad i,j=1,2 \qquad (15)$$

where $\Sigma\alpha_i = 1$, $\gamma_{ij} = \gamma_{ji}$, and $\Sigma_j \gamma_{ij} = 0$, for all i. Similarly, for equation (11) it is

$$lnc^i = \beta^i_o + \Sigma_h \beta^i_h\, lnp_{ih} + \Sigma_h \Sigma_k\, \phi^i_{hk} lnp_{ih} lnp_{ik} \qquad i=1,2;\ hk=1,2,3 \qquad (16)$$

where $\Sigma_h \beta^i_h = 1$, $\phi^i_{hk} = \phi^i_{kh}$, and $\Sigma_k\, \phi^i_{hk} = 0$, for all h (i=1,2).

The demand functions, equations (6) and (12) can be derived in share form by logarithmic differentiation of equations (15) and (16):

$$s_i = \alpha_i + \Sigma_j\, \gamma_{ij}\, lnp_j \qquad i=1,2 \qquad (17)$$

$$s_{ih} = \beta^i_h + \Sigma_k\, \phi^i_{hk}\, lnp_k \qquad i=1,2;\ h=1,2,3 \qquad (18)$$

where $s_i \equiv p_i q_i/(p_1 q_1 + p_2 q_2)$ and $s_{ih} \equiv p_{ih} q_{ih}/(\Sigma_k\, p_{ik}\, q_{ik})$.

The conditional and total price elasticities can then be easily calculated. In the case of equation (7):

$$\varepsilon^i_j = \begin{cases} (\gamma_{ii} + s^2_i - s_i)/s_i & \text{for } i=j \\ (\gamma_{ij} + s_i s_j)/s_i & \text{for } i\neq j \end{cases} \qquad i,j=1,2 \qquad (19)$$

In the case of equation (13):

$$\varepsilon^{ih}_{ik} = \begin{cases} (\phi^i_{hh} + s_{ih}^2 - s_{ih})/s_{ih} & \text{for } h=k \\ (\phi^i_{hk} + s_{ih} s_{ik})/s_{ih} & \text{for } h\neq k \end{cases} \qquad i=1,2;\ \ h,k=1,2,3 \qquad (20)$$

The total elasticities of equations (8) and (14) are then calculated for given values of ε.

It is assumed that equations (15) and (16) are exact representations of reality, but that equations (17) and (18) are random due to errors in optimization. We specify a vector of additive disturbances and assume that these disturbances are identically distributed normal random vectors with mean vector zero. Because the shares sum to one at each level of aggregation, the variance-covariance matrix is singular. Therefore, estimation requires that we omit one share equation at each level of aggregation. The choice is arbitrary because the maximum likelihood estimates of the coefficents are independent of which equation is omitted at each level of aggregation.

Although our theoretical model assumes that U.S. oil importers act as price takers, one must allow for the fact that prices are, in fact, not necessarily exogenous from a statistical viewpoint. Of course, one could argue that, for most of the 1970s, oil prices were set by the Organization of the Petroleum Exporting Countires (OPEC), with little consideration for U.S. demand conditions. On the other hand, it remains true that the United States accounts for a substantial share of the world oil market, and therefore a shift in U.S. demand will undoubtedly have some effect on world oil prices. To allow for this and to avoid any charges of bias due to the simultaneity of demand and supply, we estimate the model by iterative three-stage least squares,[10] which is numerically equivalent to maximum likelihood. The instruments which we use to endogenize prices are the production levels in the six foreign countries under consideration. However, we have verified that our main results remain largely the same if prices are treated instead as exogenous.

The yearly price data for the 1971-1979 period are from the United Nations.[11] The import data (in thousands of barrels per year) and the production data (in thousands of barrels per day) are from the American Petroleum Institute.[12]

Empirical Results

The parameter estimates for equations (15) and (16) are reported in table 3; standard errors are given in parentheses. As noted earlier, estimation requires that one share equation be dropped; from each system, the choice being arbitrary in that the parameter estimates are independent of which share is omitted. For the regional system, the share for the Rest of the World was dropped; in the Middle East system, Libya's share was dropped, and in the Rest of the World's system, Venezuela's share was dropped. Initially cost function, equation (15), did not fulfill the required curvature conditions so concavity was imposed using the procedure suggested by Lau[13]. Both cost functions, equation (16), satisfy all regularity conditions for all observations.

Conditional price elasticities for selected years are reported in table 4 for all

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[10]See E. R. Berndt, B. H. Hall, R. E. Hall, and J. A. Hausman, "Estimation and Inferences in Nonlinear Structural Models," *Annals of Economic and Social Measurement*, 1974, pp. 653-65.

[11]United Nations, *1979 Yearbook of World Energy Statistics* (New York: United Nations, 1981), table 58.

[12]American Petroleum Institute, *Basic Petroleum Data Book: Petroleum Industry Statistics* (Washington, D.C.: American Petroleum Institute, 1981), section 14, table 4a and section 6, table 3.

[13]L. U. Lau, "Applications of Duality Theory," in *Frontiers of Quantitative Economics 2*, eds. Intriligator and Kendrick (Amsterdam: North Holland, 1974).

three cost functions. They were calculated using equations (19) and (20). The

Table 3

PARAMETER ESTIMATES[a]

	i=1		i=2
α_1		.40000	
		(.12695)	
γ_{11}		.24000	
		(.62488)	
β^i_1	.42971		.47602
	(.04610)		(.08940)
β^i_2	.36118		.25690
	(.06399)		(.07877)
ϕ^i_{11}	.00925		-.05837
	(1.22534)		(.47843)
ϕ^i_{12}	.32010		-.06293
	(1.05370)		(.23847)
ϕ^i_{22}	-.84098		.07146
	(.95281)		(.23050)

[a]The numbers in parentheses are the standard errors.

conditional price elasticities across regions (ε^1_2 and ε^2_1) are positive, suggesting that Middle East crude and crude from the Rest of the World are pure substitutes (although the effect is very weak), which they must be in a two-good situation. However, the estimates reported in table 5 suggest that oil from the two regions are not gross substitutes. As expected, all the own conditional elasticities are negative, and, with the exception of Iran (ε^{12}_{12}), they seem to be fairly stable over time. The own price elasticities vary significantly from -0.453 for Indonesian crude to -3.155 for Iranian crude (1971 estimates); the differences presumably reflect the different characteristics of the respective crudes. It is of interest that the estimated own price elasticity of the demand for Iranian crude rose during the 1970s and that this rise paralleled the increasing political instability in the country, an instabilty to which the United States was particularly sensitive. This is what theory would suggest. A significant change in the characteristics of a country or its exports should lead to a significant change in the price elasticity of demand for that country's exports.

The estimates in table 4 suggest that there are large substitution possibilities between Iranian and Saudi crude, on the one hand, and between Iranian and Libyan crude on the other. This result reflects the fact that Middle East crude is

Table 4

CONDITIONAL PRICE ELASTICITIES, SELECTED YEARS 1971-1979

	1971	1973	1975	1977	1979
A-Conditional interregional price elasticities					
$\varepsilon^i_j = \partial ln q_i / \partial ln p_j \mid_{dq=0}$					
(1="Middle East," 2="Rest of World")					
ε^1_1	-.014	.000	.019	-.016	-.020
ε^1_2	.014	.000	.019	.016	.017
ε^2_1	.011	.000	.017	.013	.014
ε^2_2	-.011	.000	-.017	-.013	-.014
B-Conditional intra-"Middle East" price elasticities					
$\varepsilon^{1h}_{1k} = \partial ln q_{1h} / \partial ln p_{1k} \mid \mid_{dq_1=0}$					
(11=Saudi Arabia, 12=Iran, 13=Libya)					
ε^{11}_{11}	-.532	-.549	-.491	-.437	-.424
ε^{11}_{12}	1.053	1.106	.914	.754	.701
ε^{11}_{13}	-.521	-.557	-.423	-.318	-.277
ε^{12}_{11}	1.396	1.316	1.716	2.446	3.048
ε^{12}_{12}	-3.155	-2.967	-3.959	-5.822	-7.411
ε^{12}_{13}	1.759	1.651	2.243	3.376	4.363
ε^{13}_{11}	-1.083	-1.145	-0.834	-0.609	-0.495
ε^{13}_{12}	2.757	2.852	2.355	1.997	1.796
ε^{13}_{13}	-1.675	-1.707	-1.521	-1.387	-1.301

(continued)

Table 4 (continued)

CONDITIONAL PRICE ELASTICITIES, SELECTED YEARS 1971-1979

	1971	1973	1975	1977	1979
C-Conditional intra-"Rest of the World" price elasticities					
$\varepsilon 2h_{2k} = \partial ln q_{2h}/\partial ln p_{2k} \mid dq_2 = 0$					
(21=Nigeria, 22=Indonesia, 23=Venezuela)					
$\varepsilon 21_{21}$	-.603	-.647	-.596	-.620	-.619
$\varepsilon 21_{22}$	.093	.125	.121	.111	.106
$\varepsilon 21_{23}$	.510	.522	.475	.509	.513
$\varepsilon 22_{21}$	.219	.231	.258	.232	.227
$\varepsilon 22_{22}$	-.453	-.465	-.463	-.461	-.460
$\varepsilon 22_{23}$	.234	.234	.205	.229	.233
$\varepsilon 23_{21}$	.955	.930	1.022	.955	.948
$\varepsilon 23_{22}$	.184	.225	.208	.205	.201
$\varepsilon 23_{23}$	-1.140	1.155	-1.229	-1.160	-1.149

relatively homogeneous in terms of characteristics (particularly sulfur content).[14] However, there is also some evidence that Saudi and Libyan crudes are complements in production. This could be due to the substantial difference in the gravity of the two crudes (Libyan is much lighter than most Saudi oil). This complementarity is also apparent in table 5. One would expect two crudes to be complements if, because of their respective characteristics, they are consistently blended to produce a composite crude that is more suited than each of the individual crudes to fulfill the refining and production requirements of the U.S. economy. One would also expect two crudes to be complements if they each produce refined products that are complementary intermediate inputs in U.S. production. Regarding the Rest of the World group (table 4), we find that the

[14]See K. S. Cuddington, op. cit.

substitution possibilities are weak between all three crudes considered, particularly between Nigerian and Indonesian crudes. This result might be due to the fact that all three crudes originate from very distinct geological basins.

All the elasticities reported in table 4 are conditional elasticities, i.e., they are conditional on the volume of imports from the region under consideration. Total price elasticities between the two regions and for each of the six countries are reported in table 5. They were calculated using equations (8) and (14). A value of $\varepsilon \equiv \partial \ln q / \partial \ln p \,|\, dq_{y=0} = -0.500$ was assumed. This value of ε was chosen on the assumption that the aggregate demand for foreign oil is relatively price inelastic. The first thing to note in table 5 is that, whereas the conditional elasticities estimates in table 4 suggested that Middle East crude and Rest of the World crude were pure substitutes, the estimated total elasticities suggest that they are gross complements. This is consistent with our earlier point that the two types of crudes tend to be different. This complementarity across regions is also reflected in the consistently negative country cross elasticities between nations in the different regions. ($\varepsilon^{ih}{}_{jk}{}^{*}$, $i \neq j$). (Note that $\varepsilon^{ih}{}_{jk}{}^{*}$, $i \neq j$ necessarily has the same sign as $\varepsilon^{i}{}_{j}{}^{*}$, $i \neq j$.)[15] Complementarity across regions therefore follows from equation (8) and the fact that our choice of $\varepsilon(-0.500)$, although small in absolute value, is nevertheless large enough to offset the small positive values of $\varepsilon^{1}{}_{2}$ and $\varepsilon^{2}{}_{1}$.

The magnitude and sign of the cross elasticities between countries in the different regions ($\varepsilon^{ih}{}_{jk}{}^{*}$, $i \neq j$) do not depend on the choice of country h, i.e., $\varepsilon^{ih}{}_{jk}{}^{*}$,$= \varepsilon^{im}{}_{jk}{}^{*}$, $i \neq j$. This follows from equation (14) and the fact that $\varepsilon^{ih}{}_{jk}=0$ if $i \neq j$. Intuitively, an increase in the price of crude in country jk only influences the demand for crude in country ih ($i \neq j$) through its effect on the total demand for crude from region i.

As expected, the total elasticities tend to be more negative than the conditional elasticities. Like the conditional elasticities, they vary significantly across countries, but are fairly stable over time, with Iran again being the exception. The U.S. demand for Iranian crude became more and more responsive to changes in its price during the 1970s. This, combined with the consistently increasing relative price of Iranian crude, explains the decrease in Iran's share of U.S. oil imports during the decade. The increase in the shares of Libya and Saudi Arabia can be explained, in part, by the fact that their prices during the period fell relative to the price of Iranian crude and that their estimated cross elasticities ($\varepsilon^{11}{}_{12}{}^{*}$ and $\varepsilon^{13}{}_{12}{}^{*}$) suggest that they are both strong substitutes for Iranian crude.

[15]See equation (14) and note that $\varepsilon^{ih}{}_{jk}=0$ if $i \neq j$.

Table 5

TOTAL PRICE ELASTICITIES, SELECTED YEARS 1971-1979[a]
(11=Saudi Arabia, 12=Iran, 13=Libya, 21=Nigeria, 22=Indonesia, 23=Venezuela)

	1971	1973	1975	1977	1979
Interregional					
$\varepsilon 1_1{}^*$	-.234	-.200	-.254	-.240	-.243
$\varepsilon 1_2{}^*$	-.266	-.300	-.246	-.260	-.257
$\varepsilon 2_3{}^*$	-.208	-.200	-.218	-.211	-.212
$\varepsilon 2_2{}^*$	-.292	-.300	-.282	-.289	-.288
Saudi Arabia					
$\varepsilon 11_{11}{}^*$	-.637	-.635	-.616	-.568	-.560
$\varepsilon 11_{12}{}^*$	.974	1.034	.848	.714	.670
$\varepsilon 11_{13}{}^*$	-.571	-.599	-.486	-.386	-.353
$\varepsilon 11_{21}{}^*$	-.002	-.000	-.003	-.002	-.002
$\varepsilon 11_{22}{}^*$	-.001	-.000	-.001	-.001	-.001
$\varepsilon 11_{23}{}^*$	-.001	-.000	-.001	-.001	-.001
Iran					
$\varepsilon 12_{11}{}^*$	1.291	1.230	1.591	2.315	2.912
$\varepsilon 12^*{}_{12}{}^*$	-3.234	-3.039	-4.026	-5.863	-7.442
$\varepsilon 12_{13}{}^*$	1.709	1.609	2.180	3.307	4.287
$\varepsilon 12_{21}{}^*$	-.002	-.000	-.003	-.002	-.002
$\varepsilon 12_{22}{}^*$	-.001	-.000	-.001	-.001	-.001
$\varepsilon 12_{23}{}^*$	-.001	-.000	-.001	-.001	-.001

(continued)

[a] $\varepsilon ih_{jk}{}^* = \partial ln q_{ih} / \partial ln p_{jk} \big|_{dq=0}$

Table 5 (continued)

TOTAL PRICE ELASTICITIES, SELECTED YEARS 1971-1979[a]
(11=Saudi Arabia, 12=Iran, 13=Libya, 21=Nigeria, 22 = Indonesia, 23=Venezuela)

	1971	1973	1975	1977	1979
Libya					
$\varepsilon 13_{11}{}^*$	-1.188	-1.231	-.958	-.741	-.631
$\varepsilon 13_{12}{}^*$	2.678	2.780	2.288	1.956	1.765
$\varepsilon 13_{13}{}^*$	-1.725	-1.749	-1.584	-1.456	-1.377
$\varepsilon 13_{21}{}^*$	-.002	-.000	-.003	-.002	-.002
$\varepsilon 13_{22}{}^*$	-.001	-.000	-.001	-.001	-.001
$\varepsilon 13_{23}{}^*$	-.001	-.000	-.001	-.001	-.001
Nigeria					
$\varepsilon 21_{11}{}^*$	-.107	-.095	-.112	-.105	-.106
$\varepsilon 21_{12}{}^*$	-.045	-.051	-.053	-.050	-.049
$\varepsilon 21_{13}{}^*$	-.057	-.053	-.052	-.056	-.057
$\varepsilon 21_{21}{}^*$	-.752	-.789	-.742	-.764	-.763
$\varepsilon 21_{22}{}^*$	-.057	-.018	-.025	-.033	-.037
$\varepsilon 21_{23}{}^*$	.361	.379	.329	.365	.370
Indonesia					
$\varepsilon 22_{11}{}^*$	-.107	-.095	-.112	-.105	-.106
$\varepsilon 22_{12}{}^*$	-.045	-.051	-.053	-.050	-.049
$\varepsilon 22_{13}{}^*$	-.057	-.053	-.052	-.056	-.057
$\varepsilon 22_{21}{}^*$	.070	.088	.112	.088	.084
$\varepsilon 22_{22}{}^*$	-.602	-.608	-.609	-.605	-.604
$\varepsilon 22_{23}{}^*$	.085	.091	.059	.086	.089

(continued)

Table 5 (continued)

TOTAL PRICE ELASTICITIES, SELECTED YEARS 1971-1979[a]
(11=Saudi Arabia, 12=Iran, 13=Libya, 21=Nigeria, 22 = Indonesia, 23=Venezuela)

	1971	1973	1975	1977	1979
Venezuela					
$\varepsilon^{23}{}_{11}{}^*$	-.107	-.095	-.112	-.105	-.106
$\varepsilon^{23}{}_{12}{}^*$	-.045	-.051	-.053	-.050	-.049
$\varepsilon^{23}{}_{13}{}^*$	-.057	-.053	-.052	-.056	-.057
$\varepsilon^{23}{}_{21}{}^*$	.806	.787	.876	.811	.805
$\varepsilon^{23}{}_{22}{}^*$	.035	.082	.062	.061	.057
$\varepsilon^{23}{}_{23}{}^*$	-1.289	-1.298	-1.375	-1.303	-1.293

[a] $\varepsilon^{ih}{}_{jk} = \partial \ln q_i / \partial \ln p_j \big|_{dq=0}$

Conclusions

When analyzing the demand for imports by country of origin (or by commodity), one usually proceeds on an equation-by-equation basis, that is, one specifies and estimates a number of individual and unrelated demand equations. In this paper, we have departed from this standard approach by deriving and estimating U.S. import equations for foreign crude oil within a system framework; the translog functional form was used for this purpose. The system approach has several important advantages. It ensures that the various demand functions are consistent with one another and with underlying theory. It also leads to an increase in the statistical efficiency of the estimates. A system approach, however, may seem unfeasible if the number of countries (or commodities) is large because of problems of multicollinearity. It was made possible here by assuming that Middle East crude is weakly separable from other crudes. The separability hypothesis could, in fact, be invoked repeatedly, almost *ad infinitum*, so that very large systems can be estimated without any need to abandon theory.

We found that the estimated own and cross price elasticities vary significantly from country to country but are fairly stable over time. This is as expected, given the significant variations in the characteristics of crude oil across countries but the significant variations in the characteristics of crude oil across countries but not over time. Most of the countries' shares changed appreciably during the 1970s. Much of the change is explained by the elasticity estimates and variations in the relative prices of the different crudes.

Communication

For his article, "The Effects of Saudi Industrialization on Employment," appearing in volume XI, number 2 (spring 1986), Professor Donald Wells wishes to acknowledge that he utilized statistics organized by Edward J. Swain in an unpublished memorandum, "Saudi Arabia's Industrial Base."

Energy Research in the USSR: Preparation for the Twenty-First Century, by William J. Kelly, Hugh L. Shaffer, and J. Kenneth Thompson. Durham, North Carolina: Duke University Press, 1986. xvi + 417 pages. ISBN 0-8223-0604-2. $62.50.

Reviewed by Leslie Dienes

This monumental work examines energy research and development (R&D) in the Soviet Union (U.S.S.R.) and assesses the influence of these efforts on the future course of energy production and consumption in that country. As Robert Campbell noted earlier and the authors here reaffirm and support in great detail, energy R&D generates new options and widens the range of available choices. That role appears particularly significant in the U.S.S.R. at this juncture.

For over a decade, and with accelerating speed, the Soviet energy economy is undergoing a dramatic shift in its sources of supply—towards geographically and/or geologically far less accessible deposits, poorer quality and less transportable fuels, and, partly as a response, towards nuclear generated power and, potentially, heat. As a result of this shift, the time of relatively cheap energy and untrammeled huge increases in supply has passed. Escalating capital requirements and costs characterize the Soviet energy economy and serious supply bottlenecks have appeared, accentuated by the recent excessive Soviet dependence on hydrocarbons for hard currency earnings.

As the authors show, current energy R&D is directed towards opening these bottlenecks and achieving an optimum mix of energy sources on the supply side, while increasing the efficiency of energy utilization and thereby reducing aggregate requirements on the demand side. (The focus in the latter case is on the energy branches themselves; efficiency improvement and structural change within industry in general are considered only very briefly.) These general objectives of Soviet energy R&D are organized by the authors around six basic goals related to nuclear electrification, the three main fuels, improvements in energy efficiency, and energy modeling. To these a seventh, more long-term goal of moving the energy system towards alternative sources is also added. The detailed analysis of these basic goals forms the bulk of the study, comprising chapters 3 through 8. This main portion is bracketed by an introduction (chapter 1), that outlines the purpose and scope of the work, and two useful sections, chapters 2 and 9. Chapter 2 describes the organizational structure and behavior of energy R&D and