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THE DEMAND FOR ENERGY: AN INTERNATIONAL PERSPECTIVE

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I. Introduction

Problems of energy are today at the center stage of political and economic affairs. In the short-run, the industrialized world is attempting to cope with a radical restructuring of energy price levels and the world depression and to rechannel the flow of funds that the price changes induce. In the medium-run, many countries or regions (especially the United States, the European Community, and Japan) are attempting to insulate themselves from the vicissitudes of the international energy market by increasing their self-sufficiency. For the longer run, groups such as IIASA are investigating the problems of transition from scarce, low-cost fossil fuels to higher-cost but more abundant fuels.[2]

The two cornerstones of the uncertainties which run through all these studies are the future technology and the proper specifcation of the demand for energy. Up to now, most work in energy systems analysis--at IIASA as well as in most other institutions--has been on the question of technology and supply. Recently, however, the rapid changes

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[2]Examples of the short-term approach are [8, 15, 28]; examples of the medium-term approach are [27, 33, 35, 48, 50]; and examples of the long-term approach are [22, 29, 31, 37, 44, 49].

in price and the current economic crisis has shifted emphasis to the demand side of the equation, with special reference to the possibilities of "energy conservation."

The central uncertainties in energy demand are four: First, as far as the long-run is concerned, what is the income elasticity of the demand for energy; that is, with a given rate of growth in the aggregate output of an economy, what is the fractional increase of the demand for energy? Second, relating mainly to the medium term, what is the long-run price elasticity of the demand for energy? Especially given the dramatic changes in the relative prices of energy to other goods, it is of central importance to know what the eventual response of energy demand will be. How will energy demand respond to further policy measures? Third, in the short run, the critical question is what is the time distribution of the response to the recent price increases? Fourth, it is implicit in the questions usually raised that energy is a conventional economic good, in the sense that it responds to the laws of supply and demand in the same way that most other goods do; many have argued that energy is unique, indeed that it is the ultimate determinant of value, and that we cannot hope to explain the behavior of the demand for energy with conventional econometric models. Is this so?

In what follows I will address myself to each of the problems given above. The framework for analyzing the question is to employ simple econometric techniques, these for estimating "economic demand functions." A technical description will be provided in the next section, while results and interpretation will be provided in subsequent sections.

It should be stressed that the results presented here are preliminary: the data have not been thoroughly rechecked, and it is possible that errors have crept in.

II. Specification of the Econometric Model

The problem of estimating the demand for energy is conceptually difficult because energy is a <u>derived</u> demand rather than a final demand; that is, energy is demanded not for its own sake but because it can be combined with other inputs to produce satisfaction-yielding services. (As an example, consider the energy used in running an air conditioner.) This implies that the important factors will be both those determining the demand for final products (such as cool air in summer) as well as the competition between inputs into the productive process (as between the capital and fuel costs of air conditioners and fans). The technique outlined here specifies the way that demand and technology interact so as to determine the derived demand for energy inputs.

The bases for the estimation are two fundamental relations: (A) the technology and (B) the preference relations. Through the interaction of these two relations the price and demand for the energy products are determined.

The important assumptions are given first:

1) There is a well-behaved production function for each good, where the inputs are capital, labor, and energy.

2) Energy is aggregated in each sector into a single entity, although the type of fuel used in different sectors may differ and the efficiencies of fuels do differ.

3) Sectors are assumed to minimize the costs of production for a given level of output.

4) The residential sector is divided into a production department and a consumption department, so that we consider the residential demand for energy mediated through the production department of the residential sector.

5) Prices are assumed to be set by marking up long-run average cost by a fixed markup (which would be zero for competitive industries).

6) The forces influencing demand can be represented by a consistent preference function.

From these assumptions, it is shown how the demand for energy inputs is related to parameters of the production and preference functions, to prices, and to incomes.

Mathematical Derivation

The notation below uses the following convention:

- capital Roman letters (A, B, C, D) are economic variables;
- small Roman letters (a, b, c, d) are logarithms of economic variables; and
- parameters are represented by Greek letters (α, β, γ,...). Vectors are underlined ($\underline{\alpha}$, $\underline{\beta}$,...) while scalars are not underlined (ε, γ).

First consider the role of energy in production. Consider an economy with primary factors labor L, energy E, and capital K, and with produced goods $Q_1,\ldots,Q_n$. The production function for good i is:

$$Q_i = F^i(Q_{1i},\ldots,Q_{ni},L_i,K_i,E_i,T) \tag{1}$$

which can be approximated in a Taylor expansion by:

$$q_i = h_i^o + \sum_{j=1}^{n} \alpha_{ji}q_j + \beta_i^o \ell_i + \gamma_i^o e_i + \delta_i^o k_i + \lambda_i^o T$$
$$+ \text{ higher order terms} \tag{2}$$

In (2) h_i^o are constants, T is time--a proxy for change in technology. The parameters before factors are the production elasticities, quite similar to the input-output coefficients in a (linear) input-output model. In the CES or in the "translog" production function, the higher order terms would be included, but in what follows we will be satisfied with the first order terms. This makes the production function the well-known Cobb-Douglas vintage.[3]

Next, represent equation (2) in vector form by introducing the vectors and matrices as follows (suppressing superscripts):

$$\underline{q}=\begin{bmatrix} q_1 \\ \vdots \\ q_n \end{bmatrix} \quad \underline{\ell}=\begin{bmatrix} \ell_1 \\ \vdots \\ \ell_n \end{bmatrix} \quad \underline{k}=\begin{bmatrix} k_1 \\ \vdots \\ k_n \end{bmatrix} \quad \underline{e}\begin{bmatrix} e_1 \\ \vdots \\ e_n \end{bmatrix} \quad \underline{\lambda}=\begin{bmatrix} \lambda_1 \\ \vdots \\ \lambda_n \end{bmatrix} \quad \underline{h}=\begin{bmatrix} h_1 \\ \vdots \\ h_n \end{bmatrix}$$

$$\underline{\alpha}=\begin{bmatrix} \alpha_{11} & \cdots & \alpha_{n1} \\ \vdots & & \vdots \\ \alpha_{1n} & \cdots & \alpha_{nn} \end{bmatrix} \quad \underline{\beta}=\begin{bmatrix} \beta_1 & \cdots & 0 \\ 0 & & \vdots \\ \vdots & & \\ 0 & \cdots & \beta_n \end{bmatrix} \quad \underline{\gamma}=\begin{bmatrix} \gamma_1 & \cdots & 0 \\ \vdots & & \vdots \\ 0 & \cdots & \gamma_n \end{bmatrix} \quad \underline{\delta}=\begin{bmatrix} \delta_1 & \cdots & 0 \\ \vdots & & \vdots \\ 0 & \cdots & \delta_n \end{bmatrix}$$

Then we can rewrite equation (2) as:

$$\underline{q} = \underline{h}^o + \underline{\alpha}\underline{q} + \underline{\beta}^o\underline{\ell} + \underline{\gamma}^o\underline{e} + \underline{\delta}^o\underline{k} + \underline{\lambda}T \qquad (3)$$

or solving for q:

$$\underline{q} = \underline{h} + \underline{\beta\ell} + \underline{\gamma e} + \underline{\delta k} + \underline{\lambda T} \qquad (4)$$

where

$$\begin{bmatrix} \underline{h} \\ \underline{\beta} \\ \underline{\gamma} \\ \underline{\delta} \\ \underline{\lambda} \end{bmatrix} = [\underline{I} - \underline{\alpha}]^{-1} \begin{bmatrix} \underline{h}^o \\ \underline{\beta}^o \\ \underline{\gamma}^o \\ \underline{\delta}^o \\ \underline{\lambda}^o \end{bmatrix}$$

[3]For a discussion of the application of translog (or non-linear logarithmic systems) production and utility functions see [35] and [35].

and $\underline{I}$ is the identity matrix. We thus reduce each production function to a Cobb-Douglas function in primary factors.

Next, note that cost functions exist as dual functions to the production function.[4] Let c_i = logarithm of cost, then

$$c_i = C^i(p_\ell, p_e, p_k, T) = \beta_i p_\ell + \gamma_i p_e + \delta_i p_k - h_i$$
$$- \lambda_i T \quad . \tag{5}$$

where p_ℓ, p_e, and p_k are the logarithms of the service prices of L, E, and K, and all other parameters are the same as in the production function. A "translog" function would, in addition, add second order terms [e.g. $p_k^2, p_k p_\ell, \ldots,$], but these are again ignored.[5]

In vector form, (5) becomes

$$\underline{c} = \underline{\beta} p_\ell + \underline{\gamma} p_e + \underline{\delta} p_k - \underline{h} - \underline{\lambda} T \quad . \tag{6}$$

It is important to note that the mathematical duality of cost and production functions implies the very close similarity between the production function in (4) and the cost function in (6).

Up to now the discussion has focussed only on the characterization of the technology and cost functions. In most economies, those who purchase or demand products are not aware of these functions. Rather, they are faced with a combination of price and quantity signals, indicating the relative scarcity of different goods. In what follows, we assume that markets are cleared by the use of explicit or

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[4]See Shepard [57].

[5]The work of Jorgenson and his collaborators (see [35] for example) estimates the production function by working with the dual function as in (5).

implicit pricing, and that the pricing is cost based. Producers are assumed to price products on the basis of average cost, where they recover their average cost plus a fixed markup.[6] In addition, it is assumed that the government levies excise taxes on products. These imply that the price is given by:

$$p_i = c_i + \sigma_i \tag{7}$$

where

σ_i is the sum of the markup and the excise tax.[7]

The second fundamental relation is the preference function. It is assumed that society's preferences can be represented by a well-behaved function over the final products of the society, more precisely that a preference function exists of the form $U = U(Q_I,\ldots,Q_n)$. This can be derived either from market demand functions for decentralized economies or sectors, or from the preferences of the planners or representatives in a centralized economy or sector.[8] The major assumptions are that such a function exists, that it is well-behaved, and that the agents of the economy act (at least in the long run) to attain the most preferred set of goods. Assuming that these conditions are met, the demand functions of the economy can be represented as $Q_i = D^i(P_1,\ldots,P_n,Y)$, $i = 1,\ldots,n$, where P_i are again the prices and Y is the total income. Other variables (weather, distribution of income, form of

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[6]In a Cobb-Douglas production function, the marginal cost is a constant fraction of average cost. In a constant returns to scale technology average and marginal cost are equal.

[7]Strictly speaking, we are assuming that the sum of product of (1 + the excise tax rate) and (1 + the markup) is $\exp(\sigma_i)$.

[8]See Tsvetanov and Nordhaus [62].

government) are built into the D functions. Similarly to the production function, we can represent the demand relations as:

$$q_j = \theta_j + \sum \psi_{ij} p_i + \mu_j y + \text{higher order terms.} \quad (8)$$

There are in addition certain restrictions on the functions imposed by the budget constraint, but these will be ignored for the moment. Again we ignore higher order terms. In vector form, (8) is:

$$\underline{q} = \underline{\theta} + \underline{\psi p} + \underline{\mu} y \quad (9)$$

where $\underline{\theta}$ and $\underline{\mu}$ are column vectors and $\underline{\psi}$ is a nxn matrix of price elasticities. Also note that $\underline{\theta}$ is a function of non-price variables, as well as random terms. Solving (9) using (6) and (7)

$$\underline{q} = \underline{\theta} + \underline{\psi}\ [\underline{\beta} p_\ell + \underline{\gamma} p_e + \underline{\delta} p_k - \underline{h} - \underline{\lambda} T + \underline{\sigma}] + \underline{\mu} y$$

or

$$\underline{q} = \underline{\theta} + \underline{\beta}^*\ p_\ell + \underline{\gamma}^* p_e + \underline{\delta}^* p_k - \underline{h}^* - \underline{\lambda}^* T + \underline{\sigma}^*$$

$$+ \underline{\mu} y \quad (10)$$

where an asterisk indicated premultiplication by $\underline{\psi}$ (e.g. $\underline{\beta}^* = \underline{\psi\beta}$).

Finally we need to determine the demand for individual factors. Assuming cost minimization, the first order conditions are:

$$e_i + p_e - \gamma_i' = \ell_i + p_\ell - \beta_i' = k_i + p_k - \delta_i', \quad (11)$$

each i, where $\gamma_i' = \log(\gamma_i)$ and so forth.

Equations (10), (11) and (4) give 4n equations for 4n variables $[q_i, e_i, \ell_i, k_i]$. We wish to solve for energy demand in each sector, e_i. Using (11), eliminate ℓ_i and k_i:

$$\left.\begin{aligned} \ell_i &= e_i + p_e - \gamma_i' + \beta_i' - p_\ell \\ k_i &= e_i + p_e - \gamma_i' + \delta_i' - p_k \end{aligned}\right\} \text{ each } i = 1,\dots,n. \quad \begin{aligned}(12a)\\(12b)\end{aligned}$$

Putting (12a) and (12b) into (4):

$$\underline{q} = \underline{\beta}\,[\underline{e} + p_e - \underline{\gamma}' + \underline{\beta}' - p_\ell] + \underline{\gamma e} + \underline{\delta}[\underline{e} + p_e$$

$$- \underline{\gamma}' + \underline{\delta}' - p_k] + \underline{h} + \underline{\lambda}T$$

or

$$\underline{q} = [\underline{\beta} + \underline{\gamma} + \underline{\delta}]\underline{e} + [\underline{\beta} + \underline{\delta}]p_e - \underline{\beta}p_\ell - \underline{\delta}p_k$$

$$+ \underline{\gamma}T + A^o \quad (13)$$

where

$$A^o = [\underline{h} + \underline{\beta}\underline{\beta}' - \underline{\beta}\underline{\gamma}' + \underline{\delta}\underline{\delta}' - \underline{\delta}\underline{\gamma}'] .$$

Solving (13) and (10):

$$(\underline{\beta} + \underline{\gamma} + \underline{\delta})\ \underline{e} + (\underline{\beta} + \underline{\delta})p_e - \underline{\beta}p_\ell - \underline{\delta}p_k + \underline{\lambda}T + \underline{A}^o$$

$$= \underline{\theta} + \underline{\beta}^*p_\ell + \underline{\gamma}^*p_e + \underline{\delta}^*p_k + \underline{\mu}y - \underline{h}^* - \underline{\lambda}^*T + \underline{\sigma}^* \quad (14)$$

or finally

$$\underline{e} = \underline{A}^{+} + [\underline{\gamma}^{+*} - \underline{\beta}^{+} - \underline{\delta}^{+}]p_e + (\underline{\beta}^{+*} + \underline{\beta}^{+})p_{\ell}$$

$$+ (\underline{\delta}^{+*} + \underline{\delta})p_k + \underline{\mu}^{+}y - (\underline{\lambda}^{+*} + \underline{\lambda}^{+})T \qquad (15)$$

where the $^{+}$ indicated premultiplication by $(\underline{\beta} + \underline{\gamma} + \underline{\delta})^{-1}$, the $*$ indicated premultiplication by ψ, and $\underline{A} = \underline{\sigma}* - \underline{h}^{*} - \underline{A}^{o} + \underline{\Theta}$. Equation (15) will be called the <u>energy demand equation</u>.

<u>Remarks</u>

The specification used in equation (15) is at the same time very highly oversimplified and yet very difficult to estimate. Some remarks about its properties will help understanding of the econometric results.

1. In the simplest case, assume that each industry has constant returns to scale (so that $\beta_i + \gamma_i + \delta_i$ equals unity); that the demand elasticity matrix is diagonal; and that there is no interdependency, so that the logarithmic input-output coefficients in (2) are zero for all but primary factors. In this case the **demand equation reads**:

$$e_i = A_i + [\psi_{ii}\gamma_i - \beta_i - \delta_i]p_e + [\psi_{ii}\beta_i + \beta_i]p_{\ell}$$

$$+ [\psi_{ii}\delta_i + \delta_i]p_k + \mu_i y \qquad (16)$$

for all $i = I,\ldots,n$,

or for simplicity:

$$e_i = c_{oi} + c_{1i}p_e + c_{2i}p_{\ell} + c_{4i}p_k + c_{3i}y \quad . \qquad (16')$$

2. In the econometric estimates that follow we further simplify the structure to make the equations easier to interpret. Note that the price of capital <u>services</u> is $P_k = (r + v)P_c$, where r is the appropriate discount rate, v is the depreciation rate, and P_c is the price of capital <u>goods</u>. In what follows we assume that the price of capital goods is linearly related

to the price of GNP, or that $P_c \sim P$, where P is the GNP deflator.[9] Further assume that (r + v) is constant over time. Finally we make note of the fact that labor's share in national income is relatively stable in space and time. This fact makes it difficult to distinguish between p_ℓ and y in our basic equation. To circumvent this problem we use the equation that the price of labor is proportional to the product of the GNP deflator and per capita output, or[10]

$$p_\ell = \text{constant} + y \cdot \tag{17}$$

Substituting into (16') and using the fact that $\gamma_i + \beta_i + \delta_i = 1$ we obtain

$$e_i = c'_{oi} + c_{1i}p_e + (c_{2i} + c_{3i})y + c_{4i}p \quad .$$

Note that by the basic homogeneity of degree zero of equation (16) we have that $c_1 + c_2 + c_3 + c_4 = 0$, so we can rewrite as:

$$e_i = c'_{oi} + c_{1i}p_e + (c_{2i} + c_{3i})y - (c_{1i} + c_{2i} + c_{3i})p \quad ,$$

or in final form

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[9] This assumption is theoretically justified if the energy and labor intensities of capital are equal to the energy and labor intensities of non-capital goods. This is roughly so. On an empirical level, capital goods prices are quite closely related to other goods according to the data collected for this project.

[10] Kendrick and Sato [38] and Denison [19] give evidence on the constancy of labor's share. If labor's share is a constant fraction of GNP we have $P_\ell L = C_1 P \cdot X$, where X is GNP. If the labor force participation rate is constant then $L/Pop = C_2$, where Pop is population. Thus we can relate per capita income ($Y = PX/Pop$) and wages (P_L) as:

$$Y = PX/Pop = (PX/L)(L/Pop) = PC_2P_\ell/C_1P = C_2P_\ell/C_1 \quad ,$$

or taking logarithms and rearranging we obtain (17).

$$e_i = c'_{oi} + c_{1i} (p_e - p) + (c_{2i} + c_{3i}) (y - p) \quad (18)$$

where

$$c_{1i} = \psi_{ii}\gamma_i - \beta_i - \delta_i$$

$$c_{2i} + c_{3i} = \mu_i + (\psi_{ii} + 1)\beta_i$$

This is the simplest form of the relation. It shows that in the energy demand function the price elasticity is determined not only by the elasticity of demand for the final good, but also by the production elasticities for the inputs. In particular, the own price elasticity for energy has three terms and combines four parameters: the price elasticity for the final product (ψ_{ii}), the production elasticity of energy inputs (γ_i), and the production elasticities of the other inputs (β_i, δ_i). Note also that the time variable drops out of the demand equation. It is fundamental to note that the specification used here (as in most other demand studies) cannot separate (or identify) the demand term from the parameters of the production function. This problem implies that considerable difficulty will arise in simply applying demand theory to energy demand, and that the coefficients may be quite different from "true" demand parameters. On the other hand it may not be particularly important to know the exact elasticities since for policy and prediction only the response function is necessary.

Further, note that under the usual restrictions on the signs of parameters, the <u>own</u> price term should have a negative coefficient since all three terms are negative. On the other hand the income term is ambiguous since (Ψ_{ii} + 1) is indeterminant in sign.

3. It is clear that we will generally be unable to identify all the parameters of the structural equations without outside information. Thus in simplified equation (18), there are two coefficients to be estimated (aside from the constant) and four independent coefficients.

4. The equations as described above do not necessarily meet the budget constraints which are necessary to any set of demand equations. The first set of constraints is that the sum of the price and income coefficients in (15), (16) or (18) be identically zero in all equations. We have ensured this simply be dividing the prices by the price of output, P.

A more difficult set of conditions to satisfy is that the weighted sum of the expenditure elasticities must sum to zero. As has been shown by Koopmans and Uzawa,[11] this is not in general possible with constant elasticity demand functions of the type used here. On the other hand, if we reintroduce the omitted second order terms, these conditions can be met, at least locally. In forecasting work, where it is necessary to move beyond small variations, the best solution seems to assume that the biggest sector is the residual sector and thereby make the biggest sector the one that ensures that the accounting identities hold.

5. The fundamental problem of identifying the demand curve can be treated relatively easily. We introduce stochastic terms in equations (2), (7), and (8) as follows:

$$\tilde{\underline{h}} = \underline{h} + \underline{u} \qquad (2')$$

$$\tilde{\underline{g}} = \underline{g} + \underline{v} \qquad (7')$$

$$\tilde{\underline{\theta}} = \underline{\theta} + \underline{w} \qquad (8')$$

where $\underline{u}$, $\underline{v}$ and $\underline{w}$ are disturbances and the tildes (~) indicate that the specification includes the original equation plus the stochastic disturbance. With some tedious manipulation it can be shown that our final equation in (15) can be written as

$$\tilde{\underline{e}} = \underline{e} + \underline{z} \quad , \qquad (15')$$

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[11]See Koopmans [39], Uzawa [68].

where

$$\underline{z} = [\underline{\beta} + \underline{\gamma} + \underline{\delta}]^{-1} \left[\underline{w} + \underline{\psi} \{\underline{v} - [\underline{I} - \underline{\alpha}]^{-1} \underline{u}\} - [\underline{I} - \underline{\alpha}]^{-1} \underline{u}\right] .$$

Since the disturbance is independent of all righthand side variables, the estimates in the equation given above will be consistent.

The further question in identification concerns the independent variables in equation (15).[12] We assume that all variables are independent of the disturbances in the equation. This seems reasonable except for the price of energy, p_e, which is likely to be correlated with disturbances in the energy demand equations. For example, it is sometimes argued that the price escalation in 1973 was largely due to a very rapid growth in energy demand. We think it unlikely that a very serious bias arise for two reasons: First, energy prices are mainly determined in the world market, so that the correlation with the disturbances in individual countries is probably quite small. Second, in some sectors (especially transportation) prices are largely determined by taxes, which are theoretically exogenous and in fact unlikely to be correlated with disturbances.[13]

III. The Data and Variables

The econometric results presented below are for a group of seven western countries: Belgium, France, the Federal Republic of Germany, Italy, the Netherlands, the United Kingdom, and the United States. These countries were chosen in the first round of experiments partially because the author is vaguely familiar with their economies, partially because the

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[12]For a discussion of the identification problem in demand analysis, see Malinvaud [45], chapter 18.

[13]See Krugman [41].

assumptions made in the theoretical model are probably best realized in these economies, and perhaps most important because the rather trying data requirements were satisfied.

The time period for the study was basically from 1955 to 1972, for this is the period during which the quantity data collected by the OECD were available. The major difficulty was to gather data on prices of different fuels at the appropriate sectoral level; for this we relied on a combination of statistics published by the European Economic Community, national governments, and guesswork. The data are still in a preliminary state of collection, under the care of Mrs. Claire Doblin, and will be made available when they have been checked and collated in a convenient manner.

In what follows we consider the total consumption of fuel in each sector and ignore the composition (or breakdown) of the total consumption between fuels. The important difference between this and earlier studies is that we consider <u>the demand for net energy</u>, whereas earlier studies considered only gross energy. This distinction rests on the following fundamental hypothesis:

> <u>Within each sector, there is a subclass of fuels which are perfect substitutes. For equal levels of non-fuel cost, interfuel competition will be determined by the relative net prices of fuels</u>.

To make this definition operational we need to know the efficiency of each fuel in each sector, denoted by η_{ij}. We then calculate the net consumption (QN_{ij}) and price per unit net energy (PN_{ij}), given gross consumption (Q_{ij}) as:

$$QN_{ij} = \eta_{ij} Q_{ij} \quad ,$$

$$PN_{ij} = P_{ij}/\eta_{ij} \quad .$$

Under the fundamental hypothesis given above, we can write the sectoral aggregate net quantity as a function of sectoral net price:

$$QN_j = f(\bar{P}_j) \quad , \; j = \text{sectors}$$

where

$$QN_j = \sum_i QN_{ij} = \sum_i Q_{ij} \; \eta_{ij}$$

and

$$\bar{P}_j = \sum_i w_{ij} \; PN_{ij}$$

where the weights are the shares in the total net consumption:

$$w_{ij} = QN_{ij} / \sum_i QN_{ij}$$

and

$$\sum_i w_{ij} = 1 \quad .$$

The efficiency data are not generally available and were determined by the author in conjunction with published data (see Hottel and Howard [31]), engineering handbooks, and with the kind help of Dipl. Ing. Norbert Weyss now at IIASA , formerly of Brown Boveri. The assumed efficiencies are as follows in Table 1. The tableau of sectors and fuels is shown in Table 2.

TABLE 1. Efficiendies of Different Fuels

Fuel	Sector		
	Domestic	Transport	Industry, except energy
Solid	0.20	0.044	0.70
Liquid	0.60	0.22	0.80
Gas	0.70	0.22	0.85
Electric	0.95	0.40	0.99

In the aggregate analysis and for the energy sector we do not have data on the energy sector explicitly, so we have used the same price and efficiency data as for the industry sector. It should be stressed that the important aspect of the efficiency figures is the relative size of the efficiencies, and that the absolute levels are completely irrelevant for the estimates.

Macroeconomic Data

Gross Domestic (or National) Product was taken to be the aggregate income measure, and the aggregate price index is the GNP or GDP deflator. Per capita variables refer to total population. Weather variables record the deviation from "climatic means" in degrees centigrade at selected stations for the entire year.

Table 2. Tableau of Sectors and Fuels

Fuel	Sector				
	Energy (N)	Transport (T)	Industry (except energy) (I)	Residential Commercial and Residual (D)	Aggregate
Liquid (petroleum)	Q_{LN}, P_{LN}	Q_{LT}, P_{LT}	...	...	Q_{LA}, P_{LA}
Gas (Town Gas, Natural Gas)	Q_{GN}, P_{GN}				⋮
Solid (Coal, Lignite, Briquettes)	Q_{SN}, P_{SN}				
Electricity	Q_{EN}, P_{EN}	...		...	Q_{EA}, P_{EA}

The energy flows can be described in terms of the following tableau in Table 2 where Q_{ij} is quantity and P_{ij} the price of fuel i consumed in sector j in terms of natural units.

Pooling of Country Data

In the pooling of individual countries, it is assumed that countries have the same preference functions and production functions; since the rate and level of technological change drops out of the equation, there is no need to assume these to be the same across countries. The major difficulty in pooling countries revolves around the question of the appropriate conversions between different currencies.

The usual procedure is to use market exchange rates, but these are seriously deficient. First, it is clear that for market economies market exchange rates reflect in part volatile temporary factors, and that temporary movements do not reflect genuine changes in the relative real incomes of different countries. Is it credible that from January 1973 to February 1973 the relative real income of the USA fell 120 percent at an annual rate? This point is even clearer for countries with non-market determined (or official) exchange rates, where these are instruments of policy. A superior method of measuring real incomes is to use purchasing power parity rates, which compare the purchasing power of incomes of different countries. Since these indices will differ according to the bundle of goods used, we have taken the geometric mean of purchasing power exchange rates according to the USA and the local composition of GNP with 1960 as a base year. These are used to translate each currency into a "universal" standard of value for a given year; domestic GNP deflators are then used to indicate changes over time. It should be noted that purchasing power parity exchange rates generally lead to a lower inequality of income distribution across countries than existing exchange rates.[14]

The Lag Structure

From either a theoretical or a casual viewpoint, it is clear that the time lags in the response function are likely

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[14] This procedure is discussed by Balassa [7]. The purchasing power parities used in the present paper are drawn from Balassa.

to be quite long; it would be surprising if full adjustment in the lag took place in less than ten years. Because the sample period for an individual country is short (no more than eighteen years), it is extremely difficult to get a precise determination of the lag structure. On the other hand, if we are mainly concerned with the long-run price and income elasticities, our specifications will be directed toward getting firm estimates of the long-run elasticities and less toward a precise determination of the lag.

In the present paper we will use two different lag structures: first, the Koyck or geometric lag:[15]

$$y_t = (1-\lambda) y_{t-1} + \lambda y^*(z)$$

where

y_t is the realized value of the dependent variable;

y_{t-1} the realized value lagged once; and

y^* the desired or long-run level of the dependent variable which in turn is a function of exogenous variables z.

The Koyck lag has the advantage of being extremely parsimonious in the use of variables; this advantage must be weighed against the disadvantages that the lag structure imposed on all variables is the same and is geometric declining, and the more important statistical disadvantage that if the errors are autocorrelated the estimate of the coefficient λ is biased.

As a second form of lag structure, we have also used the polynomial or Almon lag:

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[15]See Koyck [40] and Malinvaud [45], Chapter 15.

$$y_t = \alpha + \sum_{i=0}^{T} \beta_i z_{t-i} \quad .$$

In this specification the β_i are assumed to be of degree $n \leq T$, where $\beta_i = \sum_{\theta=0}^{n} \gamma(\theta) i^{\theta}$ for $0 \leq \theta \leq T$ and $\beta_i = 0$ otherwise. For forms where there are no end restrictions, this procedure involves estimating (n + 1) rather than (T + 1) coefficients.[16] The length of lag is predetermined, as is the degree of the polynomial. This technique has the advantages that it leads to an unbiased estimate of the coefficients as well as that it allows a flexible shape of the lag; the important disadvantage, however, is that the length of the sample will be very seriously reduced if either the sample period is short or if length of lag is long.

It is clear from this very short description that in a rough sense the geometrical and the polynomial lags complement each other. If their messages are strong and similar, then we can have some confidence in the results. If the messages are weak or dissimilar, then we must be suspicious of both.

IV. Results: Individual Countries[17]

The model described above was applied to both individual countries and to all seven countries pooled. We will first present the results for the unpooled data. The specifications examined in the tables below are:

$$q_t = a_o + a_1 p_t + a_2 y_t + a_3 q_{t-1} \tag{A}$$

$$q_t = b_o + b_1 \left(\sum_{T_o}^{T_1} w_i \, p_{t-i}\right) + b_2 y_t \quad , \quad \sum w_i = 1. \tag{B}$$

---

[16] See Almon [4] or Dhrymes [20].

[17] The results for Belgium were not completed on time for the individual country results, although Belgium is included in the pooled equations.

where

(B1) has $T_o = 0$, $T_1 = 3$, w_i quadratic with $w_4 = 0$;

(B2) has $T_o = 0$, $T_1 = 5$, w_i quadratic with $w_6 = 0$.

and

q_t = per capita net energy consumption;

p_t = relative net price of energy; and

y_t = per capita real GNP;

all variables in natural logarithms.

Results for the Aggregate

First consider the aggregate equations for the economies. These aggregate four sectors: energy, transportation, industry other than energy, and residential-residual.

Tables 3 and 4 present the results in a standard format that will be used for the individual sectors as well. In this we present only the elasticities and not the overall statistics of the equations. The elasticities in the column "short-run" are defined as:

$$\text{short-run elasticity} = \frac{\text{percentage change in net energy demanded during current year}}{\text{percentage change in net energy price during current year}}$$

while the long-run elasticity is defined as:

$$\text{long-run elasticity} = \frac{\text{percentage change in net energy demanded per year after entire lag is included}}{\text{percentage change in net energy price during current year}}$$

In terms of formulas (A) and (B) above, the short-run elasticity is a_1 or a_2 in equation (A), and $b_1 w_0$ or b_2 in

Table 3. Income elasticities for different countries and different specifications: aggregate.

	Short-run			Long-run		
	A	B1	B2	A[b)]	B1	B2
France	1.11 (.26)	a)	a)	c)	1.17 (.09)	1.20 (.18)
Federal Republic of Germany	.29 (.11)	a)	a)	.61 (.31)	1.15 (.13)	1.42 (.11)
Italy	1.07 (.37)	a)	a)	1.55 (.67)	1.25 (.13)	1.16 (.26)
Netherlands	.57 (.28)	a)	a)	.78 (.46)	.48 (.34)	.05 (.50)
United Kingdom	.57 (.13)	a)	a)	.66 (.22)	.67 (.09)	.60 (.18)
United States	.39 (.10)	a)	a)	.84 (.32)	.32 (.10)	.26 (.09)

Note: Figures without parentheses are coefficients, while figures in parentheses are standard errors.

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a) Short-run elasticity assumed equal to long-run.

b) Calculation of local standard error given in Appendix.

c) Lag term had incorrect sign, so long-term elasticity not calculated.

Table 4. Price elasticities for different countries and different specifications: aggregate.

	Short-run			Long-run		
	A	B1	B2	A[b]	B1	B2
France	-.16 (.12)	-.03 (.09)	-.08 (.10)	c)	.10 (.26)	.06 (.15)
Federal Republic of Germany	-.44 (.25)	.30 (.19)	.17 (.13)	-.89 (.59)	.70 (.32)	1.45 (.47)
Italy	-.33 (.24)	-.72 (.13)	-.75 (.11)	-.50 (.39)	-1.30 (.21)	-1.33 (.45)
Netherlands	-.58 (.21)	-.68 (.19)	-.56 (.23)	-.81 (.39)	-1.20 (.25)	-1.56 (.51)
United Kingdom	-.42 (.16)	-.42 (.14)	-.35 (.16)	-.49 (.22)	-.26 (.25)	-.31 (.28)
United States	-.26 (.28)	-.50 (.19)	-.41 (.16)	-.57 (.64)	-1.73 (.36)	1.94 (.34)

Note: Figures without parentheses are coefficients, while figures in parentheses are standard errors.

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[a] Short-run elasticity assumed equal to long-run.

[b] Calculation of local standard error given in Appendix.

[c] Lag term had incorrect sign, so long-term elasticity not calculated.

equation (B). The long-run elasticity is $a_1/(1 - a_3)$ or $a_2/(1 - a_3)$ in equation (A) and b_1 or b_2 in equation (B).

First consider the income elasticities reported in Table 3: We focus only on the long-run elasticities. These show one major surprise: the elasticities appear to differ significantly across different countries. The US, UK, and Netherlands have low elasticities, while the other three countries have rather high elasticities. There is no clear indication as to whether energy demand tends to grow faster or slower than output. Moreover, these results are quite significant by the standard statistical tests.

The price elasticities for the aggregate economies are reported in Table 4. These results are in fact quite representative of the general quality of the estimates for price elasticities: they are highly variable and not well determined. Again examine specification (B1). Italy, Netherlands, and the United States have well-determined price terms, with the correct sign. France and the FRG have incorrect signs, but they are poorly determined.

It is possible to calculate a composite statistic for the sample countries: this relies on the assumption that the coefficients are samples from distributions with a common mean ($\bar{M}$) and differing variance--the variance differing because the range of the independent variables differs. These statistics are shown in Table 5 for specification (B1) (this specification was chosen to maximize sample size and minimize the standard error of the coefficients.)[18]

The results for the composite statistics give somewhat greater shape to the verbal discussion of the results for the aggregate. They indicate that demand is price-inelastic, and moderately well-determined. The income elasticity, on the other hand, is quite well determined in the aggregate, and is slightly, but not significantly less than +1.

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[18]The derivation of the composite statistic is given in the Appendix.

Table 5. Composite estimate of coefficients, specification B1, aggregate.

	Mean	Standard Deviation
Price elasticity	-0.66	0.26
Income elasticity	0.84	0.11

Note: The composite statistic is calculated by the formula for the minimum variance estimate for a sample from a different population with the same mean and different variances (see Appendix).

Individual Sectors

The national economies were also disaggregated into four sectors, and each sector was analyzed to see if there were significant effects. Each sector, it should be noted, has its individual price and quantity index, but the output indicator for each of the individual sectors is the national output indicator.

In discussing the individual countries and sectors, we will use the following criterion in determining which specification is preferred: roughly speaking, we choose the specification which has the lowest standard error for the coefficient. On the other hand, we realize that the standard errors in specification (A) are probably biased downward because of the inclusion of the lagged dependent variable, and make a rough correction by multiplying this standard error by 1.5 in making the comparisons. For most cases, this makes the specification (B1) the preferred specification; this specification is used in all composite statistics.[19]

The domestic sector is shown in Tables 6 and 7. These results are quite encouraging, indeed the most encouraging of any sector. The income elasticities are positive, presumably indicating that higher levels of income are important in inducing both central heating and the use of many energy-intensive appliances. On the other hand, the income elasticities show some irregularity across the sample.

As far as the price elasticities are concerned, these are consistently negative across both countries and specifications. The only positive coefficients are for France, but these are not significant. The FRG, Italy, the Netherlands and the United States show consistent, significant and negative price elasticities,

[19]This is in distinction to the usual procedure of choosing a specification with a high t-statistic. Put differently, we are interested in precise determination of the results, not in whether the results show a significant difference from an arbitrary number.

Table 6. Income elasticities for different countries and different specifications: domestic.

	Short-run			Long-run		
	A	B1	B2	A[b]	B1	B2
France	.93 (.55)	a)	a)	1.86 (1.54)	2.34 (.52)	3.43 (.94)
Federal Republic of Germany	.60 (.29)	a)	a)	1.30 (.71)	1.55 (.28)	1.77 (.40)
Italy	.65 (.27)	a)	a)	1.10 (.51)	.49 (.29)	.43 (.37)
Netherlands	.21 (.52)	a)	a)	.42 (1.05)	.00 (.63)	-.11 (.95)
United Kingdom	.97 (.36)	a)	a)	1.04 (.55)	1.10 (.32)	.57 (.52)
United States	.17 (.12)	a)	a)	.47 (.36)	.27 (.08)	.22 (.09)

Note: Figures without parentheses are coefficients, while figure in parentheses are standard errors.

---

[a] Short-run elasticity assumed equal to long-run.

[b] Calculation of local standard error given in Appendix.

[c] Lag term had incorrect sign, so long-term elasticity not calculated.

Table 7. Price elasticities for different countries and different specifications: domestic.

	Short-run			Long-run		
	A	B1	B2	A[b]	B1	B2
France	-.07 (.29)	.02 (.27)	.33 (.28)	-.14 (.59)	.22 (.34)	1.24 (.83)
Federal Republic of Germany	-.35 (.19)	-.35 (.18)	-.34 (.21)	-.76 (.46)	-.68 (.35)	-.49 (.25)
Italy	-.63 (.13)	-.65 (.15)	-.62 (.19)	-1.05 (.30)	-1.40 (.25)	-1.44 (.36)
Netherlands	-.58 (.21)	-.42 (.20)	-.35 (.28)	-1.16 (.58)	-1.30 (.33)	-1.37 (.55)
United Kingdom	-.36 (.19)	-.40 (.37)	-.38 (.40)	-.38 (.25)	-.30 (.45)	-.59 (.48)
United States	-.55 (.19)	.52 (.12)	-.57 (.10)	-1.53 (.71)	-1.75 (.21)	-1.90 (.20)

Note: Figures without parentheses are coefficients, while figures in parentheses are standard errors.

---

[a] Short-run elasticity assumed equal to long-run.

[b] Calculation of local standard error given in Appendix.

[c] Lag term had incorrect sign, so long-term elasticity not calculated.

while the United Kingdom is negative but only marginally significant.

We have again calculated the composite statistics in Table 8. These statistics indicate that if we treat the results as a random sample from a population with fixed mean and different variances then the price coefficient is quite well-determined, -1.14 with a standard error of 0.29, while the income elasticity is quite low and very well-determined, 0.44 (± .17).

For the transport sector, the results are quite mixed. Recall that the transport sector is largely road transport (approximately 80% of fuel is for automobiles, trucks, and buses). Further it is generally thought that transport is highly income elastic. The results of Table 9 bear this out by and large. All six countries show that transport has an income elasticity greater than unity; for high income countries (the US and FRG) the income elasticities are very close to unity, while the medium and low income countries (especially Italy and the UK) have income elasticities which are very high.

The price elasticities for the transport sector are also quite encouraging (see Table 10). We originally hoped that the wide range of prices, mainly due to taxation on fuel for road traffic, would lead to well-determined price coefficients. The major anomaly is that short-run price elasticities are too large, although they are not particularly well determined. The coefficients for the short-run--or one year--price elasticities lie in the range from .02 to -.65. These results indicate that it would not be surprising to find a rapid response of consumption in the transport sector to the very rapid rise in fuel costs over the last few years. Surprisingly, long-run coefficients hardly differ from the short-run coefficients. The long-run coefficients range from .13 to -.87. Three countries have quite sharply determined long-run coefficients: France (-.15 ± .13), the FRG (-.87 ± .18), and the UK (-.15 ± .21). The overall impression is that transport

Table 8. Composite for the domestic sector, specification (B1).

	mean	standard deviation
Price elasticity	-1.14	.29
Income elasticity	0.44	.17

Note: The composite statistic is calculated by the formula for the minimum variance estimate for a sample from a different population with the same mean and different variance (see Appendix).

Table 9. Income elasticities for different countries and different specifications: transport.

	Short-run			Long-run		
	A	B1	B2	A[b]	B1	B2
France	1.62 (.42)	a)	a)	c)	1.32 (.08)	1.34 (.15)
Federal Republic of Germany	.79 (.18)	a)	a)	1.65 (.56)	1.19 (.11)	1.06 (.16)
Italy	.61 (.21)	a)	a)	1.53 (.67)	1.65 (.14)	1.63 (.26)
Netherlands	.33 (.13)	a)	a)	1.74 (.94)	1.52 (.20)	1.18 (.24)
United Kingdom	1.54 (.50)	a)	a)	2.20 (1.05)	2.11 (.06)	2.09 (.08)
United States	.24 (.09)	a)	a)	.83 (.49)	1.01 (.15)	1.68 (.42)

Note: Figures without parentheses are coefficients, while figures in parentheses are standard errors.

---

a) Short-run elasticity assumed equal to long-run.

b) Calculation of local standard error given in Appendix.

c) Lag term outside a priori range, so long-term elasticity not calculated.

Table 10. Price elasticities for different countries and different specifications: transport.

	Short-run			Long-run		
	A	B1	B2	A[b]	B1	B2
France	-.66 (.25)	-.29 (.09)	-.18 (.08)	c)	-.15 (.13)	-.10 (.16)
Federal Republic of Germany	-.13 (.14)	-.55 (.09)	-.53 (.07)	-.28 (.31)	-.87 (.18)	-.89 (.19)
Italy	-.09 (.07)	-.24 (.26)	-.17 (.43)	-.23 (.19)	-.60 (.40)	.01 (.65)
Netherlands	.05 (.10)	-.49 (.23)	-.38 (.14)	.26 (.53)	-.37 (.40)	-.92 (.38)
United Kingdom	.02 (.12)	-.20 (.09)	-.17 (.10)	.03 (.12)	-.15 (.21)	-.16 (.20)
United States	-.22 (.14)	-1.04 (.20)	-.82 (.20)	-.76 (.59)	.13 (.47)	1.88 (1.21)

Note: Figures without parentheses are coefficients, while figures in parentheses are standard errors.

---

[a] Short-run elasticity assumed equal to long-run.

[b] Calculation of local standard error given in Appendix.

[c] Lag term had incorrect sign, so long-term elasticity not calculated.

demand is quite price-inelastic. The one disturbing feature is that the lag structure is simply implausible: the long-run coefficients in some cases are smaller than the short-run coefficients, and this is unacceptable.

Table 11 shows the composite statistic for the transport sector. As noted above, the overall result is that the income elasticity is larger than unity, and quite significantly so, while the price elasticities are small and negative.

Industry is divided into two parts, the energy and the non-energy sectors. The energy sector, strictly speaking, should not be treated in a symmetrical manner with those sectors in which energy is consumed. Nevertheless for completeness we present both sets of results.

Tables 12 and 13 present the regression results for industry, except the energy sector. The income elasticities again show the general patterns of having net demands with income elasticities scattered around unity, and they are generally pretty well determined. The price elasticities, on the other hand, show a pattern of instability, ranging from 1.0 for the FRG to -1.0 for Italy. Only four coefficients, however, are well determined: Italy, France, and the UK have a significantly negative coefficient, while the FRG has a significant positive coefficient.

The composite results for the industry except the energy sector are shown in Table 14. These show that this sector has an income elasticity below, but not significantly below unity, and a price coefficient which is negative, but again not significantly so.

Finally, we have the results for the energy sector. It should first be noted that this sector has a rather different character from the other sectors. Energy consumption in the energy sector is in reality energy consumed in transformation of one energy form into another, or in extraction and upgrading of fuels. Thus the energy consumption in the energy sector

Table 11. Composite statistic for transport, specification B1.

	Mean	Standard Deviation
Income	1.68	.10
Price		
Short-run	-.39	.12
Long-run	-.36	.22

Note: The composite statistic is calculated by the formula for the minimum variance estimate for a sample from a different population with the same mean and different variance (see Appendix).

Table 12. Income elasticities for different countries and different specifications: industry, except energy.

	Short-run			Long-run		
	A	B1	B2	A[b]	B1	B2
France	.17 (.25)	a)	a)	.29 (.45)	.57 (.16)	.18 (.26)
Federal Republic of Germany	.24 (.17)	a)	a)	.46 (.38)	1.24 (.17)	1.38 (.16)
Italy	1.18 (.22)	a)	a)	c)	1.15 (.19)	1.72 (.47)
Netherlands	.72 (.50)	a)	a)	.87 (.66)	1.72 (.70)	2.11 (1.25)
United Kingdom	-.02 (.12)	a)	a)	-.02 (.13)	.06 (.15)	-.17 (.25)
United States	.63 (.40)	a)	a)	.97 (.42)	.99 (.13)	.92 (.19)

Note: Figures without parentheses are coefficients, while figures in parentheses are standard errors.

---

a) Short-run elasticity assumed equal to long-run.

b) Calculation of local standard error given in Appendix.

c) Lag term had incorrect sign, so long-term elasticity not calculated.

Table 13. Price elasticities for different countries and different specifications: industry, except energy.

	Short-run			Long-run		
	A	B1	B2	A[b]	B1	B2
France	-.47 (.13)	-.45 (.10)	-.39 (.08)	-.82 (.46)	-.38 (.16)	-.44 (.20)
Federal Republic of Germany	-.11 (.29)	.29 (.15)	.04 (.13)	-.21 (.56)	1.03 (.25)	1.06 (.28)
Italy	-.82 (.17)	-.60 (.14)	-.49 (.13)	c)	-.96 (.22)	.45 (.41)
Netherlands	-.51 (.27)	-.34 (.28)	-.29 (.37)	-.61 (.37)	.01 (.48)	.28 (.83)
United Kingdom	-.79 (.20)	-.79 (.17)	-.63 (.23)	-.88 (.28)	-.73 (.31)	-.95 (.43)
United States	-.21 (.40)	-.09 (.18)	-.11 (.17)	-.33 (.63)	-.35 (.23)	-.47 (.26)

Note: Figures without parentheses are coefficients, while figures in parentheses are standard errors.

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[a] Short-run elasticity assumed equal to long-run.

[b] Calculation of local standard error given in Appendix.

[c] Lag term had incorrect sign, so long-term elasticity not calculated.

Table 14. Composite statistics for industry, except energy, specification (B1).

	Mean	Standard Deviation
Income	0.78	0.17
Price	-0.30	0.23

Note: The composite statistic is calculated by the formula for the minimum variance estimate for a sample from a different population with the same mean and different variance (see Appendix).

will be relatively large if the country has a large extractive industry, as in the FRG or the United States; or if the mix of fuels is tilted toward converted fuels (such as electricity or town gas) rather than low grade fuels (such as coal); or if the energy sector has low conversion efficiencies in transformation processes such as electricity generation. Thus in judging the energy-intensiveness of economies, especially where considerable specialization occurs, one should probably exclude the energy sector and consider only the rest of the economy.

Notwithstanding these caveats, we present in Tables 15 and 16 the results for the energy sector. One surprising result is that the energy sector exhibits very low income elasticities, ranging from a low of -.94 for the United Kingdom to a high of .36 for the United States. The price elasticities are again quite mixed: Italy and France show negative significant coefficients, while all other countries show insignificant coefficients.

Table 17 shows the composite statistics for the energy sector: these confirm the impression that the income elasticity tends to be somewhat low and the price coefficient is negative but insignificant.

V. Results for the Pooled Sample

The results presented above for the individual countries are not entirely encouraging; an honest man would have to admit that they shed little light on the questions that the present study set out to investigate. However, it was originally hoped that by combining the experience of the several countries in the sample the results could be sharpened. Thus the next step considers combining or pooling the data into a single relationship.

The theoretical basis for pooling countries is to assume that all countries have similar preference functions and production functions, but that the differences in incomes and

Table 15. Income elasticities for different countries and different specifications: energy.

	Short-run			Long-run		
	A	B1	B2	A b)	B1	B2
France	.34 (.31)	a)	a)	.97 (1.10)	.32 (.19)	.38 (.37)
Federal Republic of Germany	-.32 (.16)	a)	a)	-.65 (.45)	-.13 (.27)	.49 (.24)
Italy	-.09 (.31)	a)	a)	-.27 (.93)	.25 (.30)	-.98 (.45)
Netherlands	.28 (.43)	a)	a)	c)	-.01 (.89)	-1.04 (1.69)
United Kingdom	-.41 (.24)	a)	a)	-.75 (.66)	-.94 (.17)	-1.28 (.29)
United States	.27 (.10)	a)	a)	.45 (.22)	.36 (.07)	.28 (.08)

Note: Figures without parentheses are coefficients, while figures in parentheses are standard errors.

---

a) Short-run elasticity assumed equal to long-run.

b) Calculation of local standard error given in Appendix.

c) Lag term had incorrect sign, so long-term elasticity

Table 16. Price elasticities for different countries and different specifications: energy.

	Short-run			Long-run		
	A	B1	B2	A[b]	B1	B2
France	.08 (.22)	.52 (.10)	.22 (.10)	.23 (.66)	-.30 (.12)	-.48 (.23)
Federal Republic of Germany	-.28 (.26)	-.06 (.32)	-.25 (.23)	-.56 (.59)	.89 (.50)	2.15 (.43)
Italy	-.48 (.20)	-.49 (.18)	-.55 .27	-1.45 (1.17)	-1.19 (.35)	-2.41 (.72)
Netherlands	-.39 .24	-.32 (.24)	-.21 (.25)	c)	-.52 (.49)	-1.11 (.88)
United Kingdom	.01 (.30)	.11 (.25)	.04 (.23)	.02 (.67)	1.28 (.73)	2.14 (1.34)
United States	-.22 (.15)	-.18 (.14)	-.26 (.13)	-.37 (.28)	-.71 (.44)	-1.53 (.67)

Note: Figures without parentheses are coefficients, while figures in parentheses are standard errors.

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[a] Short-run elasticity assumed equal to long-run.

[b] Calculation of local standard error given in Appendix.

[c] Lag term had incorrect sign, so long-term elasticity not calculated.

Table 17. Composite statistics for energy.

	Mean	Standard Deviation
Income	0.18	0.14
Price	-0.33	0.25

Note: The composite statistic is calculated by the formula for the minimum variance estimate for a sample from a different population with the same mean and different variances (see Appendix).

relative prices lead to different energy-intensiveness in different sectors. Thus we would expect that with high gasoline prices and low incomes in Europe, the amount of gasoline consumed in Europe per person would be considerably below that in North America, which has low relative gasoline prices and high relative incomes. In addition to the systematic effects of prices and incomes, there may be other omitted variables which are crucial to the determination of energy demand. Thus weather is clearly important in determining domestic heating demands; the road network in determining automotive demand; the industrial structure in determining the industrial demand. We have assumed that these effects, which can be called <u>country effects</u>, are multiplicative and do not vary systematically over time. This implies that we can simply use country dummy variables in our logarithmic specification to represent the effects for individual countries. We would be surprised if these country effects were nil; on the other hand, we would be disappointed if they accounted for too much of the variation.

Thus the specification for the pooled model is that countries have different <u>levels</u> of energy demand, but that the elasticities, or response to prices and incomes, are constrained to be the same. In order to prepare for what follows, it should be noted how the pooling is able to reduce the chaos of the individual country results to relatively well-determined answers. Recall that the individual country results are poorly determined; this is largely due to the fact that price and income are highly collinear for an individual country, and therefore the data cannot determine the coefficients with great precision. This problem, the problem of multicollinearity, is shown graphically in Figure 1. Country A has a history of incomes and prices which determines a likelihood function for coefficients b_1 and b_2 shown by the contours lying between A and A'; the contours indicate a given confidence region for the country. For country A the individual coefficients are poorly determined and lie along a "ridge." Country B has a

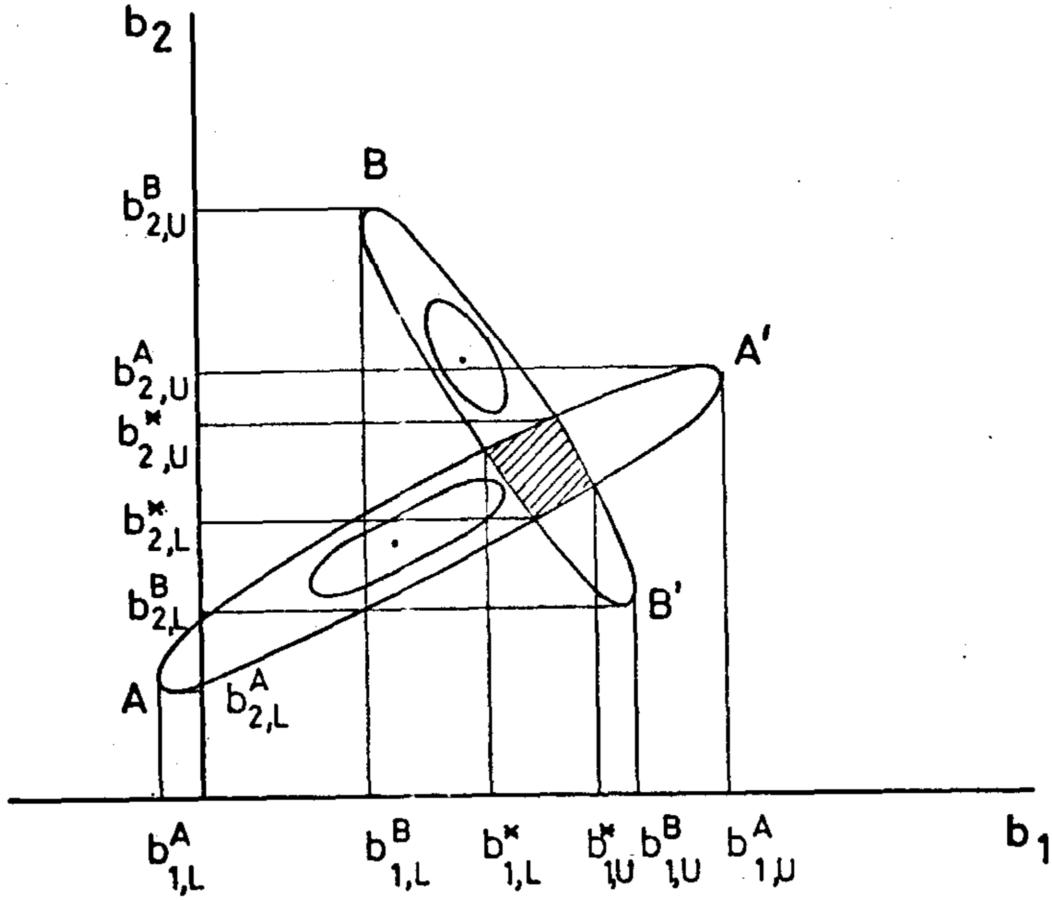

Figure 1. Shaded area represents the estimate of (b_1, b_2) obtained by pooling two samples with multicollinear data.

rather different history, but one which also exhibits high multicollinearity between the two independent variables, with a resulting likelihood function shown by the BB' contours, which lie along a different "ridge."

Consider what happens when countries A and B are pooled and constrained to have the same elasticities: only the shaded region in Figure 1 lies above the second set of likelihood contours for both countries. Thus the joint region, consistent with the histories of both countries lies in a much smaller region than that for either of the individual countries. Thus if the outer contour represents the 90% contour level, we have rather wide ranges of estimates for the parameters, with the confidence interval for b_1 lying in the range $[b^A_{1,L}, b^A_{1,U}]$ for country A and in the range $[b^B_{1,L}, b^B_{1,U}]$ for country B, with the analogous range for the coefficient b_2. By pooling the two countries, the confidence interval which is consistent with both histories is reduced to the much smaller range $[b^*_{1,L}, b^*_{1,U}]$ for b_1 and the analogous range for b_2.[20] Put differently, if the individual histories show great multicollinearity (which they do in the energy area), and if the different countries have rather different histories (which, again, they do), then it is possible to break the grip of the multicollinearity by pooling the countries. Note that it is not necessary that the outcome be so nice as that pictured in Figure 1; it could turn out that a third country lay well outside the shaded region and the coefficients would remain very poorly determined. With seven countries, it seems likely that the results will reduce the uncertainty due to the multicollinearity without lending spurious accuracy to the results.

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[20]It should be noted that the shaded region is only a heuristic device for indicating the results of pooling. It is slightly more complicated to determine the exact likelihood contours for the joint sample of A and B.

In our pooling we have used a sample period which is common for all sectors and which is as follows:

United States (1959-1972)	14	observations
Federal Republic of Germany (1960-1972)	13	
France (1959-1972)	14	
Italy (1964-1972)	9	
Belgium (1965-1972)	8	
Netherlands (1959-1972)	14	
United Kingdom (1963-1972)	10	
Total	82	observations

We kept the length of lag relatively short--a maximum of one year lag for income and four years for price. We could have extended the lag for price, but as each further year reduced the number of observations by seven, four years seemed a good compromise. Moreover, although we were interested in the lag structure, the major purpose of the study was the long-run income and price elasticities, so an attempt was made to estimate these in as sharp a way as possible.

To construct the equations we made the following simplifications. First, the current and lagged income terms appeared to have the same sized coefficients, so we constrained them to be equal. Next, we assumed that the lag on prices was linear over a five year period; this lag is undoubtedly too short, but the shape is probably roughly correct. With these assumptions we reduce the equations to the following:

$$q_{ti} = \alpha_i + \beta[\sum_{\theta=0}^{4} 0.2\ p_{t-\theta,i}] + \gamma\ [0.5y_{t,i} + 0.5y_{t-1,i}] \qquad (19)$$

where

α_i are individual country effects;

β is the common long-run price elasticity; and

γ the common long-run income elasticity.

The results for the four individual sectors and the aggregate are shown in Tables 18-22. In what follows we focus on the long-run price elasticities and the differences between individual countries. Note that because the dummy variable for the United States is omitted, country variables should be interpreted as different from the United States.[21]

Results

The results of the pooling show a considerable improvement over the unpooled data. In all of the four demand sectors the price elasticities have the right sign and are well-determined while all the income elasticities are very well-determined. First concentrating on the price elasticities, it is seen that these are -.36 (±.12) for the transport sector, -.79 (±.08) for the residential sector, -.52 (±.17) for industry other than energy, and -.58 (±.10) for the energy sector.[22] In the aggregate, the estimate is -.85 (±.10). These results are not out of line with results of other studies: for the most part, where price elasticities have been found, these lie in the range from 0 to -1.[23] Elasticities of this magnitude indicate that the long-run response of energy consumption to price is only moderate when the three factors discussed above are combined; these were the demand response proper, the production response, and the substitution between energy and other factors (see pp. f). To the extent that we can take the differences

---

[21]A note on the statistics: R^2 is the fraction of the variance of the dependent variable explained by the regression whereas $\bar{R}^2$ is corrected for degrees of freedom. SEE is the standard error of estimate of the equation. Since the equation is in logarithmic terms the SEE is roughly the fractional error (or 100 × SEE roughly the average percentage error). D.W. is the Durbin-Watson Statistic, while corrected D.W. is adjusted for jumps in the data (see Appendix).

[22]The text gives the estimated coefficients plus-or-minus the estimated standard error of the coefficient.

[23]See [5, 8, 12, 14, 25, 27, 32, 44, 61].

Table 18. Results for pooled sample, aggregate.

$$q_t = \underset{\substack{(0.170)\\ [27.800]}}{4.700} - \underset{\substack{(0.100)\\ [8.800]}}{0.850} \left[\sum_{\theta=0}^{4} 0.2\, p_{t-\theta} \right] + \underset{\substack{(0.080)\\ [10.000]}}{0.790} \left[\sum_{\theta=0}^{1} 0.5\, y_{t-\theta} \right]$$

D(UK) = 0.030 (0.030) [0.800]	D(GE) = -0.090 (0.030) [3.500]	D(BE) = 0.130 (0.140) [1.000]
D(NE) = -0.250 (0.030) [8.500]	D(FR) = -0.350 (0.040) [9.100]	D(IT) = -0.350 (0.040) [9.300]

R^2 = 0.989	D.W. = 0.840
$\bar{R}^2$ = 0.988	corrected D.W. = 0.740
SEE = 0.049	observations = 82.000

where

q_t = log (per capita net energy consumption);
p_t = log (price of net energy/GDP deflator);
y_t = log (real per capita GDP);
D = dummy variable for countries, where UK = United Kingdom, GE = FRG, BE = Belgium, NE = Netherlands, FR = France, IT = Italy;

and

top figures are estimated coefficients;
figures in parentheses are standard errors of coefficients;
figures in brackets are t-statistics.

Table 19. Results for pooled sample, domestic.

$$q_t = \underset{\substack{(0.200)\\[16.000]}}{3.310} - \underset{\substack{(0.080)\\[10.300]}}{0.790}\left[\sum_{\theta=0}^{4} 0.2\, p_{t-\theta}\right] + \underset{\substack{(0.120)\\[8.800]}}{1.080}\left[\sum_{\theta=0}^{1} 0.5\, y_{t-\theta}\right]$$

D(UK) = 0.240 (0.030) [6.600]	D(GE) = -0.050 (0.070) [1.700]	D(BE) = 0.110 (0.030) [3.200]
D(NE) = -0.090 (0.050) [1.800]	D(FR) = -0.390 (0.040) [10.200]	D(IT) = -0.460 (0.070) [7.000]

R^2 = 0.991	D.W. = 1.090
$\bar{R}^2$ = 0.990	corrected D.W. = 1.010
SEE = 0.059	observations = 82.000

where

q_t = log (per capita net energy consumption);
p_t = log (price of net energy/GDP deflator);
y_t = log (real per capita GDP)
D = dummy variable for countries, where UK = United Kingdom, GE = FRG, BE = Belgium, NE = Netherlands, FR = France, IT = Italy;

and

top figures are estimated coefficients;
figures in parentheses are standard errors of coefficients;
figures in brackets are t-statistics.

Table 20. Results for pooled sample, industry, except energy.

$$
\begin{array}{lllll}
q_t = & \underset{\substack{(0.200)\\ [15.300]}}{2.980} & - & \underset{\substack{(0.170)\\ [3.100]}}{0.520} & \left[\sum_{\theta=0}^{4} 0.2\, p_{t-\theta}\right] \\
 & & + & \underset{\substack{(0.160)\\ [4.700]}}{0.760} & \left[\sum_{\theta=0}^{1} 0.5\, y_{t-\theta}\right]
\end{array}
$$

D(UK) =	0.800	D(GE) =	0.280	D(BE) =	0.190
	(0.050)		(0.060)		(0.070)
	[1.500]		[4.600]		2.500
D(NE) =	-0.340	D(FR) =	-0.190	D(IT) =	-0.110
	(0.050)		(0.050)		(0.080)
	[6.400]		[3.800]		[1.400]

R^2 =	0.952	D.W. =	0.670
$\bar{R}^2$ =	0.947	corrected D.W. =	0.560
SEE =	0.091	observations =	82.000

where

q_t = log (per capita net energy consumption);
p_t = log (price of net energy/GDP deflator);
y_t = log (real per capita GDP);
D = dummy variable for countries, where UK = United Kingdom, GE = FRG, BE = Belgium, NE = Netherlands, FR = France, IT = Italy;

and

top figures are estimated coefficients;
figures in parentheses are standard errors of coefficients;
figures in brackets are t-statistics.

Table 21. Results for pooled sample, energy.

$$q_t = \underset{\substack{(0.120)\\ [25.600]}}{3.120} - \underset{\substack{(0.110)\\ [5.200]}}{0.580} \left[\sum_{\theta=0}^{4} 0.2\, p_{t-\theta} \right] - \underset{\substack{(0.120)\\ [0.400]}}{0.050} \left[\sum_{\theta=0}^{1} 0.5\, y_{t-\theta} \right]$$

D(UK) =	-0.370	D(GE) =	-0.210	D(BE) =	-0.600
	(0.060)		(0.070)		(0.060)
	5.800		3.000		9.200
D(NE) =	-0.630	D(FR) =	-0.910	D(IT)	-1.410
	(0.040)		(0.070)		(0.060)
	[13.500]		[12.800]		[23.200]

R^2 =	0.981	D.W. =	0.760
$\bar{R}^2$ =	0.979	corrected D.W. =	0.660
SEE =	0.079	observations =	82.000

where

q_t = log (per capita net energy consumption);
p_t = log (price of net energy/GDP deflator);
y_t = log (real per capita GDP);
D = dummy variable for countries, where UK = United Kingdom, GE = FRG, BE = Belgium, NE = Netherlands, FR = France, IT = Italy;

and

top figures are estimated coefficients;
figures in parentheses are standard errors of coefficients;
figures in brackets are t-statistics.

Table 22. Results for pooled sample, transport.

$$q_t = \underset{\substack{(0.230 \\ [1.500]}}{1.840} - \underset{\substack{(0.120) \\ [3.300]}}{0.360} \left[\sum_{\theta=0}^{4} 0.2\ p_{t-\theta} \right] + \underset{\substack{(0.800) \\ [16.600]}}{1.340} \left[\sum_{\theta=0}^{1} 0.5\ y_{t-\theta} \right]$$

D(UK) = -0.370	D(GE) = -0.630	D(BE) = -0.590
(0.060)	(0.050)	(0.060)
6.600	12.500	[9.200]
D(NE) = -0.440	D(FR) = -0.740	D(IT) = -0.350
(0.050)	(0.090)	(0.060)
[8.300]	[8.200]	[5.800]

R^2 = 0.995	D.W. = 0.660
$\bar{R}^2$ = 0.994	corrected D.W. = 0.550
SEE = 0.047	observations = 82.000

where

q_t = log (per capita net energy consumption);
p_t = log (price of net energy/GDP deflator);
y_t = log (real per capita GDP);
D = dummy variable for countries, where UK = United Kingdom, GE = FRG, BE = Belgium, NE = Netherlands, FR = France, IT = Italy;

and

top figures are estimated coefficients;
figures in parentheses are standard errors of coefficients;
figures in brackets are t-statistics.

between the coefficients seriously, they indicate that the demand for energy is most inelastic in the transport sector, followed by intermediate values for industry other than energy and energy, and that the residential sector is most elastic. The relative inelasticity of the transport sector is quite plausible, since there is probably least possibility for technological substitution in this field. On the other hand, the relatively high elasticity of the residential sector is not so obvious from a theoretical point of view.

The results for the income terms are quite striking. The income elasticities are 1.34 (±.08) for the transportation sector, 1.09 (±.12) for the residential sector, .76 (±.17) for the industry-except-energy sector, and -.05 (±.12) for the energy sector. For the aggregate the elasticity is estimated to be .79 (±.08). Again the income elasticities are plausible from an a priori point of view. It is well known that private automobiles are both highly income elastic and relatively energy-intensive, so that the high income elasticity of transportation is not surprising. More surprising, however, is that the energy sector has negative elasticity; this simply indicates that the losses in the transformation process are not related to income--nor is there any clear reason why they should be. The other sectors show elasticities in the neighborhood of unity or below unity. In the aggregate, the income-elasticity is significantly below unity.

In considering these results, three important differences from other studies should be noted: First, the results are found by pooling seven countries. As can be seen by comparing with the results from individual countries, results from exactly the same specification are unrecognizably different. Second, the concept of energy consumption is net energy, whereas most other studies for sectors examine gross energy. Since the general trend has been toward more efficient fuels (natural gas and electricity as compared to coal), this leads to a more rapid growth of net energy. Third, the demands are for the entire sector rather than a single fuel (e.g. electricity or natural gas) in a sector as an economy.

The next question to which we turn is whether there appear to be significant differences between the countries. Estimates of these differences are given by the dummy variables in the regressions. Recall that the dummy variables indicate whether the country appears different from the United States. First examining the aggregate equation shown in Table 18, we find that the differences are only marginally significant. The ranking of economies by energy-intensiveness is Belgium, the UK, the US, the FRG, the Netherlands, France and Italy. Recall that these intensities are <u>after correction for prices and income</u>. The pattern of results varies for different sectors, however. Thus the United States is highly energy-intensive in transport and energy, but in the middle of the pack in the domestic and the non-energy industrial sector.

We have also shown plots of the regressions for the four disaggregate sectors in Figures 2-6. The general quality of the fit and the overall trends can easily be judged from these graphs. As a visual guide, it should be noted that the average levels for each country are determined by the dummy variables, while the slopes, or fit for individual years, are determined from the regression coefficients. While the dummy variables guarantee that the average level for each country will be approximately correct, there is absolutely no guarantee that the general patterns of fit (or the trends for each country) will be accurate. Thus we have, roughly speaking, seven trends, corresponding to seven countries, while we have fit two coefficients. Considering the diversity and the fact that only two slope coefficients are fit for each regression, the degree of precision of the estimate is quite encouraging.

There is a troubling lack of elegance about the use of dummy variables: these are admissions that the specifications are rather weak. In addition, they may throw away considerable information about the effects of <u>international</u> difference in prices and incomes on international differences in energy intensiveness. For this reason it is useful to perform our

Period	Y	YC	I *...Observed Values +...Computed Values I	RES	RES %	I
1	.595	.735		-.140	-23.460	
2	.706	.822		-.116	-16.395	
3	.791	.870		-.076	-9.887	
4	.863	.906		-.043	-5.029	
5	.955	.961	Federal Republic of	-.006	-.618	
6	1.011	1.031	Germany	-.020	-1.935	
7	1.093	1.073		.020	1.798	
8	1.124	1.082		.042	3.708	
9	1.182	1.130		.052	4.372	
10	1.277	1.228		.048	3.790	
11	1.372	1.312		.060	4.351	
12	1.450	1.361		.089	6.165	
13	1.486	1.394		.092	6.192	
14	.549	.556		-.007	-1.286	
15	.606	.586		.021	3.430	
16	.667	.644		.023	3.387	
17	.733	.732	Italy	.001	.123	
18	.816	.823		-.007	-.872	
19	.875	.905		-.030	-3.467	
20	.996	.975		.022	2.192	
21	1.026	1.022		.004	.366	
22	1.064	1.090		-.025	-2.383	
23	.627	.714		-.087	-13.909	
24	.714	.782		-.068	-9.530	
25	.775	.807		-.032	-4.073	
26	.852	.843		.009	1.092	
27	.922	.880		.041	4.464	
28	.994	.949	Netherlands	.046	4.584	
29	1.055	1.035		.020	1.938	
30	1.106	1.082		.024	2.188	
31	1.180	1.132		.048	4.056	
32	1.239	1.214		.025	2.004	
33	1.302	1.307		-.004	-.338	
34	1.392	1.393		-.001	-.087	
35	1.435	1.458		-.024	-1.645	
36	1.491	1.468		.003	.183	
37	.540	.525		.015	2.781	
38	.609	.585		.024	3.989	
39	.681	.661		.020	2.949	
40	.742	.734		.008	1.114	
41	.818	.802		.016	1.947	
42	.889	.872	France	.017	1.912	
43	.944	.937		.007	.786	
44	.998	.996		.002	.168	
45	1.065	1.060		.005	.495	
46	1.124	1.120		.004	.336	
47	1.192	1.203		-.011	-.896	
48	1.257	1.291		-.034	-2.691	
49	1.313	1.360		-.047	-3.563	
50	1.397	1.424		-.027	-1.964	
51	2.356	2.237		.119	5.069	
52	2.366	2.279		.087	3.680	
53	2.371	2.288		.083	3.481	
54	2.405	2.325		.080	3.310	
55	2.429	2.378	United States	.051	2.096	
56	2.440	2.425		.015	.629	
57	2.466	2.489		-.023	-.945	
58	2.505	2.563		-.059	-2.340	
59	2.538	2.615		-.077	-3.023	
60	2.597	2.656		-.059	-2.273	
61	2.628	2.700		-.071	-2.716	
62	2.641	2.706		-.064	-2.431	
63	2.675	2.715		-.040	-1.488	
64	2.729	2.770		-.042	-1.531	
65	1.052	1.077		-.025	-2.336	
66	1.118	1.146		-.029	-2.568	
67	1.156	1.200		-.043	-3.760	
68	1.195	1.231	United Kingdom	-.036	-3.042	
69	1.268	1.262		.006	.453	
70	1.321	1.305		.015	1.154	
71	1.351	1.341		.010	.742	
72	1.398	1.371		.027	1.930	
73	1.435	1.400		.035	2.459	
74	1.470	1.430		.040	2.708	
75	.810	.801		.009	1.070	
76	.891	.871		.020	2.270	
77	.986	1.101		-.115	-11.649	
78	.953	1.142	Belgium	-.189	-19.860	
79	1.055	1.018		.037	3.511	
80	1.179	1.075		.104	8.852	
81	1.216	1.154		.061	5.050	
82	1.323	1.250		.072	5.476	

Figure 2. Results for transport sector, vaious years.

Period	Y	YC	RES	RES %
Federal Republic of Germany				
1	3.988	3.879	.110	2.752
2	3.990	3.946	.043	1.087
3	4.027	3.982	.046	1.133
4	4.074	4.011	.062	1.527
5	4.110	4.069	.042	1.010
6	4.123	4.139	-.016	-.381
7	4.123	4.180	-.057	-1.386
8	4.126	4.176	-.050	-1.213
9	4.198	4.211	-.013	-.305
10	4.301	4.314	-.013	-.305
11	4.348	4.393	-.046	-1.052
12	4.339	4.414	-.074	-1.715
13	4.384	4.418	-.033	-.764
Italy				
14	3.186	3.296	-.109	-3.432
15	3.269	3.325	-.055	-1.696
16	3.348	3.374	-.027	-.792
17	3.411	3.440	-.029	-.856
18	3.487	3.516	-.029	-.819
19	3.578	3.590	-.012	-.328
20	3.749	3.660	.089	2.387
21	3.744	3.678	.066	1.763
22	3.843	3.738	.105	2.741
Netherlands				
23	3.380	3.525	-.145	-4.304
24	3.468	3.575	-.107	-3.081
25	3.502	3.584	-.082	-2.331
26	3.596	3.623	-.027	-.746
27	3.688	3.663	.024	.657
28	3.721	3.738	-.017	-.445
29	3.801	3.833	-.032	-.833
30	3.840	3.876	-.035	-.922
31	3.910	3.912	-.002	-.039
32	4.053	3.994	.058	1.440
33	4.144	4.099	.045	1.080
34	4.269	4.186	.083	1.937
35	4.314	4.252	.062	1.438
36	4.459	4.285	.174	3.901
France				
37	3.421	3.450	-.029	-.847
38	3.498	3.458	.040	1.134
39	3.522	3.493	.029	.830
40	3.586	3.535	.051	1.418
41	3.658	3.581	.077	2.107
42	3.709	3.648	.060	1.631
43	3.751	3.719	.032	.863
44	3.765	3.782	-.017	-.453
45	3.822	3.849	-.027	-.713
46	3.886	3.915	-.029	-.736
47	3.956	3.996	-.040	-.999
48	4.032	4.072	-.040	-.985
49	4.046	4.109	-.063	-1.553
50	4.093	4.138	-.046	-1.117
United States				
51	4.679	4.615	.064	1.377
52	4.713	4.645	.069	1.455
53	4.709	4.642	.067	1.414
54	4.744	4.677	.067	1.413
55	4.764	4.732	.032	.668
56	4.793	4.785	.009	.178
57	4.829	4.855	-.027	-.551
58	4.874	4.935	-.062	-1.262
59	4.894	4.983	-.089	-1.824
60	4.938	5.016	-.078	-1.582
61	4.986	5.046	-.060	-1.200
62	5.014	5.031	-.017	-.331
63	5.015	5.012	.004	.070
64	5.068	5.046	.022	.426
United Kingdom				
65	4.038	4.045	-.007	
66	4.053	4.089	-.036	-.894
67	4.090	4.116	-.026	-.636
68	4.079	4.116	-.037	-.911
69	4.071	4.121	-.050	-1.225
70	4.107	4.130	-.024	-.578
71	4.138	4.141	-.003	-.072
72	4.200	4.146	.054	1.296
73	4.196	4.144	.052	1.234
74	4.223	4.146	.077	1.821
Belgium				
75	3.742	3.696	.045	1.207
76	3.773	3.760	.013	.355
77	3.819	4.001	-.182	-4.764
78	3.855	4.025	-.170	-4.397
79	3.862	3.857	.005	.141
80	3.995	3.902	.093	2.321
81	4.102	3.984	.118	2.881
82	4.157	4.080	.077	1.841

Figure 3. Results for aggregate sector, various years.

Note: Observed values are denoted by an asterisk. Actual values are denoted by a plus sign.

Period	Y	YC	I	*...Observed values +...Computed values	I	RES	RES %	I
1	2.241	2.284	I	*+	I	-.043	-1.901	I
2	2.311	2.390	I	*+	I	-.049	-2.104	I
3	2.532	2.476	I	+*	I	.056	2.222	I
4	2.678	2.564	I	+ *	I	.114	4.241	I
5	2.689	2.680	I	() Federal Republic	I	.009	.346	I
6	2.769	2.810	I	*+ of Germany	I	-.041	-1.480	I
7	2.837	2.910	I	*+	I	-.074	-2.594	I
8	2.876	2.931	I	*+	I	-.055	-1.908	I
9	2.991	2.992	I	()	I	-.001	-.046	I
10	3.126	3.124	I	+*	I	.002	.062	I
11	3.219	3.218	I	()	I	.000	.008	I
12	3.248	3.237	I	()	I	.011	.336	I
13	3.320	3.250	I	+ *	I	.070	2.122	I
14	1.675	1.780	I	* +	I	-.105	-6.264	I
15	1.812	1.813	I	()	I	-.001	-.033	I
16	1.878	1.895	I	(	I	-.017	-.906	I
17	2.050	2.019	I	()	I	.031	1.509	I
18	2.161	2.156	I	+* Italy	I	.005	.227	I
19	2.295	2.300	I	()	I	-.005	-.230	I
20	2.445	2.430	I	()	I	.015	.630	I
21	2.560	2.515	I	+*	I	.045	1.772	I
22	2.651	2.620	I	+*	I	.031	1.178	I
23	2.159	2.246	I	*+	I	-.087	-4.050	I
24	2.258	2.330	I	*+	I	-.071	-3.158	I
25	2.338	2.373	I	*+	I	-.035	-1.495	I
26	2.510	2.467	I	+*	I	.043	1.701	I
27	2.662	2.553	I	+ * Netherlands	I	.108	.071	I
28	2.697	2.664	I	+*	I	.033	1.234	I
29	2.811	2.815	I	()	I	-.004	-.130	I
30	2.877	2.905	I	*+	I	-.027	-.955	I
31	2.955	2.989	I	*+	I	-.033	-1.127	I
32	3.153	3.134	I	()	I	.019	.609	I
33	3.331	3.316	I	+*	I	.015	.464	I
34	3.463	3.454	I	()	I	.008	.241	I
35	3.530	3.562	I	*+	I	-.033	-.928	I
36	3.702	3.638	I	+*	I	.064	1.718	I
37	1.843	1.974	I	* +	I	-.131	-7.109	I
38	1.927	1.982	I	*+	I	-.055	-2.851	I
39	1.973	2.014	I	*+	I	-.041	-2.086	I
40	2.135	2.075	I	+*	I	.060	2.827	I
41	2.273	2.129	I	+ *	I	.144	6.337	I
42	2.312	2.229	I	+ * France	I	.083	3.580	I
43	2.385	2.338	I	+*	I	.048	1.992	I
44	2.411	2.441	I	()	I	-.030	-1.249	I
45	2.526	2.542	I	()	I	-.016	-.622	I
46	2.624	2.648	I	*+	I	8-.024	-.932	I
47	2.693	2.771	I	*+	I	-.078	-2.887	I
48	2.785	2.870	I	* +	I	-.085	-3.055	I
49	2.944	2.925	I	+*	I	.019	.660	I
50	3.094	2.987	I	+ *	I	.106	3.431	I
51	3.620	3.559	I	+ *	I	.061	1.687	I
52	3.660	3.600	I	+ *	I	.060	1.646	I
53	3.677	3.604	I	+ *	I	.073	1.990	I
54	3.721	3.650	I	+ *	I	.071	1.901	I
55	3.728	3.707	I	()	I	.021	.556	I
56	3.744	3.761	I	*+	I	-.017	-.442	I
57	3.795	3.834	I	United States *+	I	-.040	-1.049	I
58	3.843	3.921	I	* +	I	-.078	-2.036	I
59	3.877	3.974	I	* +	I	-.097	-2.505	I
60	3.925	4.013	I	* +	I	-.088	-2.243	I
61	3.986	4.051	I	* +	I	-.065	-1.628	I
62	4.047	4.039	I	+*	I	.009	.201	I
63	4.054	4.017	I	+*	I	.037	.916	I
64	4.092	2.038	I	+*	I	.053	1.305	I
65	2.798	2.739	I	+*	I	.060	2.135	I
66	2.782	2.803	I	*+	I	-.022	-.774	I
67	2.830	2.855	I	*+	I	-.025	-.870	I
68	2.842	2.878	I	()	I	-.036	-1.267	I
69	2.867	2.908	I	*+ United Kingdom	I	-.041	-1.441	I
70	2.923	2.941	I	*+	I	-.018	-.619	I
71	2.954	2.974	I	()	I	-.020	-.676	I
72	3.008	2.999	I	()	I	.010	.317	I
73	3.036	3.014	I	+*	I	.022	.714	I
74	3.093	3.023	I	+ *	I	.071	2.283	I
75	2.634	2.480	I	+ *	I	.154	5.850	I
76	2.674	2.595	I	+*	I	.080	2.981	I
77	2.773	2.915	I	* +	I	-.141	-5.098	I
78	2.816	2.999	I	* + Belgium	I	-.183	-6.500	I
79	2.887	2.865	I	+*	I	.022	.767	I
80	3.026	2.962	I	+*	I	.064	2.107	I
81	3.086	3.080	I	()	I	.006	.203	I
82	3.214	3.215	I	()	I	-.002	-.048	I

Figure 4. Results for domestic sector, various years.

Note: Observed values are denoted by an asterisk. Actual values are denoted by a plus sign.

Period	Y	YC	*...Observed values +...Computed values	RES	RES %
1	3.377	3.186	Federal Republic of Germany	.191	5.663
2	3.354	3.250		.103	3.086
3	3.354	3.290		.065	1.927
4	3.359	3.322		.037	2.094
5	3.414	3.376		.039	1.136
6	3.429	3.439		-.010	-.292
7	3.402	3.472		-.070	-2.070
8	3.405	3.474		-.069	-2.026
9	3.465	3.508		-.043	-1.227
10	3.575	3.592		-.018	-.491
11	3.610	3.661		-.051	-1.413
12	3.569	3.681		-.112	-3.143
13	3.621a	3.685		-.062	-1.719
14	2.649	2.745	Italy	-.096	-3.627
15	2.716	2.770		-.054	-1.973
16	2.796	2.805		-.009	-.329
17	2.808	2.857		-.049	-1.738
18	2.876	2.919		-.043	-1.492
19	2.955	2.978		-.023	-.785
20	3.165	3.037		.129	4.069
21	3.099	3.064		.035	1.139
22	3.234	3.125		.110	3.391
23	2.443	2.522	Netherlands	-.080	-3.263
24	2.523	2.570		-.047	-1.856
25	2.524	2.585		-.061	-2.428
26	2.588	2.626		-.039	-1.488
27	2.657	2.667		-.010	-.386
28	2.706	2.734		-.027	-1.007
29	2.762	2.817		-.055	-1.975
30	2.785	2.856		-.071	-2.546
31	2.737	2.880		-.142	-5.197
32	3.048	2.946		.101	3.326
33	3.071	3.026		.045	2.456
34	3.180	3.089		.091	2.852
35	3.200	3.131		.069	2.157
36	3.385	3.159		.226	6.671
37	2.850	2.868	France	-.018	-.633
38	2.943	2.871		.072	2.433
39	2.971	2.898		.073	2.462
40	3.019	2.934		.085	2.809
41	3.066	2.978		.088	2.864
42	3.115	3.039		.076	2.442
43	3.145	3.101		.045	1.425
44	3.144	3.152		-.008	-.261
45	3.178	3.209		-.031	-.961
46	3.235	3.262		-.027	-.829
47	3.304	3.331		-.027	-.831
48	3.376	3.394		-.018	-.528
49	3.287	3.418		-.131	-3.974
50	3.258	3.436		-.179	-5.487
51	3.603	3.626	United States	-.023	-.626
52	3.654	3.643		.011	.292
53	3.627	3.636		-.010	-.266
54	3.657	3.657		-.001	-.014
55	3.690	3.697		-.006	-.176
56	3.761	3.738		.023	.623
57	3.821	3.796		.024	.634
58	3.870	3.864		.005	.138
59	3.874	3.911		-.037	-.952
60	3.903	3.946		-.043	-1.096
61	3.943	3.977		-.034	-.860
62	3.987	3.970		.017	.433
63	3.957	3.955		.003	.069
64	4.047	3.978		.069	1.704
65	3.252	3.259	United Kingdom	-.007	-.209
66	3.293	3.304		-.011	-.328
67	3.335	3.335		.001	.016
68	3.313	3.345		-.032	-.975
69	3.285	3.357		-.072	-2.195
70	3.318	3.372		-.055	-1.644
71	3.394	3.391		.003	.098
72	3.471	3.405		.066	1.913
73	3.445	3.406		.039	1.141
74	3.480	3.413		.067	1.924
75	3.406	3.471	Belgium	-.065	-1.912
76	3.459	3.528		-.069	-1.986
77	3.463	3.722		-.259	-7.488
78	3.479	3.741		-.262	-7.520
79	3.492	3.606		-.114	-3.262
80	3.749	3.643		.106	2.838
81	4.047	3.715		.332	8.206
82	4.118	3.788		.330	8.018

Figure 5. Results for industry except energy, various years.

Note: Observed values are denoted by an asterisk. Computed values are denoted by a plus sign.

Period	Y	YC	I *... Observed values +...Computed values I	RES	RES %	I
1	2.598	2.431	+ *	.168	6.447	I
2	2.566	2.444	+ *	.122	4.751	I
3	2.539	2.448	+ *	.091	3.584	I
4	2.573	2.451	+ *	.122	4.729	I
5	2.584	2.470	+ *	.114	4.423	I
6	2.503	2.492	() Federal Republic	.011	.437	I
7	2.456	2.496	*+ of Germany	-.041	-1.649	I
8	2.399	2.487	* +	-.088	-3.654	I
9	2.433	2.492	*+	-.059	-2.444	I
10	2.461	2.525	* +	-.064	-2.606	I
11	2.437	2.548	* +	-.111	-4.553	I
12	2.409	2.533	* +	-.124	-5.156	I
13	2.371	2.512	* +	-.140	-5.923	I
14	1.092	1.210	* +	-.118	-10.770	I
15	1.164	1.251	* +	-.087	-7.470	I
16	1.274	1.291	()	-.018	-1.387	I
17	1.351	1.331	() Italy	.020	1.449	I
18	1.386	1.383	()	.003	.233	I
19	1.457	1.414	+*	.043	2.931	I
20	1.515	1.430	+ *	.086	5.655	I
21	1.479	1.423	+*	.056	3.757	I
22	1.442	1.427	()	.016	1.076	I
23	1.991	2.048	*+	-.057	-2.859	I
24	2.081	2.066	()	.016	.763	I
25	2.102	2.077	()	.025	1.189	I
26	2.142	2.113	()	.029	1.348	I
27	2.183	2.140	+* Netherlands	.042	1.931	I
28	2.174	2.182	()	-.008	-.373	I
29	2.244	2.230	+*	.014	.645	I
30	2.255	2.257	()	-.002	-.087	I
31	2.485	2.302	+ *	.183	7.373	I
32	2.266	2.354	* +	-.088	-3.875	I
33	2.290	2.421	* +	-.131	-5.715	I
34	2.440	2.460	()	-.021	-.851	I
35	2.474	2.478	()	-.004	-.173	I
36	2.478	2.477	()	.001	.045	I
37	1.664	1.719	* +	-.055	-3.334	I
38	1,681	1,699	()	-.018	-1.069	I
39	1.647	1.699	*+	-.052	-3.157	I
40	1.623	1.704	*+	-.081	-4.987	I
41	1.676	1.720	*+	-.044	-2.609	I
42	1.748	1.753	() France	-.006	-.320	I
43	1.775	1.792	()	-.017	-.934	I
44	1.812	1.823	()	-.011	-.600	I
45	1.842	1.859	*+	-.017	-.906	I
46	1.865	1.887	()	-.022	-1.200	I
47	1.939	1.921	+*	.018	.950	I
48	2.004	1.942	+*	.062	3.088	I
49	2.044	1.931	+ *	.113	5.550	I
50	2.054	1.925	+ *	.128	6.257	I
51	3.137	3.197	*+	-.060	-1.908	I
52	3.146	3.189	*+	-.043	-1.360	I
53	3.137	3.175	*+	-.038	-1.224	I
54	3.168	3.182	*+	-.014	-.444	I
55	3.187	3.189	()	-.002	-.065	I
56	3.173	3.194	United States ()	-.021	-.677	I
57	3.146	3.207	*+	-.061	-1.951	I
58	3.177	3.225	*+	-.048	-1.501	I
59	3.194	3.232	*+	-.038	-1.193	I
60	3.253	3.235	()	.019	.571	I
61	3.301	3.239	+*	.063	1.896	I
62	3.236	3.214	()	.023	.696	I
63	3.265	3.176	+ *	.090	2.744	I
64	3.275	3.142	+ *	.133	4.046	I
65	2.453	2.440	()	.014	.552	I
66	2.439	2.436	()	.002	.093	I
67	2.446	2.427	United Kingdom ()	.020	.804	I
68	2.414	2.409	()	.005	.198	I
69	2.376	2.391	()	-.015	-.624	I
70	2.378	2.371	+*	.006	.268	I
71	2.291	2.340	*+	-.049	-2.128	I
72	2.326	2.318	()	.009	.366	I
73	2.307	2.284	+*	.023	.999	I
74	2.238	2.253	*+	-.015	-.653	I
75	2.140	2.024	+ *	.115	5.390	I
76	2.121	2.066	+*	.055	2.585	I
77	2.131	2.166	*+	-.035	-1.650	I
78	2.088	2.171	* + Belgium	-.083	-3.971	I
79	2.058	2.115	* +	-.057	-2.753	I
80	2.183	2.143	+*	.040	1.818	I
81	2.206	2.195	+*	.011	.487	I
82	2.201	2.247	*+	-.046	-2.083	I

Figure 6. Results for energy sector, various years.

Note: Observed values are denoted by an asterisk. Actual values are denoted by a plus sign calculations without dummy variables. This procedure then takes into account not only the effect of the histories of individual countries, but also the differences of levels of income and price between countries on energy intensiveness. To obtain this different perspective, we must make the further heroic assumption that the intercepts in all countries are the same and that omitted variables are uncorrelated with energy prices and income. The quality of the fit will deteriorate if country dummies are significant, but the results may shed further light on the long-run elasticities.

Table 23 shows the estimated coefficients for the case with and without country dummy variables. Two results are clear from this table: first, the results generally hold up without country variables. Second, the fits of the equation are much worse. In considering the two equations, there are good theoretical reasons to believe that the results without country variables should show larger price coefficients: in principle, the price differences are of longer duration, and the full response to these differences should have taken place. For the time series analysis of individual countries the length of response is only five years, which is clearly too short for the response function for energy.

Two general points come out of the results without dummy variables. First, it does not appear that the results are significantly different with two exceptions: a) in the transport sector the price elasticity is much higher while the income elasticity is lower; and b) in the energy sector the income elasticity is dramatically changed. With these exceptions, these results confirm quite strongly the results with the dummy variables.

The question is how to interpret the cases where the results are quite different. In general, I suspect that for transport the pooled results without country dummies should be given considerable attention. In this sector the differences between countries are pretty clearly due to the policy of taxing

Table 23. Comparison of results with and without country dummy variables.

Sector	Price Elasticities		Income Elasticities		Goodness of Fit ($\bar{R}^2$)	
	With Dummies	Without Dummies	With Dummies	Without Dummies	With Dummies	Without Dummies
Aggregate	-.85 (.10)	-1.15 (.10)	.79 (.08)	.87 (.09)	.988	.916
Transport	-.36 (.12)	-1.28 (.06)	1.34 (.08)	.81 (.08)	.994	.959
Domestic	-.79 (.08)	-.71 (.09)	1.09 (.12)	1.39 (.12)	.990	.857
Industry except energy	-.52 (.17)	-.48 (.14)	.76 (.16)	.91 (.14)	.947	.671
Energy	-.58 (.11)	-.62 (.17)	-.05 (.12)	.94 (.23)	.979	.606

gasoline heavily in European countries, rather than supply side differences. For this reason, I suspect that we are simply getting a longer run reaction than in the case of the results with country dummies, and therefore these seem to be more adequate results from a theoretical point of view. For the energy sector, on the other hand, I suspect that the differences are simply supply side differences, in particular differences in energy resource availability, rather than demand. Clearly, the reason the demand in the energy sector is high for the US, the UK and the FRG and low for Italy and France is due to the resource endowments of the respective countries. The fact that wealthier countries happen to have larger energy resources is probably more accidental than causal. For this reason, the results with country dummies are probably preferable to the results without country dummies.

One must be quite cautious in use of the data without country dummies. In essence the effective number of observations is very small and the extremes (such as the United States for transport) are determining the coefficients: while the coefficients may be unbiased, the autocorrelation of the residuals means that the standard errors are very high. Thus, where the differences between the estimates with and without country dummies are large, the uncertainty about the long-run coefficients is also large. Particularly for the transport sector, the discrepancy is so large that we must look for further information to resolve the differences in estimates. On the other hand, the price elasticities for the domestic and industrial sectors agree quite well in both procedures, so these can be regarded as better determined.

VI. Projections for the United States

An important application of the results of the present study is in forecasting the growth of energy demand over the short and medium term. Forecasts of this kind remain one of the important tasks of the present study, and the current section is only a preliminary indication of the qualitative results that will come out of a fully prepared forecast. Nevertheless, since the question of forecasts is of such great importance for planning purposes, it was thought useful to present the techniques and some preliminary estimates at this stage.

In making the forecasts, we have only relied upon calculations for the aggregate, rather than for individual sectors; and we have applied the projections only to the United States. However, since the estimates of the elasticities we use are from the pooled data, and since the magnitude of the shifts are approximately the same, the results for other OECD countries would be approximately the same. In projecting future demands, given model estimates of coefficients, the other determining factors are the relative prices of energy to non-energy goods and growth in per capita GNP. We have used the conventional figures for GNP growth--that "potential GNP" would grow at 4.0% from 1972 to 1985 and at 3.5% from 1985 to 2000, while population is taken as US Census series E.

More complicated is the question of price trends over the longer horizon. The results incorporate four different assumptions about relative price trends:

1) the "historical price series" which assumes that the declining relative price trend which was evidenced from 1955 to 1970 would continue indefinitely. This series shows a declining relative price trend of 1.2% annually;

2) the "constant 1974 price" series, which assumes that the discontinuity which occurred between 1970 and 1974 reflected irreversible structural shifts, and that the 1974 relative prices would maintain themselves indefinitely;

3) the "100% erosion of 1974 price" series, which assumes that the energy crisis of 1970-75 was a transient phenomenon, due to temporary shortages and exercise of market power, and would be eroded

away over the period 1975 - 1985.

(4) The "50% erosion of 1974 price" which assumes that only 50% of the difference between the "historical" and "constant 1974" price series would be eroded by competitive forces.

It should be emphasized that the assumptions about price can only be guesses: not only do they reflect uncertain judgments about political and economic events--such as the strength of the cohesive bonds between producing nations or between consuming nations--but they may not even be consistent with the technological constraints of the energy sector; only when the demand model is combined with a more complete model of supply (such as the linear programming model in [49]) can the consistency be assured.

The major advantage of the econometric technique over non-statistical techniques is that it allows for estimation of the uncertainty of the predictions. Therefore, in addition to the maximum likelihood point projections, we have also calculated in the standard error of the forecasts as calculated by standard techniques. (See Malinvaud [45], pp. 208 ff.)

In what follows, it should also be noted that because of autocorrelation of the errors the standard errors in our equations are underestimated (see Malinvaud [45] pp. 433-37). We have therefore made a crude correction by multiplying the standard errors of the coefficients by $\sqrt{2}$ and the standard error of the equation by $\sqrt{5}$.[1]

The results are shown in Figures 7 and 8 . The first point is that under most realistic scenarios about price there

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[1] Using (1-D.W./2) as an estimate of the autocorrelation coefficient for the errors, and using the fact that the composite right hand side variables have autocorrelation of about 0.4, we find that the standard error of the equation is expected to be underestimated by a factor of $\sqrt{5}$ and the standard error of the

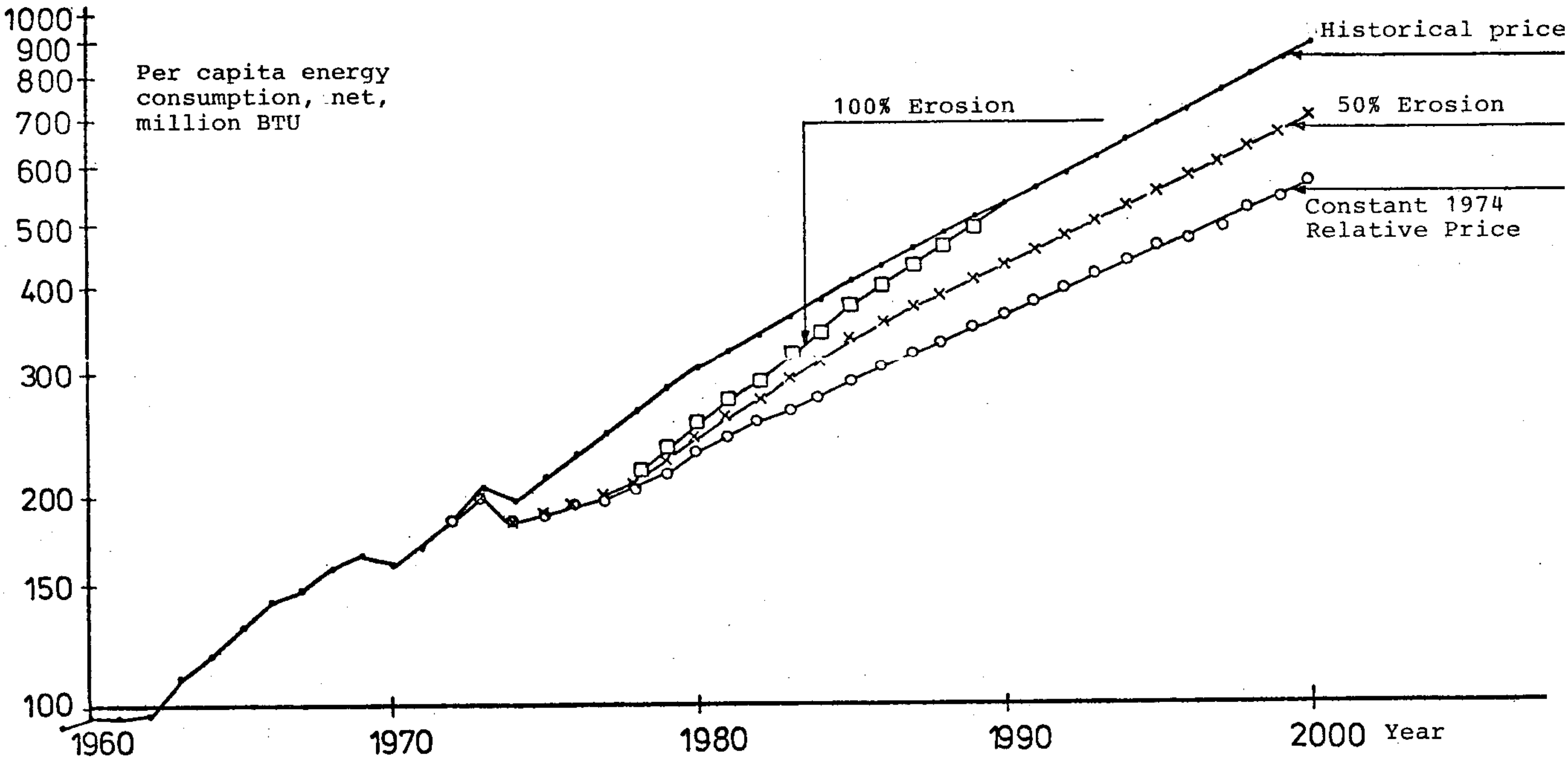

Figure 7. Projections for the United States, 1959 to 2000, various price hypotheses.

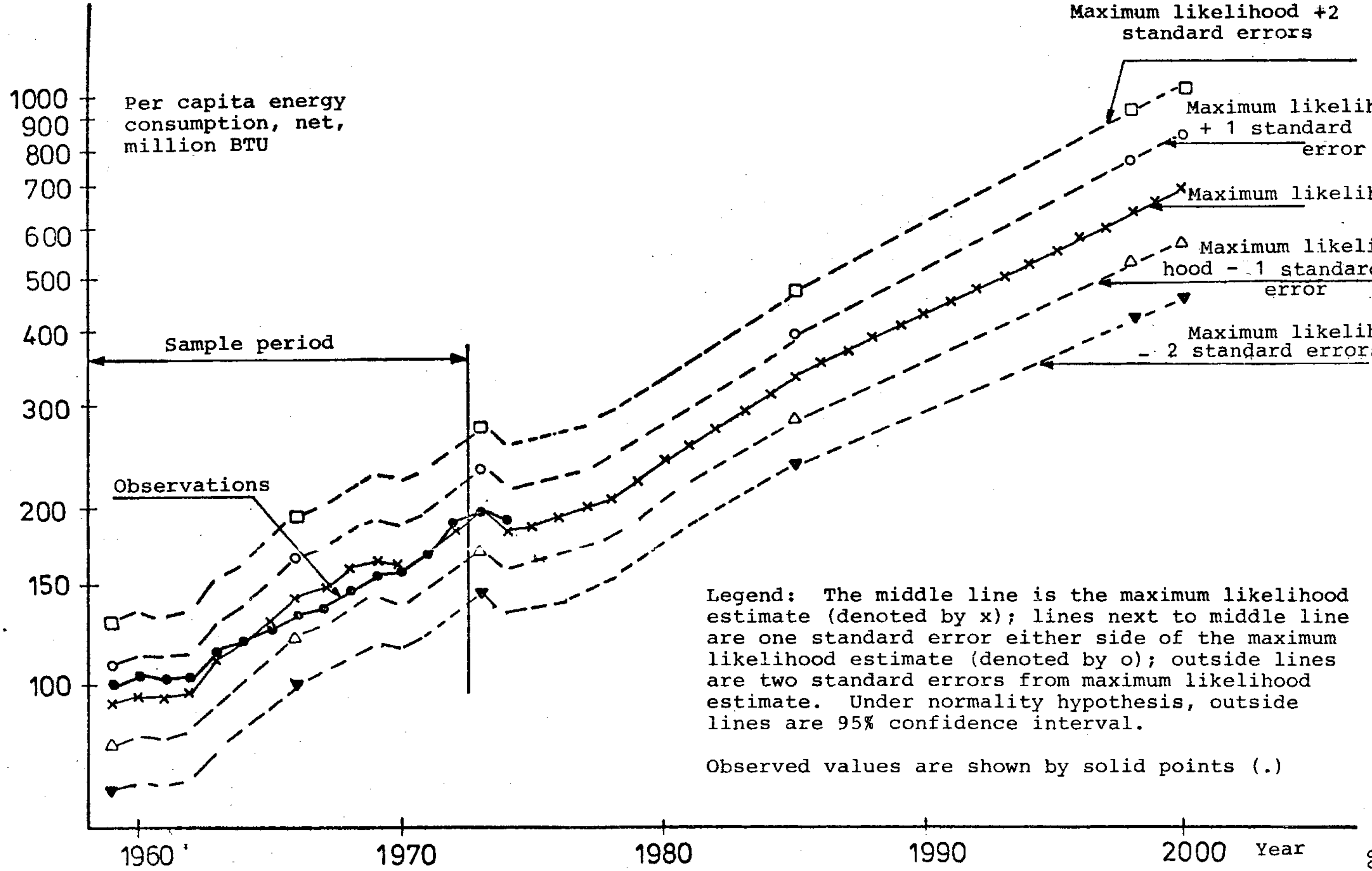

Figure 8. Maximum likelihood path for 50% erosion, and likelihood contours one and two standard errors beyond maximum likelihood estimate, United States, 1959 to 2000, and observed values 1959-1974.

should be relatively moderate growth of energy demand over the period 1972 to 1980; in the constant 1974 price case, the growth in energy demand is fairly flat from 1972 to 1978, but accelerates after that. Note as well that there are quite significant differences between the extreme paths by the end of the century. In particular, the historical path shows rapid growth in demand, averaging about 3.2% per annum once the effect of the events of 1970 to 1974 have disappeared, while the growth rate for the constant 1974 price path shows a growth rate of 2.2% per annum, one full percentage point slower.

It can be seen that two different sources of uncertainty are contained in our projections. First, there is the uncertainty in the evolution of prices, as reflected in the four different relative price paths. And second there is the inherent uncertainty of the projections due to the uncertainty of the values of the elasticities. Figure 7 shows that the uncertainty about the path due to the evolution of prices is not terribly great in the immediate future (note that the historical price series assumes that the events of the last five years did not take place), but this uncertainty compounds with time until the end of the century when it amounts to a difference of 57% between the extreme paths. The other uncertainty involves the uncertainty of the parameters, shown in Table 10. This uncertainty is of the same order of magnitude as that for price. If we assume that by the end of the century the initial conditions have damped out, then the 67% uncertainty range is 41% between the maximum likelihood plus and minus one standard error. It must be stressed that these are uncertainties which are inherent in the problem and cannot be resolved within the methodological framework used here. It is conjectured that they are also realistic reflections of the real uncertainties that we face in planning.

VII. Summary and Conclusions

The present paper reports on the preliminary results of a study of energy demand from an international perspective. The major difference between this study and earlier studies were: a) from a theoretical point of view, it attempts to estimate the demand for net energy in four major sectors of the economy, without regard at this stage to the breakdown between the different fuels; b) that it attempts to compare the energy demand functions of seven different Western countries over the period 1955-1972, both in individual estimation and by pooling the data.

The results of the study are somewhat mixed. On an individual country level, the regression results show considerable lack of precision, as well as a certain number of contradictory conclusions. It was surmised from these results that it is extremely difficult even from a time period as short as twenty years to get reliable estimates of energy demand functions from the specification used in the present paper.

When the seven countries are pooled (with country dummy variables) the results are more encouraging. First, the price elasticities are all of the correct sign (negative) and inelastic (that is, less than one is absolute value). They indicate a moderate but slow reaction of energy demand to the price of energy products. The major surprise was that the income elasticity of energy demand tends to be relatively low. In three of the four sectors (energy, industry except energy, and domestic) the estimated income elasticities were between zero and one, indicating that with relative prices of energy to other goods constant, per capita net energy demand tends to grow slower than per capita income.

A second important conclusion is that the net energy consumption of the aggregate economies, as well as different sectors, is relatively well-explained by population, per capita income, and relative prices. Without dummy variables, between 60% and 96% of the sample's variance is explained by these factors, while country dummy variables raise the explanatory power to 95% to 99% of the variance.

Moreover, it appears that relative prices play a crucial role in determining the energy intensiveness across space and time. With no exceptions the price elasticities stand out quite clearly in the pooled results.

In a final set of regressions, countries were pooled without allowing for individual country effects. These results confirm the results with dummy variables except for transport --where the price elasticity is dramatically higher--and energy--where the income elasticity is much higher.

At the end, very preliminary projections were made for the United States using the results of the regressions as well as possible price paths. The projections indicate that the recent rise in energy prices should have a substantial effect on the growth of energy consumption for the period until about 1980, but that after 1980 the growth rate in energy consumption would be about the same--perhaps a percentage point higher, perhaps a point lower--as the path without the dramatic price changes of the 1970-1975 period. Emphasis was placed on the uncertainty of these results, both because of the uncertainties about the elasticities and because of the uncertainties about price and income trends. The statistical uncertainty of the projections was presented, and it was concluded that the size of the uncertainty about demand at the end of the century was about equally due to the uncertainty about price and income and to the uncertainty about the structure of the equation.

To conclude on a more general note, we have learned a great deal about the structure of energy demand within and across different countries. These results can be used to sharpen forecasts and to complement energy supply models, but they are plagued by unsolved problems, problematical data, and uncertain estimates. Perhaps in the end we will find that the limits to knowledge about the future are greater than the limits to growth in the future.

APPENDIX

1. The composite statistic is calculated as follows. We assume that the coefficients of the country equations are drawn from populations with a common mean μ and different variances σ_i^2. If we desire to make the usual significance tests we further assume that the distribution is normal. We find a set of weights $(a_1, \ldots, a_n)$, and a composite statistic $M = \Sigma a_i m_i$, $\Sigma a_i = 1$, where the $\{a_i\}$ are chosen to minimize the variance of the composite statistic. Thus we choose $\{a_i\}$ to

$$\text{minimize} \quad \sigma^2(M) = \Sigma a_i^2 \sigma_i^2$$

$$\text{subject to} \qquad \Sigma a_i = 1$$

and where

$$M = \Sigma a_i m_i \quad .$$

Maximization shows that

$$a_i = c\sigma_i^{-2}$$

where

$$c = \Sigma \sigma_i^{-2} \quad .$$

So our composite statistics are

$$M = \Sigma m_i \sigma_i^{-2} / \Sigma \sigma_i^{-2} \tag{A1}$$

$$\sigma^2(M) = \Sigma \sigma_i^2 \sigma_i^{-2} / \Sigma \sigma_i^{-2} = n / \Sigma \sigma_i^{-2} \quad . \tag{A2}$$

2. The calculation of standard errors for the long-run elasticities for the Koyck or geometrical lag is complicated by the non-linearity. In specification (A), the relevant standard errors are $\sigma(\frac{a_1}{1 - a_3})$ or $\sigma(\frac{a_2}{1 - a_3})$. Following Champernowne [13] we calculate a local standard error as:

$$\left(\frac{E\left(\frac{a_1}{1 - a_3}\right)}{\sigma\left(\frac{a_1}{1 - a_3}\right)}\right)^{-2} = \left(\frac{E(a_1)}{(a_1)}\right)^{-2} + \left(\frac{E(1 - a_3)}{\sigma(1 - a_3)}\right)^{-2} . \quad \text{(A3)}$$

Since all coefficients except the denominator of the left hand side are known, we can calculate the local standard error from (A3). A proof is given in Champernowne [13] (p. 155 f.). Note that this calculation assumes independence of the estimates of a_1 and a_3.

3. In the estimate of the Durbin-Watson statistic for the pooled sample with n countries we have (n - 1) jumps which are due to the pooling. Assume the correct structure is

$$u_{t,i} = \rho u_{t-1,i} + \varepsilon_{t,i}$$

where $\varepsilon_{t,i}$ i drawn from a population with mean zero, equal variances for all countries, and independence of successive errors. Then it is easily verified that

$$u_{t,i} = \sum_{\theta=0}^{\infty} \rho^{\theta} \varepsilon_{t-\theta,i} .$$

Further note that $E(u_{t,i}, u_{v,j})$ is 0 for all t,v and $i \neq j$. Thus if the index w runs over "program periods," w = 1,...,W, we have

$$D.W. = \frac{\Sigma(u_w - u_{w-1})^2}{\Sigma u_w^2}$$

$$E(D.W.) = \left(\frac{W - 1}{W}\right)\left[2 - 2\frac{(W - n + 1)\rho}{W}\right] .$$

To calculate the corrected Durbin-Watson statistic we use the fact that the corrected Durbin-Watson, $\bar{d}$, is related to the calculated Durbin-Watson, $\hat{d}$, by:

$$\bar{d} = \left(\frac{W - 1}{W - n + 1}\right)\left[2\left(\frac{W - n + 1}{W}\right) - 2 + \frac{\hat{d}\,W}{W - 1}\right] .$$

Note that for seventy-six observations and two exogenous variables the lower and upper limits on the Durbin-Watson statistics are 1.55 and 1.66, respectively (see Durbin and Watson [23]).

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