Oil Characteristics and the U. S. Demand for Foreign Crude by Region of Origin

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The purpose of this paper is to model and estimate the United States demand for foreign crude oil by region of origin. Given the large share of foreign oil in U. S. total energy requirements, concern is often expressed in the U. S. about the dependency of that country on foreign oil suppliers, and particularly, on sometimes politically volatile regions.

The paper also allows us to apply the approach recently proposed by Kohli and Morey [1988] to model the demand for imports by region of origin to a single commodity, rather than to aggregate imports. This will enable us to take some of the physical characteristics of the good directly into account. Moreover, we will rigorously incorporate into the analysis a political variable, the international reputation of the exporting region.

The demand for imports by region of origin is conventionally modeled by setting up a system of demand equations, treating the goods (the crudes, in the context of this paper) from the different regions as different economic goods.[1] When such a system is estimated, one finds that the parameter estimates (e.g. intercepts and slope coefficients) differ between all country-specific equations. It is the author's hypothesis that these differences occur because crude oils from different regions possess different characteristics.[2] The authors intend to explain these differences by using the approach proposed by Kohli and Morey [1988], and in particular by taking the important characteristics of the oil into account. For example, rather than just assuming that the U. S. demand for Algerian crude oil is simply not the same as the U. S. demand for Indonesian crude, the authors argue that the two demand functions are in fact identical if all the relevant characteristics of the Algerian and Indonesian crudes are taken into consideration. If it is found, for instance, that the U. S. demand for Algerian crude is less price elastic than the U. S. demand for Indonesian crude, it will not be because the two types of oil are fundamentally different, but rather because they possess different levels of the characteristics.

A single import demand function is derived within a demand theoretic framework from a CES aggregator function that incorporates characteristics. Five characteristics are considered: gravity, sulfur content, availability, distance to the U. S., and reputation of the oil exporting country. The model is estimated with data from eight of the largest suppliers of crude oil to the U. S. during the late seventies and early eighties: Algeria, Indonesia, Iran, Libya, Mexico, Nigeria, Saudi Arabia, and Venezuela. The model can be used to determine the importance of the different characteristics. A number of price and characteristics elasticities of demand are reported.

The authors' approach makes it possible to evaluate the benefits (or the costs) that the U. S. would experience if the prices and/or the characteristics of foreign crude oil changed. The consequences of numerous scenarios could thus be evaluated (e.g. OPEC price changes, disruption in supplies). It is also possible to make a prediction of the U. S. import share for an oil exporting region not included in the sample simply on the basis of the price and the characteristics of its oil.

The paper proceeds as follows. The theoretical model is presented in Section I and its empirical implementation is discussed in Section II. Our empirical results are reported in Section III, and

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[1]For example, Kohli and Morey [1986] derive and estimate such a system, using a Translog cost function as a departure point. The import allocation model was first used by Armington [1969].

[2]The characteristics approach has been pioneered by Lancaster [1966].

Section IV makes some suggestions for further research.

I. The Model

Imports of foreign crude are used as inputs by the U. S. refining industry, together with domestic crude oil, labor, capital, and materials. Assume that this technology is weakly separable between imports of foreign crude and the other inputs, so that imports of foreign crude oil can be consistently aggregated.[3] Let the corresponding aggregator function be as follows:

$$q = f(Y, A). \tag{1}$$

q is an index of aggregate imports of foreign crude, $Y \equiv [y_i]$ where y_i is the quantity of U. S. imports of crude oil from region i ($i = 1, ..., I$), and $A \equiv [a_{ki}]$, a_{ki} being the amount of characteristic k ($k = 1, ..., K$) associated with the oil from region i. Note the distinction between q, aggregate crude oil imports, and the total physical quantity (in barrels) of imported crude oil: $y \equiv \Sigma_i y_i$. Unlike y, q takes the characteristics of the oil into account; it is not observable, but it can be deduced once that the model has been estimated. $f(\cdot)$ is assumed to be monotonically increasing, linearly homogeneous, and concave in the components of Y.

The CES functional form is used to approximate $f(\cdot)$. This choice is motivated by the fact that it is well known and relatively simple. Moreover, it easily allows for the incorporation of characteristics [Morey, 1981]. Thus,

$$f(Y, A) = [\Sigma_i (y_i)^\beta h(a_{1i}, \ldots, a_{ki}, \ldots, a_{Ki})]^{1/\beta} \tag{2}$$

where $h(\cdot)$ is a function of the K characteristics and is assumed to have the following exponential form:

$$h(a_{1i}, \ldots, a_{ki}, \ldots, a_{Ki}) = \exp(\alpha_0 + \Sigma_k \alpha_k a_{ki}) \qquad i = 1, \ldots, I. \tag{3}$$

The CES function constrains all Allen elasticities of substitution to be the same. It is used here in spite of this rather restrictive property in order to keep the empirical implementation of the model manageable. For the same reason, we chose a very simple functional form for $h(\cdot)$; it can be seen that $\ln h(\cdot)$ is linear in the a_{ki}'s, and it can thus be interpreted as a first-order approximation to an arbitrary function of the K characteristics. For the CES function to be well behaved it is necessary that $1 > b \neq 0$.

Assuming cost minimization, the technology can also be represented by a CES cost function that is the dual of (2):

$$C(q, P, A) = qc(P, A) = q[\Sigma_i h(i)^{-1/(\beta-1)} p_i^{\beta/(\beta-1)}]^{(\beta-1)/\beta} \tag{4}$$

where $P \equiv [p_i]$, p_i being the price of oil from region i, and $h(i) = h(a_{1i}, ..., a_{ki}, ..., a_{Ki})$. The cost minimizing demand for oil imports from region i, y_i^*, can be obtained by differentiation of (4), a result known as Shephard's [1953] lemma. It is convenient to express these demands in share form:[4]

$$\begin{aligned} s_i^* &= [h(i)/p_i]^\sigma / \Sigma_j [h(j)/p_j]^\sigma \\ &= [\exp(\sigma\alpha_0 + \Sigma_k \sigma\alpha_k a_{ki})/p_i^\sigma] \\ &\quad /[\Sigma_j \exp(\sigma\alpha_0 + \Sigma_k \sigma\alpha_k a_{kj})/p_j^\sigma] \\ &\qquad i = 1, \ldots, I, \end{aligned} \tag{5}$$

where $s_i^* \equiv y_i^*/\Sigma_j y_j^*$ is the share of region i in U. S. oil imports, and $\sigma \equiv 1/(1-\beta)$ is the elasticity of substitution. Note that all the share equations are identical. The only differences between the shares of the I oil exporting regions are due to the differences in the values of the exogenous variables ($p_i, a_{1i}, \ldots, a_{ki}, \ldots, a_{Ki}$) in the numerator of (5), but all the parameters ($\alpha_0, \alpha_1, \ldots, \alpha_K, \sigma$) are the same. Demand equations are normally allowed to differ between goods, in this case between oil imports from different regions. However, when all important characteristics that explain variations in demand are included in the analysis there is no reason to have different demand equations for different goods.

The characteristics approach which we use presents a number of important advantages. First,

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[3]See Berndt and Christensen [1973].

[4]Differentiation of (4) yields the following:

$$y_i^* = \partial C(\cdot)/\partial p_i = q[\Sigma_j h(j)^{-1/(\beta-1)} p_j^{\beta/(\beta-1)}]^{-1/\beta} [h(i)/p_i]^{1/(1-\beta)}.$$

Converting this result into shares, one obtains (5).

there is, strictly speaking, only one equation to estimate, and yet the model is compatible with a system-wide approach and with the underlying aggregator function. When characteristics are not included, each share equation is different: their parameters (intercepts and slope coefficients) vary from equation to equation. Economic theory dictates that all demand equations be estimated jointly as part of a system to ensure they are consistent with one another. As the number of goods (regions of origin) increases, the number of parameters increases as well, and joint estimation becomes unfeasible unless more structure is imposed on the model.[5] This is not so with our approach since the number of parameters that must be estimated only depends on the number of characteristics: it is independent of the number of goods. Hence, it is particularly useful if the number of important characteristics is relatively small.

Second, we should stress that to estimate (5) it is not necessary to include data from every country that exports oil to the U. S. Estimation of all unknown parameters can be done with a subset of I regions.[6] This obviously facilitates the empirical work since it becomes possible to proceed with the data of only the major suppliers to the U. S. The parameter estimates can nevertheless be used to determine the share of any area, including omitted ones, simply on the basis of its export price and the characteristics of its oil. One could even calculate the potential share of a region where oil is yet to be produced, merely by hypothesizing the characteristics and the price of its oil. This is clearly not possible with the conventional approach which does not allow for the parameters of excluded share equations to be deduced.

A third advantage of our approach is that it makes it possible to get some insight about the role of oil characteristics in determining the U. S. demand for foreign crude. One can predict how one exporter's share would change if the characteristics of its oil or someone else's changed.

Finally, our CES cost function (4) can be used to evaluate the cost (or cost savings) that the U. S. would experience for a given level of aggregate oil imports if the prices or the characteristics of the oil it imports were to change.

[5]See Kohli [1985], and Kohli and Morey [1986].

[6]Naturally, statistical efficiency increases with the number of countries included.

II. Empirical Implementation

Characteristics

Equation (5) is estimated using data from eight major oil suppliers to the U. S.: Algeria, Indonesia, Iran, Libya, Mexico, Nigeria, Saudi Arabia, and Venezuela. Five characteristics are considered: gravity, sulfure content, availability, distance to the U. S., and reputation.[7]

Gravity, measured in American Petroleum Institute (API) degrees, is an index of the oil's specific weight; the higher the API number, the lighter the oil. Light oil is more easily processed into light products like gasoline and jet fuel, whereas heavy oil is more conducive to the production of heavy products such as fuel oil and asphalt. *Ceteris paribus,* lighter oil is considered higher quality oil, and this difference is reflected in the price of the oil to a large extent. However, the relationship between the oil's gravity and a country's demand for that oil is not unambiguous because a country's demand for light versus heavy oils is dependent on the relative prices of the different refinery products, and on the oil gravity its refineries are designed to accept. For example, many West Coast refineries are currently changing their equipment so that they can process very heavy crudes (10° to 20°), the type of crudes they expect to receive from the new California fields. This decision will bias these refineries towards heavy oils in the future.

The oil's percentage sulfur content by weight varies from one sedimentary basin to another. Generally speaking, Middle East and Latin American crudes tend to have a relatively high sulfur content, while African and Indonesian crudes are on the low side. Sulfur is an undesirable characteristic. It causes corrosion and hazards which increase refining costs. Sulfur in the

[7]Some of the other characteristics of possible importance are pour point (the temperature at which the oil flows) and paraffinity (wax content of the oil). We tried to minimize the number of characteristics included in the analysis in order to limit the number of parameters that have to be estimated, and to show that import shares can be explained with only a handful of characteristics. For a discussion of the physical characteristics of oil, see Cuddington [1980], McCaslin [1976], and Rifai [1975].

crude also leads to sulfur in the residual fuels which will either cause air pollution or will have to be removed at high cost.

It is well possible that the attractiveness of low sulfur oils has increased over time as the result of legislative efforts directed at reducing pollution levels.[8] Unfortunately there is no single national standard for the emission of sulfur. The 1970 Clean Air Act Amendments set ambient air quality standards for sulfur dioxide (SO_2), but they did not set any emission standards. They left it to the individual states to devise their own schemes (State Implementation Plans — SIP) to meet the standards. Most of the SIP's were approved by the Environmental Protection Agency (EPA) in 1972 and were to become effective by the mid-seventies. The SIP's generally regulate SO_2 emissions from fuel burning devices, but they do not set any specific emission standards for oil refineries.

The 1970 Amendments, however, did require the Federal Government to set some national standards on sulfur oxides emissions from new or modified sources (the so-called New Source Performance Standards — NSPS). It was up to the EPA to define NSPS's for each of six criteria pollutants, including SO_2. NSPS's for SO_2, which vary by manufacturing process, were promulgated in 1974, but they did not apply to existing sources. Thus, one can think that their effect has increased gradually over time, as the proportion of new and modified refineries has risen. By 1976 it became clear, however, that the ambient standards were not met in many areas. This lead to the 1977 Amendments which added some teeth to the Clean Air Act by giving the Federal Government more enforcement capabilities, for instance by allowing it to withhold federal funds or to stop the construction of new polluting sources in the non-attainment regions. It is thus possible that the attitude of oil refiners and fuel users had effectively changed only at about that time. To test these various hypotheses, one allows α_2, the coefficient of sulfur content, to change through time. One can consider the following three specifications.

$$\alpha_2 = \alpha_{20} + \alpha_{21} D_{78} \tag{6.1}$$

$$\alpha_2 = \alpha_{20} + \alpha_{22} T_{75} \tag{6.2}$$

$$\alpha_2 = \alpha_{20} + \alpha_{23} T_{78} \tag{6.3}$$

where D_{78} is a dummy variable that is zero until 1977, and unity thereafter; T_{75} is a time trend starting in 1975, and T_{78} is a time trend originating in 1978.

The third characteristic which one considers is shipping distance to the U. S. Distance increases transportation costs, delays, and risks. Other things equal, one would assume close suppliers to be more desirable than distant ones.

Availability is the fourth characteristic which to consider. If the crudes of two regions (e.g. Indonesia and Brunei) had all the same physical characteristics and the same prices, one would expect U. S. importers to be perfectly indifferent between the two. The relative share of the two oils would then be random, and one assumes that the probability of choosing one over the other simply would depend on the relative availability of the two oils. One uses production levels as a proxy for availability: assuming that, *ceteris paribus*, large producers are more likely to capture a large share of the U. S. market.

Finally, political factors should be given some consideration as well. Indeed, the state of the relations between the U. S. and the various oil exporting nations is likely to influence the import decision. This is particularly relevant here since our sample contains two countries, Iran and Libya, whose relations with the U. S. have, to say the least, deteriorated significantly during the sample period. One therefore consider as a fifth characteristic the reputation of the exporting region.

Data

The model is estimated with annual data covering the period 1975-1984. Data are required on the quantities and the prices of U. S. crude oil imports from the eight countries under consideration, as well as data on gravity, sulfur content, production, distance to the U. S., and reputation. The import data, in thousands of barrels per year, are from the American Petroleum Institute (1986, Section IX, Table 4). Production data, in thousands of barrels per day, are from the same source (Section VI, Table 3). The price and gravity data

[8] See Tietenberg [1984] and National Commission on Air Quality [1981] for details.

are drawn from United Nations (1985) and Department of Energy (1985); prices vary between \$10.46 and \$40.78 per barrel, whereas gravity ranges from 26° to 44° API.[9] Sulfur contents were obtained from Petroleum Intelligence Weekly [1982]; they vary between 0.1 and 1.7%. Note that it is assumed that gravity and sulfur content of each country's crude are constant throughout the period of analysis. While not literally correct, this assumption is a close approximation to reality. Distances, measured in nautical miles, are approximate shipping distances from each country's main port to Galveston, Texas (Long Beach, California in the case of Indonesian crude); they were obtained from Caney and Reynolds [1981].

Getting some data about the reputation of the various exporters proved to be quite difficult. One data set that seemed to suit the need almost perfectly is the Conflict and Peace Data Bank (COPDAB); Azar [1980]. It records all events that make up bilateral relations between nations. The events, classified in cooperative and conflictual groups, cover a wide range of occurrences, including those of a political, military, economic, and cultural nature, and they are weighted according to their assessed importance. The data set was used to construct an indicator of the quality of the relations between the U. S. and each of the eight oil exporting nations. Unfortunately COPDAB data is presently only available until 1978, and it was necessary to link these series with data from another source.

For this purpose, they turned their attention to credit rating indexes published by various financial reviews such as *Euromoney* and *Institutional Investor*.[10] Admittedly these indexes are not perfectly fit for the paper's purpose since they concentrate more on credit worthiness than on the state of bilateral relations. One could also argue that these indexes do not necessarily reflect U. S. attitudes, but rather the views of all Westen investors. Yet, it turns out that credit rating data correlate quite well with COPDAB data.[11] Among the longest series available, which cover all eight countries in the sample, are those published by *Institutional Investor*. These are the ones which are being used as an index for reputation after 1978.

Stochastic Specification and Estimation Technique

System (5) consists of eight highly nonlinear demand equations.[12] One assumes that they are random due to errors of optimization, and one specifies a vector of additive disturbances. One assumes that these errors are correlated across equations, but independent through time. The model is estimated using the algorithm proposed by Berndt, Hall, Hall and Hausman [1974]. This method is essentially an iterative and nonlinear version of Zellner's [1962] method for seemingly unrelated regressions (SUR), and it is numerically equivalent to maximum likelihood. Because all shares add up to one, the variance-covariance matrix is singular and one equation must be omitted, but the results are independent of which equation is left out. It is also visible from (5) that α_0 is undetermined. One can therefore set this parameter to zero without loss of generality. One thus ends up with six free parameters (seven if use of (6.1)-(6.3) is made) for a total of 70 observations (seven independent equations *times* ten observations each).

III. Empirical Results

Parameter Estimates

Parameter estimates of equation (5) are reported in Table 1.[13] The logarithms of the likelihood function (*LL*) and the pseudo-*R* squared (R^2p) proposed by Baxter and Cragg [1970] are reported as well.[14] The estimates in the first column

[9] The price, gravity, and sulfur data are for one of each country's leading type of crude oil, namely: Saharan (Algeria), Minas (Indonesia), Iranian Light (Iran), Es Sider (Libya), Isthmus (Mexico), Bonny Light (Nigeria), Arabian Light (Saudi Arabia), and Tiajuana (Venezuela). The prices are generally January 1 official sales prices (F.O.B.). Note that relative prices faced by U. S. refineries may have been distorted (in favor of low quality oils) by the U.S. Entitlement Program. No attempt is made here to correct for this effect.

[10] See Krayenbuehl [1985], for instance.

[11] This was confirmed to us privately by Edward Azar.

[12] Even though, algebraically speaking, there is only one equation to estimate, we prefer to treat (5) as a system since the random disturbances are likely to be correlated across regions. The estimation procedure which we use makes it possible, however, to impose all the parameters to be the same across equations.

[13] All estimations were done with TSP, version 4.1A; the reported t values are numerical estimates of asymptotic t values, and they must be interpreted with care given the highly nonlinear structure of the model.

TABLE 1

Parameter Estimates

$$s_i^* = [\exp(\Sigma_k \sigma \alpha_k a_{ki}) / p_i^{\sigma}] / [\Sigma_j \exp(\Sigma_k \sigma \alpha_k a_{kj}) / p_j^{\sigma}]$$

Parameters	version 0	version 1	version 2	version 3
σ	3.35157	3.30458	3.35080	3.37813
	(82.21)	(740.51)	(86.12)	(1091.14)
α_1	0.01492	0.01706	0.01498	0.01791
	(27.80)	(219.79)	(21.04)	(223.52)
α_2 (α_{20})	−0.22743	−0.20898	−0.22759	−0.19689
	(−48.39)	(−274.38)	(−29.25)	(−246.60)
α_{21}	—	−0.01163	—	—
		(−47.25)		
α_{22}	—	—	−0.00015	—
			(−0.30)	
α_{23}	—	—	—	−0.00395
				(−52.59)
α_3	−0.00008	−0.00008	−0.00008	−0.00008
	(−85.39)	(−789.04)	(−85.65)	(−1030.75)
α_4	0.00013	0.00013	0.00013	0.00012
	(75.54)	(698.11)	(76.47)	(934.23)
α_5	0.00207	0.00195	0.00206	0.00190
	(24.94)	(209.74)	(26.24)	(285.00)
LL	190.897	212.727	191.379	215.341
R^2p	0.95957	0.99949	0.96329	0.99970

Note: the characteristics are defined as follows:

1. gravity
2. sulfur -α_{21}, α_{22}, and α_{23} are defined as in (6.1)-(6.3)
3. distance
4. availability
5. reputation

(version 0) assume that the impact of sulfur is fixed through time. The estimates in the second column (version 1) are obtained with inclusion of a dummy variable (D_{78}) that allows for a discrete change in α_2 in 1978 as indicated in (6.1) above, while those in the last two columns (versions 2 and 3) are obtained with the help of time trends starting in 1975 and 1978, respectively and acting on α_2 as shown by (6.2) and (6.3).

It appears that σ is substantially greater than unity; to no surprise this implies that the crudes from the different regions are quite good substitutes for one another. Of particular interest are the signs of the parameters associated with the characteristics. Note that all these estimates have highly significant t values.

As expected, gravity, availability, and reputa-

[14]For comparison purposes we also estimated the system of share equations derived from an ordinary (i.e. without characteristics) CES cost function; the corresponding logarithm of the likelihood function was much lower (176.180), even though the number of parameters was larger. This finding gives considerable support to our approach.

tion all impact positively ($\alpha_1 > 0, \alpha_4 > 0, \alpha_5 > 0$) on a country's share of U.S. crude oil imports, while sulfur content and distance both have a negative effect ($\alpha_2 < 0, \alpha_3 < 0$). Versions 1 to 3 of the model allow for the impact of sulfur to vary through time. The estimate of α_{21} in column 2 shows that this impact increases significantly in absolute value in 1978. The estimate of α_{22} (column 3), on the other hand, is not significantly different from zero, although it does have the expected negative sign. Thus, no gradual increase in sulfur undesirability is noticeable as early as 1975.

Yet, as shown by the estimate of α_{23} (column 4), a trend is highly significant as of 1978, that is after the Clean Air Act was tightened up. A likelihood ratio test leads to the rejection of version 0 in favor of both versions 1 and 3 (the test statistics are respectively 42.70 and 47.92 for a critical χ^2 value of 6.63 at the 99% confidence level with one degree of freedom), whereas version 0 cannot be rejected when confronted to version 2 (the test statistic is barely 0.96).

Judging from the values of the logarithms of the likelihood functions, version 3 does a better job than version 1 at explaining the data. That is, a gradual increase in sulfur undesirability as of 1978 is more likely than a once-for-all increase at that same date. Therefore one retains version 3 as a preferred specification.

Price and Characteristic Elasticities of Demand

Further insight into the importance of prices and characteristics can be gained by examining the estimated price and characteristic elasticities of demand. Differentiating (5), we can calculate the following elasticities of shares with respect to prices:[15]

$$\varepsilon_{ij} \equiv \partial \ln s_i^* / \partial \ln p_j = \begin{cases} -\sigma(1 - s_i^*) & i = j \\ \sigma s_j^* & i \neq j \end{cases} \quad i, j = 1, \ldots, I. \tag{7}$$

It is visible from (7) that the CES functional form constrains all cross elasticities to depend only on j: they are independent of i. That is, a change in the price of one region's oil changes the shares of all other regions by the same percentage. Estimates of the own price elasticities (based on version 3 of the model) are reported for selected years in Table 2; estimates of the cross price elasticities are shown in Table 3. All own price elasticities are quite large in absolute value, varying between –2.30 and –3.36. The cross price elasticities tend to be much smaller, and they vary a fair bit across countries and through time, ranging from 0.02 to 1.34.

One can also calculate characteristic elasticities of demand. Characteristics can change: availability can vary as a country increases or decreases its oil production; distances can be affected by the building of new pipelines, the discovery of new fields, or the relocation of U. S. refineries; average gravity and sulfur contents are influenced by new discoveries; a country's relations with the U. S. can evolve significantly through time as recent history with respect to Iran and Libya points out. A change in the characteristics of one of the imported crudes will generally impact on the U. S. market shares of the various oil producers. Differentiating (5), the share elasticities with respect to characteristics can be calculated as follows:[16]

[15]Differentiating (5) with respect to p_j, $(i \neq j)$ we obtain:

$$\begin{aligned} \partial s_i^* / \partial p_j &= \sigma[h(j)/p_j]^\sigma [h(i)/p_i]^\sigma \\ &\quad /\{p_j \Sigma_m [h(m)/p_m]^\sigma\}^2 \\ &= \sigma s_i^* s_j^* / p_j. \end{aligned}$$

Hence,

$$(\partial s_i^* / \partial p_j)(p_j / s_i^*) = \sigma s_j^*.$$

Similarly, differentiating (5) with respect to p_i, one gets:

$$\partial s_i^* / \partial p_i = -\sigma s_i^* (1 - s_i^*) / p_i,$$

so that:

$$(\partial s_i^* / \partial p_i)(p_i / s_i^*) = -\sigma(1 - s_i^*).$$

[16]Differentiation of (5) with respect to a_{kj} for $i \neq j$ yields:

$$\begin{aligned} \partial s_i^* / \partial a_{kj} &= -\sigma[\partial h(j) / \partial a_{kj}] h(j)^{\sigma-1} p_j^{-\sigma} \\ &\quad [h(i)/p_i]^\sigma / \{\Sigma_m [h(m)/p_m]^\sigma\}^2 \\ &= -\sigma \alpha_k s_i^* s_j^* \end{aligned}$$

so that:

$$(\partial s_i^* / \partial a_{kj})(a_{kj} / s_i^*) = -\alpha_k a_{kj} \varepsilon_{ij}.$$

Similarly, for $i = j$ we get:

$$\partial s_i^* / \partial a_{ki} = \sigma \alpha_k (1 - s_i^*) s_i^*.$$

Hence,

$$(\partial s_i^* / \partial a_{ki})(a_{ki} / s_i^*) = -\alpha_k a_{ki} \varepsilon_{ii}.$$

TABLE 2

Own Price Elasticities of Demand for Selected Years

$$\varepsilon_{ii} = \partial \ln s_i^* / \partial \ln p_i$$

i	1975	1978	1980	1982	1984
Algeria	–2.743	–2.744	–2.808	–2.823	–2.665
Indonesia	–3.206	–3.135	–3.120	–3.141	–3.082
Iran	–3.166	–3.218	–3.360	–3.348	–3.337
Libya	–2.927	–2.959	–3.162	–3.100	–3.042
Mexico	–2.967	–2.866	–2.974	–2.034	–2.300
Nigeria	–2.737	–2.936	–2.936	–3.016	–2.926
Saudi Arabia	–3.032	–2.798	–2.392	–3.165	–3.267
Venezuela	–2.868	–2.991	–2.897	–3.020	–3.029

TABLE 3

Cross Price Elasticities of Demand for Selected Years

$$\varepsilon_{ij} \equiv \partial \ln s_i^* / \partial \ln p_j, (i \neq j)$$

j	1975	1978	1980	1982	1984
Algeria	0.635	0.634	0.571	0.555	0.713
Indonesia	0.172	0.244	0.259	0.237	0.296
Iran	0.213	0.160	0.018	0.030	0.041
Libya	0.451	0.420	0.216	0.278	0.336
Mexico	0.411	0.512	0.404	1.344	1.079
Nigeria	0.641	0.442	0.442	0.362	0.453
Saudi Arabia	0.346	0.580	0.986	0.213	0.111
Venezuela	0.510	0.388	0.482	0.359	0.349

$$\mu^k{}_{ij} \equiv \partial \ln s_i^* / \partial \ln a_{kj} = -\alpha_k a_{kj} \varepsilon_{ij}$$
$$k = 1, \ldots, K; i, j = 1, \ldots, I. \qquad (8)$$

Again one sees that the cross elasticities are independent of i: they only depend on the country whose oil characteristics are changing. 1980 estimates of own and cross characteristic elasticities are reported in Tables 4 and 5 respectively. These elasticities tend to be largest for gravity, although availability seems also to play an important role in the Saudi case, and distance seems to matter particularly for the two Persian Gulf states in our sample (Saudi Arabia and Iran). Large differences across exporting regions are apparent. They reflect differences in the prices and the character-

TABLE 4

Own Characteristics Elasticities of Demand, 1980 Estimates

$$\mu_{ii}^{k} \equiv \partial \ln s_i^* / \partial \ln a_{ki}$$

i	*k*=1	*k*=2	*k*=3	*k*=4	*k*=5
Algeria	2.212	–0.059	–1.140	0.352	0.303
Indonesia	1.900	–0.065	–0.407	0.774	0.383
Iran	2.046	–0.982	–3.322	0.771	0.104
Libya	2.095	–0.264	–1.457	0.714	0.325
Mexico	1.758	–0.931	–0.157	0.709	0.414
Nigeria	1.945	–0.061	–1.410	0.746	0.301
Saudi Arabia	1.456	–0.849	–2.327	2.842	0.343
Venezuela	1.349	–1.028	–0.407	0.774	0.383

Note: the characteristics are defined as follows:
1. gravity
2. sulfur
3. distance
4. availability
5. reputation

TABLE 5

Cross Characteristics Elasticities of Demand, 1980 Estimates

$$\mu_{ij}^{k} \equiv \partial \ln s_i^* / \partial \ln a_{kj}, (i \neq j)$$

j	*k*=1	*k*=2	*k*=3	*k*=4	*k*=5
Algeria	–0.450	0.012	0.232	–0.072	–0.062
Indonesia	–0.157	0.005	0.159	–0.050	–0.027
Iran	–0.011	0.005	0.018	–0.004	–0.001
Libya	–0.143	0.018	0.100	–0.049	–0.022
Mexico	–0.239	0.127	0.021	–0.096	–0.056
Nigeria	–0.293	0.009	0.213	–0.112	–0.045
Saudi Arabia	–0.601	0.350	0.959	–1.172	–0.142
Venezuela	–0.224	0.171	0.068	–0.129	–0.064

Note: see Table 4 for a list of the characteristics

TABLE 6

Elasticities of Total Cost with respect to Prices and Characteristics, 1980 Estimates

$\Gamma_i \equiv \partial \ln C(\cdot) / \partial \ln p_i$ *and* $\gamma_{ki} \equiv \partial \ln C(\cdot) / \partial \ln a_{ki}$

i	Γ_i	γ_{1i}	γ_{2i}	γ_{3i}	γ_{4i}	γ_{5i}
Algeria	0.177	–0.198	0.005	0.102	–0.032	–0.027
Indonesia	0.073	–0.064	0.002	0.064	–0.020	–0.011
Iran	0.006	–0.005	0.002	0.008	–0.002	–0.001
Libya	0.077	–0.073	0.009	0.050	–0.025	–0.011
Mexico	0.140	–0.117	0.062	0.010	–0.047	–0.028
Nigeria	0.137	–0.129	0.004	0.093	–0.049	–0.020
Saudi Arabia	0.265	–0.229	0.134	0.366	–0.447	–0.054
Venezuela	0.125	–0.083	0.063	0.025	–0.048	–0.024

Note: see Table 4 for a list of the characteristics

istics of the various crudes.

Price and Characteristic Elasticities of Total Cost

As already mentioned, estimates can be used to evaluate the costs or cost savings to the U. S. of changes in the prices or characteristics of the imported crudes for a given level of aggregate oil imports. Let Γ_i be the elasticity of costs with respect to the oil price from region i. Shephard's (1953) lemma implies the following:[17]

$$\Gamma_i \equiv \partial \ln C(\cdot) / \partial \ln p_i = h(i)^{\sigma} p_i^{(1-\sigma)} / [\Sigma_j h(j)^{\sigma} p_j^{(1-\sigma)}] \qquad i = 1,\ldots,I. \tag{9}$$

Next, let γ_{ki} be the elasticity of costs with respect to characteristic k of country i's oil. Differentiating (4) and making use of (5) and (9), we get:[18]

$$\gamma_{ki} \equiv \partial \ln C(\cdot) / \partial \ln a_{ki} = -\sigma \alpha_k a_{ki} \Gamma_i / (\sigma - 1) \qquad k = 1,\ldots,K; i = 1,\ldots,I. \tag{10}$$

1980 estimates of (9) and (10) are reported in Table 6. Once again one sees that gravity has a relatively large impact; moreover, the influence of characteristics on costs often seems to be just as important as the role of prices. As an illustration, we can calculate the effect that a change in the gravity of Saudi oil would have on U. S. costs. Judging from the estimate of γ_{1i} in Table 6, a 3

[17]Shephard's [1953] lemma implies that:

$\Gamma_i \equiv (\partial C / \partial p_i)(p_i / C) = p_i y_i^* / C = p_i y_i^* / (\Sigma_j p_j y_j^*)$.

From footnote 4 we get:

$p_i y_i^* = p_i q [\Sigma_j h(j)^{-1/(\beta-1)} p_j^{\beta/(\beta-1)}]^{-1/\beta} [h(i) / p_i]^{\sigma}$.

Hence,

$p_i y_i^* / (\Sigma_j p_j y_j^*) = h(i)^{\sigma} p_i^{1-\sigma} / [\Sigma_j h(j)^{\sigma} p_j^{1-\sigma}]$.

[18]Differentiation of (4) with respect to a_{ki} gives:

$$\partial C / \partial a_{ki} = (-1/(\beta) q [\Sigma_j h(j)^{-1/(\beta-1)} p_j^{\beta/(\beta-1)}]^{-1/\beta} [h(i) / p_i]^{-\beta/(\beta-1)} [\partial h(i) / \partial a_{ki}] = (-1/\beta) q [\Sigma_j h(j)^{-1/(\beta-1)} p_j^{\beta/(\beta-1)}]^{-1/\beta} \alpha_k h(i)^{\sigma} p_i^{1-\sigma}.$$

Thus,

$$(\partial C / \partial a_{ki})(a_{ki} / C) = -(1/\beta) \alpha_k a_{ki} \Gamma_i.$$

degree drop in Saudi API (from 34° to 31°) would, *ceteris paribus,* increase U. S. costs by approximately 2.29% ($905.4 million, 1980 figure). Or consider a change in the sulfur content of Algerian oil. As shown by the estimate of γ_{2i}, a 10% increase in the sulfur content of Algerian crude would, other things equal, increase U. S. costs by approximately 0.05% ($23.0 million). Lastly, let us contemplate an improvement in U. S.-Libyan relations: according to the estimate of γ_{5i}, a 10% improvement in Libya's reputation, as measured by our political index, would lead to a 0.11% reduction in U. S. costs ($49.5 million).

Large Changes in Prices and Characteristics

Clearly, the price and characteristic elasticities defined by (7)-(10) are valid for very small changes only. To assess the effect of large changes, one can use equations (4) and (5) directly, simply calculating the shares or costs at the old (P^0, A^0) and at the new (P^1, A^1) sets of prices and characteristics. Thus, for large changes, we have the following:

$$\Delta s_i^* = s_i^*(P^1, A^1) - s_i^*(P^0, A^0) \quad i = 1, \ldots, I \tag{11}$$

where $s_i^*(P, A)$ is given by (5), and

$$\Delta C = q^0[c(P^1, A^1) - c(P^0, A^0)]. \tag{12}$$

(12) is conditional on q^0, the initial quantity of aggregate curde oil imports.[19] Consider again a change in the sulfur content of Algerian oil or an improvement in U. S.-Libyan relations. Using (12) together with 1980 data and estimates of Table 1, column 4, one finds that a 10% increase in the sulfur content of Algerian crude would increase U. S. costs by approximately $23.0 million, while a 10% increase in Libyan reputation would save the U. S. the equivalent of $50.3 million. These figures are almost identical to the ones obtained in the previous paragraph with the help of the point elasticities reported in Table 6. But this need not be the case.

Consider, once again a change in the gravity of Saudi oil. A 3 point drop in gravity (from 34° to 31° API) would, other things equal, reduce the Saudi share by nearly half and cost the U. S. the equivalent of $838.8 million (1980 estimate). This figure is substantially lower than the one obtained earlier with the use of the estimate of γ_{1i}.

The point elasticities are even more inappropriate if one wants to evaluate the effects of very large changes. Consider the effect of the 1979 Iranian revolution which resulted in a severe deterioration in U. S.-Iranian relations, and a dramatic drop in the production, and hence availability, of Iranian oil, thus obliging the U. S. to switch to other, presumably more expensive, sources. Had Iran's 1980 oil output reached its level of two years earlier, the U. S. would have saved $315.8 million; this figure is more than double the figure of $147.2 million which is obtained with the help of the point elasticity γ_{4i}. And had Iranian reputation in 1980 been the same as the reputation of Saudi Arabia, the U. S. would have saved $49.0 million on its oil bill (the corresponding figure is $24.9 million if we use the approximation given by γ_{5i}).

It is noteworthy that these amounts are distinct from, and overshadowed by, the effect of the huge price increase which took place largely as the result of the Iranian events, and which made up the second oil shock: assuming other things equal, this price increase alone has cost the U. S. approximately $23.6 billion for the eight countries in our sample.

It is possible to use our estimates of (4) to assess the value to the U. S. of the various characteristics of its imported oil. More specifically, we can calculate the price variation that would be necessary to offset a change in a characteristic for the U. S. to be indifferent, that is ΔC in (12) to be zero. Thus, still using 1980 figures, we find that a 10% increase in the API of Saudi oil would be worth about $2.35 per barrel to the U. S. A 10% increase in the sulfur content of Libyan oil would have to be accompanied by a 34 cents per barrel price reduction for the U. S. to be indifferent, while a 10% increase in Iranian reputation would be worth about 22 cents per barrel. Approximations to these figures can be obtained with the help of the point elasticities Γ_i and γ_{ki} reported in Table 6.

[19] q^0 can be calculated by dividing the initial import bill by $c(P^0, A^0)$.

The Cost of Clean Air

Finally, one can use the authors' estimates to assess the costs to U. S. refiners of the 1977 Clean Air Act Amendments. According to version 3 of the model, the Amendments have lead to a gradual increase in the absolute value of α_2. Using (6.3) together with the estimates of Table 1, column 4, one finds that $\alpha_2 = -0.19689$ until 1977; by 1980, it is equal to –0.20874, and by 1984, it has fallen to –0.22454. It is visible from (4), that a change in one of the parameters of $c(\cdot)$ will impact on total costs. Let $c(\cdot)$ be the original unit cost function, and let $c'(\cdot)$ be the unit cost function obtained by fixing α_2 at its 1977 level. The cost to U.S. refiners of the 1977 Clean Air Act Amendments can then be calculated as follows:

$$\Delta C = q_0[c(P^0, A^0) - c'(P^0, A^0)]. \qquad (13)$$

The 1980 estimate of (13) is \$706.8 million; this is about 1.6% of the oil bill from the eight nations in our sample. This figure obviously does not include the higher cost of oil from other (including domestic) sources, or the capital expenditures which may have been necessary as a consequence of the 1977 Amendments. Alternatively, we may ask ourselves by how much the prices of the various crudes would have had to fall to leave U.S. importers indifferent to the 1977 toughening up of the Clean Air Act. Using once again (4) as a starting point, we obtain a range of figures which extends from 5 cents per barrel (Algerian crude) to 86 cents per barrel (Mexican crude).

IV. Conclusions

Rather than summarizing here our findings, we use this section to offer some suggestions for further research. As usual in empirical work, it would be desirable to use better and more disaggregated data. In our case, this would mean in particular distinguishing between crudes originating from different basins, rather than just between crudes of different national origins. However, sufficiently detailed import data might be impossible to get. It would also be desirable to use more general functional forms than the ones used here to approximate $C(\cdot)$ and $h(\cdot)$, although the nonlinearity of the model, as it is, might preclude this. A more promising avenue for furture research might be to incorporate the relevant characteristics of the oil importer into the aggregator function. The U. S. demand for foriegn crude presumably depends on some of its own characteristics, for instance the design of its oil refineries. The types of crudes that the U. S. demands is probably also influenced by the domestic relative prices of the refinery products; it might therefore be appropriate to consider these prices as well. If all relevant domestic characteristics and prices were included into the analysis, one could utilize a data set covering multiple importers. Indeed, there is no reason, once this is done, why the U. S. demand for foreign crude should be different from, say, the Japanese demand. One could thus derive an equation which would explain the variations in demand, both across oil exporters for a given importer, and across importers for a given

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The Demand for Money in Socialist Tanzania

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Introduction

In advanced countries, monetary policy most often is employed in attempting to modify short-run business cycle fluctuations, although long-run price stability is likewise an important objective. Less developed countries, understandably, place greater policy emphasis on long-run economic growth. For these countries, money expansion is frequently a major source of government revenue. Public demand for this newly created money, in turn, has important implications for critical macroeconomic variables such as incomes, prices, and interest rates. As a consequence, money demand plays a central role in the success or failure of development policies.

Nevertheless, until recently, there was very little research on money demand in less developed countries.[1] Two early works were by Adekunle [1968] and Wong [1979].[2] Adekunle compared money demand functions for groups of countries which differed by their levels of development. Wong's study focused on the importance of including measures of credit restraint in money demand functions for developing countries. None of these studies contained data for African countries, many which did not receive political independence until the 1960's. Thus, very little is known about the monetary proclivities of people living on this continent. That gap in the literature was partially filled with the recent publication of three papers on money demand in Africa: Darrat [1985] on Kenya; Arize and Lott [1985] on Nigeria; and Domowitz and Elbadawi [1987] on the Sudan.

This paper presents results of the study of money demand in Tanzania, an East African nation which obtained its independence in 1961. To better understand the generality of its applicability, conventional monetary theory must be tested in a wide variety of settings, both temporally and geographically. From that perspective, the findings presented here are quite rich and merit attention for a number of reasons. First, as noted above, current knowledge about monetary relations in Africa is quite limited, and this paper extends the literature on that subject. Second, Tanzania is one of the poorest of the world's poor countries, significantly more so than Nigeria, Kenya, and the Sudan which were examined in previous studies. Tanzania's 1985 per capita gross domestic product of $295 is considerably exaggerated due to an over-valued exchange rate.[3]

Third, under President Julius Nyerere, Tanzania actively pursued socialist policies following the Arusha Declaration in 1967. Not only is available knowledge concerning money demand in a socialist setting scarce, but supporters of socialism frequently claim that individuals practicing socialism are driven by a different set of values than are individuals residing in capitalist countries. President Nyerere felt that was the case in Tanzania [Nyerere, 1969, p. 43-4].

> "Certainly Tanzania was part of the Western capitalist world while it was under colonial domination, but it was very much on the fringe. Certainly our independent nation inherited a few capitalist institutions, and some of our people adopted capitalist and individualistic ideas as a result of their education or their envy of the colonial representatives whom they encountered. But the masses of the people did not become capitalistic, and are not filled with capitalist ideas. By far the largest part of our economy is not organized on capitalist lines. Indeed, whenever we try to help Africans to become capitalist shopkeepers, capitalist farmers, industrialists, etc., we find that most of them fail because they cannot adopt the capitalist practices which are essential to commercial success. ....(D)ogmatists often attribute these African failures to the machinations of a racial minority—thus revealing their racialism and non-socialist beliefs—instead of recognizing that capitalism demands certain attributes among its practitioners which the ma-

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[1] By way of contrast, there is a rich literature on money in the U. S. and other developed countries. For recent surveys of that literature, refer to Laidler [1985] and Judd and Scadding [1982].

[2] Meiselman [1970] also contained papers on money demand for individual developing countries.

[3] While the International Monetary Fund (*International Financial Statistics*) reports that the average official exchange rate for 1985 was 17.47 Tanzanian shillings per dollar, black market rates in excess of 100 were not uncommon.