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ENERGY DEMAND ELASTICITIES IN SOUTH AFRICA

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EXECUTIVE SUMMARY

In this report the price elasticities of energy demand have been studied in an international context in general and in a South African context in particular. The meaning and usefulness of price elasticities have been outlined and the price elasticities of energy demand in South Africa have been estimated and been collected. In an international level, price was found to be an important determinant of energy demand. As far as South Africa is concerned, the estimated elasticities fall within the range of estimated elasticities abroad. Short-run elasticities found to be much smaller than long-run elasticities and elasticities of individual energy carriers found to be more elastic than aggregate energy elasticities. Finally, the long-run elasticities of individual fuel carriers although fairly elastic are in general smaller than unit.

A variety of policy issues accrue out of these findings. Firstly, the fact that energy demand responds to changes in price means that pricing can be used as an effective instrument for energy policy. Conservation and interfuel substitution can be promoted and be motivated through price manipulation. Although the response will take some time, it is virtually unrefutable that price is an important instrument in the hands of policy makers. The importance of the pricing mechanism is particularly important in the field of liquid fuels in South Africa. However, legislation makes difficult the estimation of elasticities in this area. We suggest that much opportunity for further research exists in this area which however should be coupled with research on energy pricing - macroeconomy feedbacks.

Secondly, the fact that energy price elasticities are different than zero means that models which omit price from the set of explanatory variables are mispecified. As the majority of models in South Africa do not use price as an explanatory variable and energy prices are rising forecasts overestimate the energy demand. This overestimation in its turn causes misallocation of resources in the form of excess capacity expansion. Overestimation of future electricity demand and of SASOL fuel will have repercussions not only for ESCOM and SASOL, but also for the country as a whole as precious capital and foreign exchange would have been spent on unused idle capacity. Analysts and planners in energy industry should recognise the importance of elasticities

and incorporate them in their forecast of future energy demand. Their job would be further assisted if the government made known and explicit their pricing energy policy in general and the pricing mechanism in particular. For example, for a fuel whose price is regulated the government could state that is interested in conservation and substitution of the particular fuel for others and therefore it intends to increase its real price by an x amount per year over an horizon of say 5 years and it relative to other fuels price by a y amount per year. Such an explicit policy not only would assist energy analysts and forecasters but could also speed up the market adjustment mechanism as it would influence consumers expectations. Energy consumers knowing that the particular fuel will be more expensive in the future will switch much sooner to other fuels and/or conservation and they would not expect the price to reveal by itself its future direction.

Finally, the finding that most energy carriers are price inelastic (at least in the short-term) creates the opportunity for the government and utilities to increase their revenue. This is particularly important for the current situation in South Africa as sanctions make capital expensive and scarce. Provided that research shows that an increase in the price of energy would not have adverse repercussions for growth, employment and other macroeconomic targets the government should as a matter of policy increase the price of energy. This will not only promote con ervation and substitution of certain fuels for others or other factors of production but it will also increase the government´s revenue and therefore decrease the budget deficit. Even if there are philosophical objections over higher taxation, high energy taxes can be compensated with lower tax rates elsewhere (eg GST or general income tax) where lower taxes can promote higher growth.

INTRODUCTION

Demand elasticities refer to measures of the responsiveness of quantity demanded to changes in the determinants of demand. The own price elasticity of energy demand is the percentage of change in quantity demanded resulting from a given percentage change in the price of energy, assuming all other factors affecting demand remain constant.

Elasticities with respect to other prices, termed cross-elasticities, and with respect to income and output, termed income and output elasticities are similarly defined. This report is concerned mainly with the own price elasticity of energy demand and unless it is otherwise mentioned the term ´price elasticity´ will refer to the own price elasticity of energy demand.

A price elasticity of demand is a convenient way of summarizing how changes in market price or quantity consumed affect each other. A reliable measure of the energy elasticity would be valuable in a wide variety of applications involving pricing decisions. For example, the effectiveness of an excise tax in reducing gasoline consumptions, or the impact of a reduction in oil imports on the domestic price of Sasol Oil would become readily apparent.

Provided that elasticities are different than zero their omission from forecasting, energy planning and analysis can have severe repercussions. To mention just one example electric utilities base their decision for capacity expansion on long term forecasts. Omitting the effects of price on the demand for electricity from the forecasting model can be damaging.

In an environment with increasing electricity prices the deficient model will over estimate the future demand and as a result overcapacity will be built and resources will be misallocated. The repercussions will be felt not only by the utility but by the country as a whole, as precious capital and foreign exchange would have been spent on an unused idle capacity. The results will be equally damaging in environment of decreasing electricity prices. In that case the model will under estimate future demand, the utility will find itself short of generating capacity and as a result black-outs will disturb the country´s economic activity. Side effects will be overused existing generating capacity and shaken confidence on the utility´s reliability.

The importance of elasticities became profound after the oil crisis of 1973 and a variety of studies appeared in the international journals in the following the crisis years. The number of studies on the subject multiplied with such a rate that soon the need for literature reviews become obvious. In 1975 Taylor (1975) reviewed selectively 13 studies. In 1977 the British Department of Energy (1977) reviewed 42 studies. Bohi (1981) reviewed more than 47 studies in 1981 and in 1984 he updated (Bohi et al 1984) his review by examining another 40 studies.

A common characteristic of the studies reviewed is that they use data mainly from the United States and Britain and when cross-section studies require data from many different countries, data from the industrialized countries are used. This selective coverage stems out of the lack of energy data from underdeveloped and developing countries and out of the lack of energy specialists in these countries. As a result the countries that most need an appropriate energy policy have to use educated guesses or to assume that demand is price neutral.

South Africa belongs to this latter category. A recent review (Pouris 1986) on the demand for electricity in South Africa was unable to identify any study taking into account the effect of price changes on the demand for electricity.

The present report purports to cover this gap by outlining the current state of the art on the subject of energy elasticities as it springs out of an international literature review and to estimate the energy elasticities in South Africa. It is envisaged that the study will answer the following four questions:

1. Are the long-run energy demand elasticities statistically different from zero?

2. Is price an effective energy policy instrument? Can energy conservation be promoted through price manipulation?

3. What is the size of the energy demand elasticities?

4. What modifications are necessary on the energy forecasts which assume zero price elasticity?

DEFINITIONS

The term elasticity was first defined and used by Alfred Marshall (1885,1890) and refers to the percentage change in quantity demanded (Δ_q / q) divided by the percentage change in price (Δ_p / p).

$$e_p = - \frac{\text{\% change in quantity}}{\text{\% change in price}}$$

Prior to Marshall, there has been no generally accepted terminology or measure of the relationship between price and quantity, although concepts similar to elasticity had been suggested. Mill (1848) compared percentage changes in price and quantity, but he did not divide the two to get what we call elasticity. Similarly Cournot (1838) showed the relationship between the ratio of the change in quantity demanded to the change in price (Δ_q/Δ_p) and the ratio of quantity demanded to price (q/p), but he did not suggest dividing the two ratios to measure elasticity.

The price elasticity of demand is derived from the demand curve, which shows the absolute quantity demanded as a function of price. Since the rate of demand rises if the price falls, and vice versa, the elasticity of demand is actually negative. By definition, demand is inelastic if the elasticity is less than one and is elastic if the elasticity is greater than one. An elasticity of one is called unit, or unitary elasticity. If demand is elastic, a given percentage increase in price causes a larger percentage decline in the quantity demanded, or a given percentage reduction in price causes a larger percentage increase in quantity demanded. In the case of perfectly (indefinitely) elastic demand any increase in price, however small, will cause the quantity demanded to decline to zero, and any reduction in price, again no matter how small, will cause the quantity demanded to increase without limit. Demand is usually elastic for commodities for which there are good substitutes, so that the demand facing a firm is expected a priori to be more elastic than the demand facing an industry since a buyer may substitute the products of other firms in the industry.

Conversely, if demand is inelastic the percentage change in quantity is smaller than the percentage change in price. An increase in price therefore causes a proportionally smaller decline in the quantity demanded, and a reduction in price causes a proportionally smaller increase in the quantity demanded. In the limiting case of zero elasticity (perfectly inelastic demand) neither an increase nor a reduction in price has any effect upon the quantity demanded.

Products that have no good substitutes, like tobacco, or that require a very small proportion of the consumer's income, like salt, frequently have inelastic demands.

The elasticity of the price elasticity of demand is inextricable linked with the seller's total revenue. For example, if the price of a commodity with inelastic demand is increased, the total revenue of the seller will increase even though the quantity demanded declines somewhat, since the increase in price more than offsets the reduction in volume. This creates a presumption that a seller faced with an inelastic demand will raise his price and will continue to do so until demand becomes elastic. Similar reasoning shows that a reduction in price reduces total revenue if demand is inelastic but increases total revenue if demand is elastic, since the increase in volume more than offsets the reduction in price. Finally, an increase in price reduces total revenue if demand is elastic and does not change total revenue if demand has unit elasticity.

A variety of other elasticities appear in the literature. The most important other than the price elasticity of demand are: elasticity of supply, income elasticity of demand, cross elasticity of demand and elasticity of price expectations.

The elasticity of supply is defined as the percentage change in the quantity offered for sale divided by the percentage change in price. The elasticity of supply is derived from the supply curve, which shows the absolute amount producers wish to sell as a function of price. Since sellers wish to sell more at a higher price, the elasticity of supply is positive. If the supply curve is inelastic, a relative larger increase in price is required to produce a given (percentage) increase in quantity supplied. If the supply curve is elastic, the sellers are more responsive to a change in price, and the increase in the quantity supplied is larger, on a percentage basis, than the increase in price.

Changes in quantities bought can come from changes in buyer´s incomes, as well as from changes in price. When demand is a function of incomes, prices and other variables being held constant, elasticity is income elasticity of demand. It is defined as

$$e_y = \frac{\text{\% change in quantity}}{\text{\% change in income}}$$

where e_y, is the coefficient of income elasticity. With one exception, the sign of e_y is positive, which is to say that quantities purchased go up and down with incomes. When e_y lies between 0 and 1, income elasticity is said to be low, and when e_y is greater than 1, it is high. Products and services with low income elasticities are those occupying small positions in consumers´ budgets, One way to define a necessity is to so name any good with a very low income elasticity. Such a definition is free of value judgments. Products with high income elasticities are those whose purchase takes large parts of consumers´ budgets. Although it looms large in family budgets, housing seems to have an income elasticity close to unity. Negative income elasticities apply to so-called inferior goods. For them increases in income cause declines in quantities bought. Just why inferior goods exist at all is explained by the theory of consumer behavior.

Cross elasticity of demand concerns the relations between the quantities bought of one commodity and the prices of another. The demand for commodity A is a function of the price of commodity B. Held equal are tastes, incomes, and commodity A´s price. Cross elasticity is defined as

$$e_{AB} = \frac{\text{\% change in quantity of A}}{\text{\% change in price of B}}$$

The sign of coefficient e_{AB} is positive if A and B are substitutes. Thus, for example, a rise in the price of beef causes, other things being equal, an increase in the purchase of chicken. The size of the coefficient shows how close A and B are as substitutes.

Sometimes, in antitrust work, a monopolized product is defined as one whose cross elasticities with its substitutes are low. A negative coefficient shows how close A and B are complements.

The cross-elasticity formula is used as a way of expressing the competitiveness faced by a firm or firms. Thus, the formula can be set up to show the sales of firm C as they are affected by changes in the price changed by its rival, firm D. Many variations on this theme are possible.

Finally, the elasticity of price expectations is a concept first proposed by J R Hicks in 1939. This elasticity is defined as the percentage change in expected future prices divided by the percentage change in current prices. The coefficient can be positive or negative. If it is positive and greater than unity, the elasticity of price expectations is high, meaning that buyers and sellers, seeing current prices go up, will then expect future prices to go up even more. When they act on this belief, they cause the very price increases they foresee. A high elasticity of price expectations, then, is unstabilizing. In contrast, a low elasticity means that increases in current prices are believed to cause smaller relative changes in expected future prices. And if the coefficient is zero or negative, current price increases are regarded as merely temporary. An important question, of course, is how widely shared are similar elasticities of price expectations at any one time.

THE IMPORTANCE OF ENERGY ELASTICITIES

Estimates of energy elasticities are important for energy policy, forecasting and financial management of energy industries. In its general concept policy is concerned with the maximization of an ´ophelimity´ function which attempts to incorporate and reflect the general interest, in whatever sense, that may be taken. The ´general interest´ is a function of a certain number of variables which are called ´target variables´. In the context of energy policy, such targets may be the volume of energy consumption, the rate of exploitation of indigenous fuels, the level of employment in the energy sector, the proportion of primary fuels to be consumed, the level of national energy independence etc.

These ´target variables´ may be linked with other variables which are under the command of the government and are called ´instruments´ or ´political parameters´. Such instruments may be taxes, subsidies, exploration and export licences, tax concessions, directed government expenditure etc.

Elasticities are important for energy policy because they connect a possible target variable (ie demand) with a possible instrument variable (ie price). An estimate of the gasoline price elasticity of demand, for example, could show directly the effects of an excise tax in reducing consumption or conversely it could indicate the effect of a gasoline shortage (eg because of sanctions) on the price of SASOL oil. In the limited case when the estimated elasticity is zero, price would be ineffective as a policy instrument for the manipulation of demand. When however, the elasticity is different than zero price is an effective policy instrument and can be used for demand management, determination of the fuels to be used more intensively, determination of the level of exports etc.

Energy price elasticities are also important for forecasting future energy demand. A non-zero elasticity indicates that price affects the demand for energy and therefore price should be included in the set of explanatory variables. The omission of price from the set of explanatory variables would imply that price would remain in the future in the same level as in the past. While this assumption can be legitimate, it should be stated explicitly. It is known that in economics it is not, as a rule, possible to experiment.

That is to say, there is hardly ever an opportunity to hold constant a number of factors while a particular co-variation is being studied or to control their influence by experimental design. Therefore, it is important to include in any modelling effort all possible variables in order to be able to hold constant their influences.

This necessary but not sufficient condition for success has not always been observed and many attempts have been made to explain one variable, say y, in terms of another, say x, on which theory suggests it is largely dependent, without at the same time holding constant a number of other influences. As a consequence, the explanation will frequently not be a good one, but even if it is reasonably good, owing to a moderate degree of intercorrelation between x and the omitted variants it will be dependent on the continuation of these intercorrelations for its stability. To the extent that they represent merely sampling phenomena they will break down, and with them will disappear the simple relationship between x and y.

Finally elasticities and their size are important for planning and financial management in the energy industries. A fuel producer knowing the approximate elasticities could determine the effect of a change in price on his revenue. If for example electricity had an inelastic demand (elasticity less than unity) an increase in its price will increase the total revenue of the utility even though the quantity demanded will decline, since the increase in price more than offsets the reduction in volume. Similar reasoning shows that a reduction in price reduces total revenue if demand is inelastic but increases total revenue if demand is elastic, since the increase in volume more than offsets the reduction in price.

The importance of such estimates is profound. Utilities can raise capital by increasing prices only if they face an inelastic demand.

MODELLING APPROACHES

A variety of models have been used for the estimation of energy elasticities. They can be classified to:

structural models
reduced form end use models
reduced form static models and
reduced form dynamic models.

The structural models of energy demand behaviour start with the identity

$$Q_i = \sum_{K=1}^{M} R_{Ki} A_{Ki} \qquad (1)$$

which states that the total consumption of fuel i is the sum of fuel consumed to each type of equipment in the capital stock A. R_{Ki} is the utilization rate of the k^{th} type of equipment of the i^{th} fuel.

A structural model of energy demand behaviour explicitly recognizes the derived nature of the demand by specifying separate demand functions for the equipment stock and the utilization rate. Typically, the behavioural relationships are identified separately:

$$A_i = f(P_i, P_j, P_a, Y, X);\ i \neq j. \qquad (2)$$

$$R_i = g(P_i, Y, Z). \qquad (3)$$

Equation 2 indicates that the demand for equipment using fuel i depends on the price of fuel i, the price of alternative fuel j, the price of the equipment P_a, income Y (or value added, in the case of a firm), and a vector of other variables X (such as household size). The utilization rate specified in Equation 3 depends on the own-price P_i, income Y, and a vector of other variables, $Z. P_j$ is not a relevant argument since the fuel type is constrained by the appliance chosen (unless the equipment has dual fuel-burning capacity).

The interdependence of these two functions illustrates the joint nature of the decision process and indicates that both the capital stock and utilization rate are endogenous factors of energy demand.

If information on equipment stocks is unavailable, the model represented by Equation 1,2, and 3 must be simplified, with an inevitable sacrifice of model detail. When stock data are available, but not data on stock prices, a reduced-form end-use model is an option. In an end-use model the equipment stock (or saturation rate) is held constant at the observed level without any attempt to explain what determines that level, in order to focus on the determinants of the utilization rate, conditional on the equipment stock. The identity equation (Equation 1) is used to obtain a weighed sum of the contribution of each unit of equipment for total fuel consumption. This approach is frequently referred to as the Fisher-Kaysen (1962) model.

In the absence of equipment stock data, another option is to collapse functions 2 and 3 into a single reduced-form equation, based on the generalization of Equation 1:

$$Q_i = h(A_i, R_i) \qquad 1'$$

where A_i and R_i are vectors of individual equipment types using fuel i. Substituting Equations 2 and 3 into Equation 1′ yields the reduced-form equation,

$$Q_i = k(P_i, P_j, Y, X, Z); \quad i \neq j. \qquad 4.$$

A variation of Equation 4 is sometimes used when equipment stock data are available:

$$Q_i = b(P_i, P_j, Y, X, Z, A). \qquad 4'.$$

Equation 4′ differs from an end-use model in that the appliance stock is not tied to consumption by the identity equation (Equation 1) and end-use elasticities cannot be calculated.

Because Equations 4 and 4′ fail to capture the relationship between the utilization rate and equipment stock, the distinction between short and long run adjustments is blurred. Hence, models of this type are referred to as reduced-form static models. Frequently, the distinction between short and long run adjustments is inferred from the type of data used, where time-series observations are used to measure short-run adjustment and cross-section data are used to measure long-run adjustments. However, the distinction achieved by this procedure is not very satisfactory.

To overcome this deficiency, another device is commonly used to capture the dynamics of the demand process. A distinction is made between actual consumption Q_t and desired consumption Q_t^* at time t, where the difference reflects the difficulty of adjusting equipment stocks to the desired configuration warranted by a change in relative fuel prices (or other variables). A partial or flow adjustment process is assumed.

$$Q_i = Q_{t-1} + d(Q_t^* - Q_{t-1}) \quad 5.$$

where d lies between zero and unity to reflect the partial adjustment in actual consumption toward desired consumption.

With Q_i in Equation 4 expressed in terms of desired consumption Q_t^* of fuel i, the unobserved variable may be eliminated by substituting Equation 5 into Equation 4 to yield an expression in terms of the observable variable Q_t. The result is an equation that includes the lagged value of consumption Q_{t-1} as an explanatory variable. When Equation 4 is expressed in linear form, the coefficient of Q_{t-1} gives an estimate of the adjustment parameter, which may be made to distinguish short from long run response coefficients.

Each of these models- structural, reduced-form end-use, reduced-form static, and reduced-form dynamic- have inherent advantages and weaknesses. The structural model incorporates the greatest amount of theoretical information about the nature of energy demand behaviour and empirical detail. It is also the most cumbersome to estimate. End-use models retain the distinction between capital stock and the utilization rate and can provide estimates of separate end-use elasticities, but are limited to conclusions about the short run. The reduced-form static model provides the least amount of information, but it is relatively simple to estimate. The flow adjustment or reduced-form dynamic model expands on the static version in a potentially useful way, but the distinction between short and long run adjustments is generally based on an arbitrary specification of the adjustment process. The choice of approach is governed by the objective of the analysis, the availability of capital stock information, and the ease with which the model is employed.

PROBLEMS OF ESTIMATING ENERGY ELASTICITIES

A variety of methodological, statistical and conceptual issues make the estimation of elasticities problematic. Apart from discrepancies in statistical data series, the most frequent source of inconsistencies and source of debate are the degree of aggregation, the specification issues and the interpretation of empirical results.

The level of aggregation in the data has been found to make a difference in the estimated results of demand models and the issue appears to be equally well supported theoretically by both, those who support a fine level of detail and those advocating a higher level of aggregation. Those favouring the use of disaggregated data argue that aggregated data average over disparate characteristics of economic units and reduce the amount of pertinent information in the sample. The disparities among energy users should be particularly pronounced in the industrial sector where different plants in the same industry use different production processes and industry groupings combine widely different commodities and processes. In its extreme form this school of thought finds its adherence among the extreme individualists who believe that the purpose of economic science is to formulate rules of behaviour which, derived by deduction from the principles of economic rationality, are entirely a social and a historical. Such an approach will apply with equal validity to Robinson Crusoe, shipwrecked and struggling for survival on an uninhibited island, and to the capitalist entrepreneur. Of course such a theory of economic activity as formal as this belongs like mathematics to the realm of a priori knowledge and is therefore not subject to empirical verification, either statistical, or historical. On the other side lie those who argue that social sciences should follow the example of physical sciences in order to succeed. The advances of physical sciences are to a great extent due to the fact that simple relationships (laws) are attainable because they typically describe the aggregate behaviour of many million entities. This suggests that success in finding laws in the social sciences is most likely in the field where the behaviour of a large number of objects is being described. Particularly in the energy sector a high level of aggregation could be beneficial. Aggregated data used for the estimation of elasticity would capture the full effect of a change in energy price on the demand for it and give more reliable estimates. A sectorial aggregation, for example, usually hides the more esoteric interactions taking place among different sectors of the economy. Increasing energy prices can increase the relative price of commodities embodying higher than average energy intensity and motivate substitutions away from these commodities thereby reducing energy demand in the economy. If, however, the substituted and substituting commodities belong to different sectors and are modelled separately, the price induced impact will not be detected as such. An example is the substitution between transportation and telecommunication services. As energy prices rise, transportation cost may rise relative to telecommunication costs. Firms may substitute telecommunications (eg teleconferencing) for transportation and overall energy consumption in the economy may decrease. If transport and telecommunication are modelled separately, the price effect through the structural change will not be detected. This interaction implies that the sum of the weighed elasticities, of all individual units, industries or sectors would be smaller than the elasticity of the entire economy and therefore sectorial analyses will give elasticities for the total economy which are biased downwards.

The specification problem revolves around the variables to be included and the functional form to be adopted in the estimation of elasticities. In economics it is not, as a rule, possible to experiment. That is to say, there is hardly ever an opportunity to hold constant a number of factors while a particular covariation is being studied or to control their influence by experimental design. The data which are available contain the variation due to all the influences operating in the real world, and it is from this mass of information that confirmation of expected relationships must be sought. It will thus be seen that the information cannot be got into a form in which it is suitable for the study of partial relationships unless we succeed in holding constant a number of other influences which happen to have been operating at the time.

This necessary but not sufficient condition for success has not always been observed, and many attempts have been made to explain one variable, say y, in terms of another, say x, on which theory suggests it is largely dependent, without at the same time holding constant a number of other influences. As a consequence, the explanation will frequently not be a good one, but even if it is reasonably good, owing to a moderate degree of intercorrelation between x and the omitted variates it will be dependent on the continuation of these intercorrelations for its stability. To the extent that they represent merely sampling phenomena they will break down, and with them will disappear the simple relationship between x and y.

There is another consideration to be kept in mind. Suppose that in the above example y stands for quantity purchased (by definition equal to quantity sold) and y stands for the price of the commodity. Further, suppose market conditions to be such that x enters into a supply relation as well as a demand relation. There are then two independent relations connecting x and y, and the slope of the regression between them may approximate to one or to neither of them. If all the demand factors except price have been constant over the period of observation while the other supply factors have varied the regression line will approximate to the demand curve: or, mutatis mutandis, to the supply curve. If both sets of variates have shown fluctuation over the period, no very definite relation between y and x is likely to emerge from the data, and any regression obtained will not necessarily approximate to either curve.

If, therefore, we are looking for stable relationships, it is clearly necessary to introduce as far as possible all the important influences on the dependent variate. If we are able to do this and succeed in introducing all the more important influences in the period, then at least the partial derivatives will be good estimates of the true net relationships existing in the data.

In practice however, several probably important variables have to be omitted from the calculation either in order to make the equation manageable or because they cannot be quantified. Examples are advertising and expectations, changes in official attitudes, clear air preferences and social attitudes to convenience (eg with regard to coal). The omission of these variables may be even more important if, as is likely, they vary broadly in parallel with income and/or prices. The costs, efficiencies and lifetime of appliances for using individual fuels are also nearly always omitted because of the problems of collecting data, and because to include it would make the analysis very much more complicated.

The choice of functional form is another decision facing demand modelers. Log-linear, linear, and translog are the most popular options. The log-linear form is convenient because parameter estimates measure elasticities directly, while linear forms are preferred by those who question the reasonableness of assuming constant elasticities at all price level. Linear and log-linear forms are restrictive in their assumptions about underlying utility functions of households and production functions of firms. In particular, the underlying functions must be linear, implying that elasticities of substitution in consumption and production are constant and equal. The functional form, in addition, imposes restrictions on the data that can affect parameter estimates.

The translog is one of several so-called flexible functional forms developed to relax the restriction imposed by linearity. While more flexible in form, the translog also has limitations. Two limitations are particularly troublesome in energy demand models. First, and most important, the translog models are static

and hence unable to capture the intertemporal properties of demand. Second, the procedure generates a large number of parameters so that, to preserve degrees of freedom, restrictive assumptions are required to reduce the number of independent parameters.

Finally, the interpretation, of any findings and their translation into instruments for policy formulation are troublesome. Elasticities are unlikely to have stayed constant over time. Demand for a fuel will be more elastic if an alternative is available at a competitive price; the large changes over time in the availability of some fuels (eg off-peak electricity) will therefore have affected the price elasticities of other fuels. Price and income elasticities probably also change over time because of changes in the level of income and in the energy intensity of the economy. The output elasticities of industrial energy demand may also vary through the business cycle and with longer terms structural changes. Therefore, the estimation of elasticities may be particular to an epoch and locality with only historical value. In such a case the past can provide only limited guidance for the future and any attempt to forecast the future will be futile.

A META SURVEY

This chapter reports the results and conclusions of 3 reviews on elasticities of energy demand. The first review was undertaken by the British Department of Energy (1977) and includes 42 studies. The second review (Bohi 1981) includes 47 studies and the third one (Bohi et al 1984) is an update of Bohi (1981) and includes 40 studies. While some overlapping exists between the first and second reviews the three reviews together cover more than 100 studies.

In 1977 the British Department of Energy set up a working group on Energy Elasticities to review more widely the Departments state of understanding and methods of handling the relationships between energy consumption and price. The interest in the extend to which prices affect energy consumption was due to the development of OPEC and due to competition of gas with electricity in the U.K market.

The working group tabulated the results of 42 studies (Annex 1) and concluded "From the available data, it is not possible to derive a full set of United Kingdom energy elasticities with useful accuracy. The estimation of price-elasticities and cross-elasticities is especially difficult because of the small size of the variations in prices prior to 1973. Even if a stable set of elasticities could be quantified for the past, recent changes in the general energy price level and the pattern of energy supplies would be expected to cause price responses in the future to differ markedly from those in the past. One feature of energy responses to changes in price or income is that they are usually spread over many years due to behavioural and physical delays, for example in adjusting stocks of energy-using equipment. The pattern of these delays is unlikely to have been stable and there is not sufficient data to quantify them satisfactorily. They require, however, a distinction between - "short-term" and "long-term" elasticities. The appropriate definition of "short-term" and "long-term" will vary from case to case".

Further the Working group identified the Transport sector as an area where elasticities merit major consideration and suggested that "The improvement of our understanding of and ability to predict energy price responses appears more likely to come from:

i) More technical information on how fuels are used and the economic and physical constraints on rates of change and

ii) The analysis of the effects of the large 1973 and post-1973 energy price changes.

The second review (Bohi 1981) is based on research performed under a grant to Resources for the Future from the Electric Power Research Institute. Its goal was a comprehensive survey of the econometric literature on energy demand elasticities, and an evaluation of the reliability of the estimates for forecasting purposes. The benefits of this effort were supposed to be "an advance in the practice of demand estimation generally. By informing users what they can and cannot expect from researchers, it can sharpen the criteria that are used to commission such studies and judge their results. By alerting researchers to some special problems to estimation, it can help them avoid pitfalls and blind alleys; these can be especially serious when rapid changes are taking place in the economy. And by offering a careful critique of the state of the art, it can provide guidance for students and analysts new to demand estimation" One third of the study (approximately 55 pages) were spent reviewing a number of issues that confront any econometric study of demand and some that have special interpretations when applied to energy products. The author concluded that "often it is not possible to deduce with reasonable certainty the magnitude or direction of the effect of those issues on estimated elasticities. For this reason, it is fortunate that the literature on energy demand has approached these questions in a variety of ways. What may otherwise seem to be a profusion of alternative estimates provides a means for evaluating the sensitivity of elasticity estimates for the problems encountered and the approaches taken. The rest of the study reviews a major portion of the international literature on elasticities organizing them first by major consuming sector and then by estimation procedure. Further, the studies are distinguished according to the type of model and data employed. The tabulation of the reported studies and the references appear in Annex 2.

Table 1 summarizes Bohi´s conclusion about the estimated elasticities for each fuel and consuming sector and compares them with the range of estimates found in the literature (excluding values related to specific regions or end users) The author emphasizes that "the conclusions reported refer to national markets for each fuel and consuming sector, and relate to uniform nationwide price increases. They are also premised on markets associated with the economic and institutional conditions of the late 1970´s. Consequently the figures are not necessarily appropriate for subclasses of consumers (say, by region or income), nor can they be used reliably to forecast events after major economic and institutional changes have occurred. Similarly, caution is required in using these elasticities to evaluate government policies if a policy change alters incentive structures in private markets and therefore induces a change in behavioral responses".

TABLE -1. SUMMARY OF INFORMATION ON PRICE ELASTICITIES OF DEMAND BY FUEL AND SECTOR

	Estimates in the literature[a]		*Conclusions about the estimates*	
Fuel and sector	*Short-run*[b]	*Long-run*[a]	*Short-run*[b]	*Long-run*[c]
Electricity				
Residential	-0.06 to -0.49	-0.45 to -1.89	-0.2	-0.70
Commercial	-0.17 to -0.25	-1.00 to -1.60	Uncertain	Uncertain
Industrial	-0.04 to -0.22	-0.51 to -1.82	Uncertain	Between -0.5 and -1.0
Natural gas				
Residential	-0.03 to -0.40	-0.17 to -1.0	-0.10	0.5
Commercial	-0.03 to -0.40	-0.17 to -1.0	Uncertain	Near -1.0
Industrial	-0.07 to -0.21	-0.45 to -1.5	Uncertain	Uncertain
Electric utilities	-0.06	-1.43	-0.06	Uncertain
Gasoline	-0.11 to -0.41	-0.36 to -0.77	-0.2	-0.7 or more elastic
Fuel oil				
Residential	-0.13 to -0.3	-1.1 to -1.76	Uncertain	Uncertain
Commercial	-0.07 to -0.2	-1.1 to -1.76	Uncertain	Uncertain
Industrial	-0.11 to -0.22	-0.8 to -2.82	Uncertain	Uncertain
Electric utilities	-0.10	-1.50	-0.10	Uncertain
Coal (steam)				
Industrial	-0.10 to -0.49	-0.49 to -2.07	Uncertain	Uncertain
Electric utilities	-0.09 to -0.46	-0.67 to -1.15	-0.09	Uncertain

[a] Excluding outlying values related to regions or end uses.

[b] Refers to a response period of one year.

[c] The response period is indefinite, but is generally interpreted to be less than ten years.

The "estimates in the literature" in table 1 indicate that long-run elasticities are fairly elastic and that invariably consumption response accumulates significantly over time so that the bulk of the total response occurs after the first year. Bohi's "conclusions about the estimates" are subjective evaluations based on unquantifiable and not explicitly mentioned qualities of the studies reviewed. For example, the elasticities for fuel oil demand were deemed uncertain in all categories owing to poor information about consumption by sector, and the estimates of elasticities for natural gas because of a combination of poor data and the confusing effects of disequilibrium markets.

The major conclusions are:

1) Relative fuel prices are important in energy consumption decisions and should be incorporated in demand analysis

2) Consumption response cumulates over time and the strength of a price effect should not be judged on the basis of short term results.

3) An upper bound on energy price elasticities exists. While prices are important and the consumption response builds over time, one should avoid imputing an elastic response to any fuel price change in any major consuming sector without special justification.

The third review (Bohi 1984) covers at least 40 recently published econometric studies of energy demand. These studies are considered to provide more reliable evidence for the size of energy elasticities because they are based on data taken from the period after 1974 when energy prices began to rise rapidly; because they utilize more extensive data banks and finally, because the data is analysed more carefully through comparisons of the results of alternative estimates and functional forms. The empirical results of the studies reviewed are compared among end-use sectors, fuel types and modelling issues and tabulations are presented in Annex 3. The authors conclude that "Residential demand for electricity appears to have a price elasticity near -0.2 in the short run and near -0.7 in the long run..... Residential natural gas demand appears to respond to price to the same extend as electricity in the short run, but is substantially less elastic in the long run (-0.3)... Very little information is conveyed about commercial and industrial energy demand behavior. Based on available evidence, both commercial and industrial demand seem to be more elastic than residential demand across all fuels. However, the evidence is very tenuous. The demand for gasoline appears to have a short run price elasticity on the same order as that for electricity and natural gas, and a long-run elasticity slightly less than unity. The income elasticities reported for gasoline are generally larger than those for other fuels and sectors. Gasoline consumption appears to be a normal good, or perhaps even a superior good, in contrast to other fuels. (Finally) as a tentative conclusion, the energy crisis does not appear to have affected the structural characteristics of demand as related to the usual economic determinants; rather the changes have occurred in those determinants of demand that are incorporated in constant terms and error terms".

It should be noted that the derived conclusion as in Bohi (1981) are highly subjective. The authors claim that "in addition to the usual measures of statistical significance and conformity among studies, results from studies that use highly disaggregated data, that model the structural elements of demand behaviour, and that are generally consistent with the economic theory of demand are considered more reliable".

The following tables show the range of elasticities estimated by various studies and the consensus elasticity defined as the average value of the values provided by the different studies. It becomes obvious that while all elasticities fall within the theoretically expected bounds (0 to −∞) the disparity between least and most elastic price elasticities spans more than two orders of magnitude in some cases.

TABLE 2 . The Residential/Commercial Sector: Range of Long-Term Price Elasticities of Demand for Energy by Fuel

	Elasticity Range		
Fuel	*Least Elastic*	*Most Elastic*	*Consensus Elasticity*[a]
Oil	−0.3	−9.5	−1.4
Gas	0.0	−3.9[b]	−1.2
Coal	c	c	c
Electricity	0.0	−2.6	−1.1
Aggregate	−0.3	−0.9	−0.5

Sources:

J. A. Edmonds, *A Guide to Price Elasticities of Demand for Energy: Studies and Methodologies*, Institute for Energy Analysis, Oak Ridge, Tenn., Research Memorandum (ORAU/IEA-78-15(R), 1978).

D. R. Bohi, *Analyzing Demand Behavior: A Study of Energy Elasticities* (Baltimore, Md.: Johns Hopkins University Press for Resources for the Future, 1981).

L. D. Taylor, *The Commercial Demand for Energy: A Review of Existing Knowledge* (Department of Economics, University of Arizona, 1977).

J. A. Edmonds, B. Cohen, and S. Wagner, "Factor Substitution in the Industrial Sector with a Case Study of the Oak Ridge Industrial Model," Draft report, 1981.

T. H. Morlan, D. H. Skelly, and A. P. Reznek, *Price Elasticities of Demand for Motor Gasoline and Other Petroleum Products*, DOE/EIA-0291, U.S. Department of Energy (May 1981).

W. D. Nordhaus, *International Studies of the Demand for Energy*, selected papers presented at a conference held by the International Institute for Applied Systems Analysis (Amsterdam: North-Holland; 1978).

M. S. Commons, "Implied Elasticities in Some United Kingdom Energy Projections," *Energy Economics*, vol. 3 (July 1981).

Energy Modeling Forum, *Aggregate Elasticity of Energy Demand*, vol. 1. Energy Modeling Forum, Stanford University, Stanford, Calif., 1980.

Report of the Working Group on Energy Elasticities, Energy Paper 17 (London: Her Majesty's Stationery Office, 1977).

[a] Consensus elasticities were obtained by averaging values from source studies.

[b] The elasticity value of "large" specified by the Federal Energy Agency for the Project Independence model is not further defined.

[c] No longer a significant residential/commercial fuel.

TABLE 3 . The Industrial Sector: Range of Long-Term Price Elasticities of Demand for Energy by Fuel

	Elasticity Range		
Fuel	*Least Elastic*	*Most Elastic*	*Consensus Elasticity*[a]
Oil	−0.0[b]	−4.7	−2.0
Gas	−0.0[b]	−3.9	−1.3
Coal	−0.0[b]	−2.2	−1.1
Electricity	−0.1	−2.0	−1.1
Aggregate	−0.1	−1.1	−0.4

Sources: Sources consist of references listed in table 5-1 plus individual studies.

[a] Consensus elasticities were obtained by averaging values from source studies.

[b] Very small negative value—between 0 and −0.05.

TABLE 4 The Transport Sector: Range of Long-Term Price Elasticities of Demand for Energy by Fuel

	Elasticity Range		
Fuel	*Least Elastic*	*Most Elastic*	*Consensus Elasticity*[a]
Oil	−0.2	−1.5	−0.6
Gas	b	b	b
Coal	b	b	b
Electricity	b	b	b
Aggregate	−0.4[c]	−0.4[c]	−0.4[c]

Sources: Sources consist of references listed in table 5-1 plus individual studies.

[a] Consensus elasticities were obtained by averaging values from source studies.

[b] Not a significant transport fuel.

[c] Only one study calculates this magnitude. See J. A. Edmonds, *A Guide to Price Elasticities of Demand for Energy: Studies and Methodologies*. Institute for Energy Analysis, Oak Ridge, Tenn., Research Memorandum (ORAU/IEA-78-15(R), 1978), p. 14.

ELASTICITIES: WHAT HAVE WE LEARNED?

A vast body of evidence has been reviewed in the previous sections. Here we delineate the general conclusions.

Result 1. Price matters. The theoretical expectation that price is an important determinant of demand is verified empirically for energy commodities. Demand responds to higher energy prices as other factors of production substitute energy, technological progress assists in more efficient use of energy and expensive energy carriers are substituted by less expensive ones.

Result 2. Long-run energy price adjustments are substantially greater than adjustments occurring in the short term - immediately after the price change. This result suggested by differences in short and long-run elasticities occurs because capital stock changes dominate quantitatively utilization changes and capital stock turns over slowly.

Result 3. The law "Price affects energy demand" is valid, for all countries and all time periods. Although the majority of studies examine data from the U.S.A and U.K over the most recent period, studies utilizing data from other countries and time periods derive similar conclusions.

Result 4. The long-run price elasticity for electricity demand probably exceeds unity for all sectors but may be as low as -0,5. The long run price elasticity for gasoline ranges from -0,36 to -0,77 while the demand elasticities for natural gas are uncertain mainly due to the fact that virtually never has been an unconstrained market for natural gas. Further, the long-run elasticity for fuel oil appears to be elastic ranging between -1,1 to -1,76.

ENERGY ELASTICITIES IN SOUTH AFRICA

Energy elasticities have not been examined rigorously in a South African context. A variety of reasons have contributed to the lack of research in this area. The lack of energy economics courses in South Africa, the legislatively imposed secrecy on liquid and nuclear fuels and the prevailing misconception that price is not important in determining demand are some of the reasons. The earliest study on elasticities was published in 1977 in "The Outlook for Energy in South Africa" (Dept of Planning and the Environment, 1977) by G L de Wet and I Chown.

The authors used a log-linear function to estimate the demand for energy in different sectors and for different fuel carriers. The function contains the own price, the price of a substitute or complement, income or production and an approximation of it, and the lagged value of the dependent variable as explanatory variables, while the quantity demanded is the dependent variable.

The analysis and estimation of elasticities appear in Annex 4 while here we provide a summary of the results. It is important to note that de Wet et al have estimated only short term elasticities and no comments have been made for the long run effects. We extended their calculations in estimating the long-run elasticities where possible.

As the estimated function is of the form:

$$\ln Q_t = a + b\ln P_t + c\ln Y_t + d\ln Z_t + f\ln Q_{t-1}$$

where Q is the quantity demanded, P is its price, Y is income in the case of final consumption or output in the case of intermediate demand, Z is a vector of other variables and Q_{t-1} the demand in period t-1, the long run price elasticity is given by

$$ep = \frac{b}{1 - f}$$

The following table gives the estimated elasticities

TABLE 5 Energy Elasticities in South Africa

	FUEL CARRIERS					
Sector	Electricity		Petroleum		Coal	
	short term	long term	short term	long term	short term	long term
Household	-0.30	-1.68	-0.23	-0.79	NR	NR
Industrial	-0.06	-0.38	-0.24	-1.42	-0.45	NA
Transport	-0.28	-0.88	NR	NR	-0.27	NA

NR: non-reported
NA: non-available

All elasticities conform with the prior expectation. Short-run elasticities are smaller than long-run, all elasticities have the expected signs and the size of the long run elasticities is within the range limits of elasticities estimated abroad.

In order to verify and validate the estimated elasticities we estimated the aggregate price elasticity of electricity demand in South Africa. A general distributed lag formulation of the type:

$$E_t = \sum_{i=0}^{n} a_i P_{t-i} + Q_t + U_t$$

has been used for the estimation of the long run price elasticity of electricity demand. E_t denotes the demand for electricity in t period, P_t denotes the price of electricity in t period and, Q_t the economic activity during the t period.

Two different estimation procedures were used (in order to determine the stability of the estimates) for the estimation of the long run elasticity. First we estimated the necessary coefficients after a stepwise regression procedure (annex 5) and then through a direct OLS procedure (Annex 6)

Annex 5 and 6 contain the complete analysis and estimation of aggregate elasticity. The aggregate elasticity is found to range between -0.9 and -1.1. This range is higher than the weighted average of elasticities of the individual sectors. Using as weights the sectoral consumption of electricity in South Africa in the year 1964 and the estimated sectorial elasticities the aggregate elasticity is estimated to be -0.67. However, we expected that difference for those reasons explained in the chapter "Problems of estimating energy elasticities"

Electricity elasticity has a particular significance for the South African energy scene. The most important fuel carrier in South Africa is coal and 54% of the locally consumed coal is burned to produce electricity. This means that 54% of the demand for coal for local consumption is derived demand from the demand for electricity. As approximately 20% of the cost of electricity is due to fuel cost an increase in the price of coal will cause an increase in the price of electricity which in its turn will cause a reduction in the demand for coal. Assuming a price elasticity of electricity demand of -1 and a fuel cost component for the generation of electricity of 20% the price elasticity of coal demand for electricity generation is -0.20. In other words if the price of coal increases by 100% the price of electricity increases by 20%. As the long-run elasticity of electricity demand assumed to be -1 the demand for electricity will decrease by 20%. Consequently the demand for coal for electricity will decrease by 20%. Therefore an increase of 100% in the price of coal for electricity causes a 20% decrease in the demand for it and the long run elasticity of coal for electricity is -0.20.

With a similar reasoning we can derive the elasticity for coal demand for SASOL fuel which represents approximately 20% of the total coal consumption. The demand for coal for electricity and for SASOL fuel together represent approximately 75% of the total inland consumption of coal and therefore the estimation of the two elasticities and their weighted aggregation could give an adequate approximation of the elasticity of the demand for coal in South Africa. However, the Petroleum Products Act and the amendment Bill of 1984 forbid the transmission and publication of any information related to liquid fuels in South Africa and therefore there are no data available related to consumption of liquid fuels in the country. Consequently the estimation of price elasticity of liquid fuels[1] and the derived elasticity of coal for the production of liquid fuels cannot be estimated. The demand for coal from industry, domestic market, coke users etc, represent small portion of the total demand (e.g industry 9%, domestic 4,5% coke producers 6.2% etc) and the exercise of estimating elasticities in such a detail is useful only for narrow and specific purposes. Similarly the contribution of gas in the country's energy consumption is very small to warrant a detailed analysis. Kotze et al (1985) suggest that gas contributes only 7.8% in volume terms in the countries energy consumption.

In a more aggregate level Bitsakis (1986) has estimated the price elasticity of energy for the various energy consuming sectors in South Africa. Five different models were used for the estimation; a linear model, a linear model including a lagged value of the independent variable, a log-linear model, a log-linear with a lagged variable and a translog model. With data from the period 1960 - 1983 and through the generalized least squares method the elasticities exhibited in the following table were estimated.

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[1] In the Annual Report 1983 of the Department of Mineral and Energy Affairs it has been mentioned that after account has been taken of factors such as inflation motor vehicle population and speed limits the long term price elasticity of petrol has been estimated to be -0.50

Table 6 *Elasticities of Energy Demand for Various Models*

Model	Income Short-term	Income Long-term	Price Short-term	Price Long-term	Adjustment Parameter
Households					
linear		0,75 (0,06)		0,12 (0,08)	
linear lagged	0,57 (0,22)	0,76	−0,11 (0,07)	−0,14	0,26 (0,30)
log linear		0,73 (0,06)		−0,08 (0,08)	
log linear lagged	0,55 (0,27)	0,74	−0,07 (0,07)	−0,09	0,25 (0,36)
Agriculture					
linear		0,90 (0,24)		−0,22 (0,10)	
linear lagged	0,89 (0,25)	0,91	−0,23 (0,11)	−0,25	0,03 (0,20)
log linear		0,76 (0,22)		−0,14 (0,09)	
log linear lagged	0,06 (0,10)	1,23	−0,03 (0,05)	−0,52	0,95 (0,13)
Transport					
linear		0,73 (0,04)		−0,20 (0,08)	
linear lagged	0,67 (0,19)	0,73	−0,19 (0,05)	−0,20	0,08 (0,26)
log linear		0,64 (0,04)		−0,12 (0,03)	
log linear lagged	0,48 (0,19)	0,64	−0,10 (0,04)	−0,13	0,24 (0,29)
Industry/Commerce					
linear		0,82 (0,22)		−0,14 (0,14)	
linear lagged	0,63 (0,33)	0,80	−0,14 (0,15)	−0,18	0,21 (0,25)
log linear		0,96 (0,25)		−0,15 (0,15)	
log linear lagged	1,00 (0,33)	1,15	−0,15 (0,15)	−0,17	0,13 (0,22)
Mining					
linear		0,59 (0,11)		0,35 (0,11)	
linear lagged	0,18 (0,08)	0,47	0,19 (0,07)	0,51	0,62 (0,16)
log linear		0,48 (0,09)		0,38 (0,10)	
log linear lagged	0,19 (0,09)	0,46	0,20 (0,09)	0,49	0,59 (0,18)

The price elasticities of energy demand estimated through the translog model are variable and are presented in the next figure

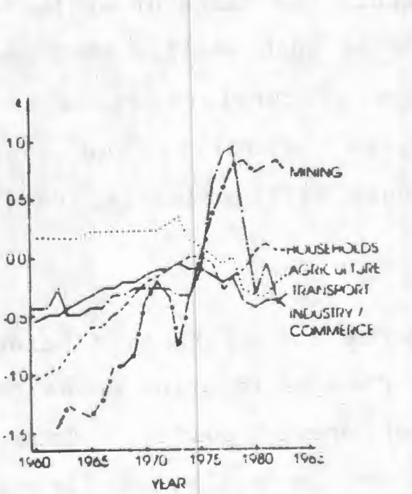

Fig.1 Price Elasticities of Energy Demand for the Translog Model

The long-term price elasticities in all sectors with the exception of mining fall within the range -0.08 and -0.52. The author noted that the low elasticity in the transport sector is probably due to the fact that only public transport is included in the analysis and that the positive elasticity in the mining sector is due to the omission of explanatory variables (lurking variables)

The elasticities of aggregate energy demand appear to be less elastic than the fuel specific elasticities. This phenomenon is in agreement with the theoretically appealing rationale that interfuel substitution is easier than conservation and substitution of energy for other factors of production.

Finally in an even more aggregate level Contogianni (1982) has estimated that the short term and long term price elasticities of electricity, gas and fuels (as group) are -0.06 and -0.20 respectively in South Africa.

DISCUSSION AND CONCLUSIONS

In this report the price elasticities of energy demand have been studied in an international context in general and in a South African context in particular. The meaning and usefulness of price elasticities have been outlined and the price elasticities of energy demand in South Africa have been estimated and been collected. In an international level, price was found to be an important determinant of energy demand. As far as South Africa is concerned, the estimated elasticities fall within the range of estimated elasticities abroad. Short-run elasticities found to be much smaller than long-run elasticities and elasticities of individual energy carriers found to be more elastic than aggregate energy elasticities. Finally, the long-run elasticities of individual fuel carriers although fairly elastic are in general smaller than unit.

A variety of policy issues accrue out of these findings. Firstly, the fact that energy demand responds to changes in price means that pricing can be used as an effective instrument for energy policy. Conservation and interfuel substitution can be promoted and be motivated through price manipulation. Although the response will take some time, it is virtually unrefutable that price is an important instrument in the hands of policy makers. The importance of the pricing mechanism is particularly important in the field of liquid fuels in South Africa. However, legislation makes difficult the estimation of elasticities in this area. We suggest that much opportunity for further research exists in this area which however should be coupled with research on energy pricing - macroeconomy feedbacks.

Secondly, the fact that energy price elasticities are different than zero means that models which omit price from the set of explanatory variables are mispecified. As the majority of models in South Africa do not use price as an explanatory variable and energy prices are rising forecasts overestimate the energy demand. This overestimation in its turn causes misallocation of resources in the form of excess capacity expansion. Overestimation of future electricity demand and of SASOL fuel will have repercussions not only for ESCOM and SASOL, but also for the country as a whole as precious capital and foreign exchange would have been spent on unused idle capacity. Analysts and planners in energy industry should recognise the importance of elasticities and incorporate them in their forecast of future energy demand. Their job would be further assisted if the government made known and explicit their pricing energy policy in general and the pricing mechanism in particular. For example, for a fuel whose price is regulated the government could state that is interested in conservation and substitution of the particular fuel for others and therefore it intends to increase its real price by an x amount per year over an horizon of say 5 years and its relative to other fuels price by a y amount per year. Such an explicit policy not only would assist energy analysts and forecasters but could also speed up the market adjustment mechanism as it would influence consumers expectations. Energy consumers knowing that the particular fuel will be more expensive in the future will switch much sooner to other fuels and/or conservation and they would not expect the price to reveal by itself its future direction.

Finally, the finding that most energy carriers are price inelastic (at least in the short-term) creates the opportunity for the government and utilities to increase their revenue. This is particularly important for the current situation in South Africa as sanctions make capital expensive and scarce. Provided that research shows that an increase in the price of energy would not have adverse repercussions for growth, employment and other macroeconomic targets the government should as a matter of policy increase the price of energy. This will not only promote conservation and substitution of certain fuels for others or other factors of production but it will also increase the government´s revenue and therefore decrease the budget deficit. Even if there are philosophical objections over higher taxation, high energy taxes can be compensated with lower tax rates elsewhere (eg GST or general income tax) where lower taxes can promote higher growth.

To summarise, although much quantitative uncertainty about responses of energy demand to prices remain the current ´paradigm´ is that energy elasticities are different than zero and hence important and therefore require special attention due to particular circumstances in South Africa. The creation of a data bank with information about the characteristics of energy using machinery would be particularly useful. If for example we knew the age profile of the motor vehicle population and their efficiencies we could easily determine how gasoline consumption would be affected by a tax on gasoline or a tax on the use of old cars. Different model specifications and degrees of aggregation should also be tried in order to identify the sensitivity of energy elasticities.

Other related important questions which need answers are:

1. How raising energy prices affect growth
2. Is energy supplement or complement for capital and labour
3. Is energy taxation more harmful (beneficial) than other forms of taxation (eg income tax)
4. How energy pricing policy affects social classes and income distribution
5. What is the price elasticity of foreign oil supply to South Africa and what policy can counteract the liquid fuel embargo
6. What are the income elasticities of energy demand
7. What are the price elasticities of energy supply.

REFERENCES

J Bitsakis (1986) "Aspects of Energy-economy interactions in South Africa" South African Journal of Economics vol 54 No 2 June 1986

Bohi D R (1981) "Analysing Demand Behaviour - A Study of Energy Elasticities" John Hopkins University Press.

Bohi D R and Zimmerman M B (1984) "An update on Econometric Studies of energy demand behaviour" Ann Rev. Energy 9:105-54.

Contogiannis E (1982) "Consumer Demand Functions in South Africa: An Application of the Houthakker and Taylor Model" South African Journal of Economics, vol 50, no 2, pp125-35

Cournot, A A (1838) "Researches into the mathematical Principles of the Theory of Wealth" Kelly New York.

Department of Energy (1977) "Report of the Working Group on Energy Elasticities" Energy Paper No. 17, HMSO London.

Fisher F M and C Kaysen (1962) "A Study in Econometrics: The Demand for Electricity in the United States", Amsterdam, North Holland

Kotze D J and CJ Cooper (1985) "Energy Projections for South Africa" Institute for Energy Studies) Rand Afrikaans University Printers Johannesburg.

Mashall A (1885) "On the graphic method of Statistics" Jubilee Volume of the Statistical Society Royal Statistical Society p251-260 London Stanford.

Marshall A (1890) "Principles of Economics" 9th Ed. 3rd 1961 Macmillan New York and London.

Mill J S (1848) "Principles of political Economy, with some of their Applications to Social Philosophy" 7th Ed. 1961, (ed) by W J Ashley, Kelly, New York.

Pouris A (1986) "Demand for Electricity in South Africa: A Survey" The South African Mechanical Engineer 36(1): 14-20.

Taylor L D (1975) "The Demand for Electricity: A Survey" Bell Journal of Economics 6(1) 74-110

ANNEX 1

Tabulation of estimated price and income elasticities of energy demand.

Source: Department of Energy (1973), "Report of the Working Group on Energy Elasticities" Energy Paper No 17, HMSO, London

Price Elasticities

Tabulated below are a wide range of econometric estimates of energy elasticities. They include all the substantial published studies of price-elasticities (mainly American) which have come to the attention of the Working Group together with a number of internal papers. They are all mainly concerned with price-elasticities although, as noted elsewhere, to estimate price-elasticities it is necessary at the same time to estimate the effects of other variables.

The tables record in some detail the differing sets of data and techniques used by various authors to estimate price-elasticities. No two studies can be said to be analysing the same problem. Some differences are trivial - such as differing conventions for weather adjustments. However, some are probably very important, such as the differing time periods and geographical areas, the differing definitions of price (eg marginal versus average, and measured relative to other fuel prices or all fuel prices, or all commodity prices), and the exclusion or otherwise of stocks of energy-using equipment.

Because of lack of data, few studies have disaggregated demand into mode of use (eg space heating) and none by type of household (eg by income) and no studies have attempted to include price expectations.

Column 2 of the tables shows the elasticity which is being measured. For example, the first study listed, by Hoque and Nobay, estimated the elastiicity of total domestic electricity consumption with respect to the ratio of the average domestic electricity price to the average price of all fuels in the domestic market. For brevity this is described as "total domestic electricity consumption as $f(P_e/T_e)$". The symbols used in this column and in column 4 have the following meanings:

Y = Income
Q = Quantity of fuel consumed
P = Price (average real prices unless stated otherwise, in the market being studied)
G = Number of consumers with gas supply
L = Hours of daylight
IIP= Index of Industrial Production

Subscripts: e = electricity
g = gas
sf = solid fuel
c = coal
p = petrol
f = all fuels
of= all other fuels (ie excluding the main fuels under discussion)
w = wages and salaries
oil=oil
t = time

Regression techniques:
OLS = Ordinary Least Squares
2SLS = 2-stage Least Squares
LIML = Limited Information Maximum Likelihood

Table 1 Heat and power fuel price-elasticity estimates

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
A. DOMESTIC ELECTRICITY						
(i) Electricity Council. J Hoque and A R Nobay, in Appendix II to *Economic Planning and Electricity Forecasting* by Prof Sir Ronald Edwards (1966).	Total domestic electricity consumption as f(P_e/P_f).	England and Wales quarterly time series 1955 (Q1) to 1965 (Q1).	Y, temperature. Exponential lag	−0.41	−0.91	2.89
(ii) K Wigley, *A Programme for Growth – 8: The Demand for Fuel 1948-1975. A sub model for the British Fuel Economy*, DAE Cambridge (1968).	Domestic electricity consumption per head of population as f(P_e/P_f). (Market share model)	Great Britain annual time series 1955-65.	Y, population, temperature. No lags (Market share model)	1955: −0.61 1960: −0.51 1965: −0.46		2.7
(iii) R J Ruffell. *An Econometric Analysis of the Household demand for Electricity in Great Britain 1955-68*, PhD thesis, University of Bristol (1973).	A. Total domestic electricity consumption per electricity bill as f(P_e)(marginal price). ('marginal price' = final marginal rate).	A. England and Wales quarterly time series 1955 (Q2) to 1968 (Q1) and cross section (Area Boards) pooled.	A. Appliance stock (disaggregated), utilisation (disaggregated by appliance type), Y, P_g, P_{st}, temperature, L, G, lags: values of Y, P_g, P_{st}, P_e weighted averages of 12 quarters: for Y weights equal, for P_g, P_{st}, P_e weights vary		utilisation effect −0.19	4.35
	B. Domestic off-peak electricity consumption per bill as f(P_e) (marginal price).	B. As A	B. As A (excluding G)		utilisation effect −0.44	1.46
	C. Total domestic electricity consumption per bill as f(P_e) (marginal price) ('marginal price' = weighted marginal price actually faced by consumers, ie some consumers are not on *final* rate).	C. As A	C. As A		utilisation effect −0.31	10.11
	D. As A	D. As A	D. Y, P_{st}, P_g, G, temperature, L. Lagging as A.		utilisation + appliance stock effects −0.22	
	E. As A.	E. England and Wales annual time series (a) 1955 – 68 (b) 1955 – 65	E. Y, P_{st}, P_g, temperature. No lags	(a) 1967/68 −0.16 (b) 1965/66 −0.22		

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity* Short run	*Elasticity* Long run	*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
DOMESTIC ELECTRICITY (continued)						
(iv) G J Doumenis, *The Demand for Electricity in Great Britain, a Study in Econometrics.* PhD thesis Southampton (1965)	A. Domestic electricity consumption per head as f(P_e)	A. Great Britain annual time series 1947 – 61	A(a) Y, appliance stock. No lags. (b) Y, No lags.	A(a) −0.37 (b) −0.64		
	B. As A. using simultaneous equations	B. As A.	B. Demand equation: (exponential lag). Y, $P_{appliances}$, appliance stock per head. Supply equation: time, P_m, number of consumers, investment expenditure, interest rate.	B(a) by OLS method: −0.62 (b) by 2SLS method: −0.69 (c) by LIML method: −0.75		(c) 4.34
	C. Total electricity consumption per head as: a, b, c. f(P_e) d. f (P_e/P_g) e. f (P_e/P_e) f. f (P_e)	C. As A.	C(a) logarithms of Y (b) logs of differences in Y (c) as a, + time (d) as a. +P_g (e) as a. +P_e (f) as a. + $P_{appliances}$ No lags.	C(a) −0.78 (b) −0.70 (c) −0.60 (d) −2.05 (e) −2.30 (f) −0.93		(a) 5.75 (b) 4.78 (c) 4.67 (d) 9.65 (e) 7.96 (f) 3.33
	D. As C.	D. Annual time series: (a) USA 1947 – 61 (b) Sweden 1946 – 60 (c) Germany 1950 – 60 (d) France 1947 – 61 (e) Greece 1948 – 61	D. Y. No lags.	D(a) −1.26 (b) −3.06 (c) −0.33 (d) −0.13 (e) −0.81		
(v) R Stone, *The Measurement of Consumers' Expenditure and Behaviour in the United Kingdom* 1920 – 38 Vol 1 (1954) Cambridge.	Domestic electricity consumption per consumer as f (P_e).	United Kingdom annual time series 1920 – 38	Y, temperature, time. No lags.	−0.58		3.87
(vi) Department of Energy EcS Division (1974).	Domestic electricity consumption per consumer as f (P_e).	United Kingdom annual time series: A. B. 1951 – 72 C. 1951 – 64 D. 1965 – 72	A temperature, Y, P_e, G. B temperature, Y, P_e, G. C as (b). D as (b). Lags: simple lagging of variables by 0 – 3 yrs (0 – iii).	A(0) −0.77	A (i) −0.82 A (ii) −0.91 A (iii) −0.76	A (0) 1.94 A (i) 2.67 A (ii) 2.53 A (iii) 1.37
				B(0) −1.02	B (i) −1.03 B (ii) −0.50 B (iii) −0.69	B (0) 2.36 B (i) 3.21 B (ii) 2.27 B (iii) 1.30
				C(0) −1.80	C (i) −1.31 C (ii) −1.59 C (iii) −1.84	C (0) 2.36 C (i) 1.56 C (ii) 1.55 C (iii) 1.85
				D(0) +0.17	D (i) +0.93 D (ii) +0.52	D (0) 0.03 D (i) 0.52 D (ii) 2.33

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
DOMESTIC ELECTRICITY (continued)						
(vii) H S Houthakker, P K Verleger and D Sheehan, *Dynamic Demand Analysis for Gasoline and Residential Electricity*, Lexington Mass. Data Resources Inc. (1973).	Domestic electricity consumption per head as f (P_e) (marginal price).	USA annual time series (1961 – 71) and cross-section pooled.	Y, exponential lag.	−0.09	−1.0	4.45
(viii) R Halvorsen, 'Residential Demand for Electrical Energy', *Review of Economics and Statistics* February 1975.	Domestic electricity sales per consumer as: A and C, f (P_e) (marginal price). B, f (P_e). A. Direct effect of price. B. Reduced form (ie including 'average price effect') C. Total effect calculated from results of A.	USA annual time series 1961 – 69 and cross-section (48 contiguous States) pooled.	A. Simultaneous equations. Demand equation: Y, P_g, $P_{appliances}$, temp, time, housing and density variables. Supply equation: Q_e per consumer, P_w, $P_{generating\ fuel}$, housing and density variables. B. Single equation, as Demand above Lags: A(a) Static (since pooling States, a long term estimate is achieved.) A(b) 1st Order Pascal (λ 0.8) A(c) 1st Order Pascal (λ 0.4) A(d) 2nd Order Pascal (λ 0.8) A(e) 2nd Order Pascal (λ 0.4) A(f) 5 yr inverted V A(g) 9 yr inverted V A(h) 5 yr average A(i) 9 yr average B. Static C. Static		A (a) −1.15 A (b) −1.08 A (c) −1.20 A (d) −1.00 A (e) −1.21 A (f) −1.11 A (g) −1.00 A (h) −1.11 A (i) −1.01 B. −1.52 C. −3.70	A (a) 38.3 A (b) 12.0 A (c) 10.9 A (d) 11.1 A (e) 11.0 A (f) 11.1 A (g) 11.1 A (h) 11.1 A (i) 11.2 B. — C. —

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient* (t = coefficient ÷ estimated standard error)
				Short run	*Long run*	
DOMESTIC ELECTRICITY (continued)						
(ix) R Halvorsen, 'Demand for Electric Power in the United States' (Discussion Paper No. 73 – 13, presented at Winter Meeting of the Econometric Society New York (December 1973). Later published as 'Demand for Electric Energy in the United States', *Southern Electric Journal*, Vol 42, No. 4, April 1978.	Total Domestic Electricity sales as f (P_e)	USA annual time series 1961 – 69 and cross-section (48 contiguous states) pooled	A. Simultaneous equations. Demand equation: Y, P_e, temperature, popln. density and housing variables. Supply equation, Type I: P_e, $P_{generating\ fuel}$, Q_e per consumer, Q_e (commercial and industrial), population density. Supply equation, type II: P_e for three consumption levels, Q_e per consumer.		A. Supply equation type I, using 2SLS method: −1.04. Supply equation type II, using 2SLS: −0.97. Using OLS, regardless of type: −1.00.	
			B. Reduced form. Y, P_e, temperature popln. density and housing variables. No lag (but cross section and hence long run estimates).		B. Using OLS: −1.33	7.9
(x) J M Griffin, 'The Effects of Higher Prices on Electricity Consumption', *The Bell Journal of Economics and Management Science*, Autumn 1974.	Domestic consumption per head of population as f (P_e).	USA annual time series 1951 – 71.	Simultaneous Equation System. 10 behavioural equations. 4 linking equations, 11 identities. Demand equations include: Y P(appliances), appliance stock. Polynomial distributed lag of Y and P_e.	−0.06	−0.52	
(xi) H S Houthakker, 'Some calculations on electricity consumption in Great Britain', *Journal of the Royal Statistical Society*, Vol. 114 Part III (1951).	Domestic electricity consumption per consumer on two-part tariff as A. f (P_e) (marginal price) B. f (P_e).	A. Great Britain annual time series 1937-38 and cross-section (42 towns) pooled. B. Time series 1920-33.	A. Y, P_g (marginal), appliance stock B. Y Lags: $P_{g,t-1}$ and $P_{e,t-1}$ used.		A. (with linear equation) −0.50 A. (with logarithmic equation) −0.89 B. (with logarithmic equation) −0.61	 4.69 6.78

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient* (t =coefficient ÷estimated standard error)
				Short run	*Long run*	
DOMESTIC ELECTRICITY (continued)						
(xii) F M Fisher and C Kaysen, *A Study in Econometrics, the Demand for Electricity in the US,* (1962), North Holland.	Change in total domestic electricity consumption as f (P_e)(ratio of current to long run average prices)	USA annual time series 1946-57 and cross-section (47 states) pooled.	Short run (Appliance stock assumed to grow constantly): Y Long run: Appliance stock disaggregated as a f (Y, P_g, $P_{appliances}$, $P_{gas\ appliances}$, change in long run Y) Both cases: Population, no. of marriages, change in no. of households wired. Lags: distributed weights of past Y.	Approx. average over 47 states of −0.5	Mainly + ve	Only 16 of 47 states significant
(xiii) T D Mount, L D Chapman and T J Tyrrell. *Electricity Demand in the United States; An Econometric Analysis*, Oak Ridge National Laboratory, National Science Foundation, Environmental Program (June 1973).	Total domestic electricity consumption as f (P_e).	USA annual time series 1947-70 and cross-section (47 contiguous states) pooled.	Y, P_g, $P_{appliances}$ population, temperature. Exponential lag A. Constant elasticity model using OLS method. B. Variable elasticity model using OLS method (for 1971). C. Variable elasticity model using 'instrumental variables' method (for 1971).	A. −0.14	A. −1.21 B. −1.20 C. −1.24	12.5
(xiv) D Blain, 'Influence of Prices on the Consumption of Electricity' in *Energy Systems Forecasting, Planning and Pricing,* Proceedings of a French-American Conference. University of Wisconsin-Madison, 23 September – 3 October 1974.	Low voltage electricity as a proxy for residential demand; (includes lighting and some other consumption by non-residential consumers), as f (P_e).	France time series 1954 – 72.	8 regressions on first differences. (a) 1 regression, no lag (b) 7 regressions: various lags of price. Y, temperature.	(a) −0.06	(b) −0.20 to 0.67 (larger values for lags averaged over 2 – 3 years).	(a) 0.25 (b) 1.5 to 2·5.

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity* *Short run*	 *Long run*	*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
DOMESTIC ELECTRICITY (continued)						
(xv) V K Smith and C J Cicchetti. 'Measuring the Price Elasticity of Demand for Electricity: The US Experience' in *Energy Systems Forecasting, Planning and Pricing*, Proceedings of a French-American Conference. University of Wisconsin-Madison, 23 September – 3 October 1974.	Sales per customer as $f(P_e)$.	New York State time series, 1951 – 70. Sales by 7 utilities.	Y or number of housing units, static and dynamic equations were tried in all cases, those of 'best fit' being presented – 5 of the 7 had best fit with exponential lag. (a) using OLS method (b) using 2SLS method. (c) using 2SLS adjusted for auto correlation.	Range within utilities: (a) −0.12 to −0.75 (b) −0.09 to −1.08 (c) −0.09 to −0.68		Range of: (a) 2.73 to 17.10 (b) 1.62 to 11.33 (c) 1.71 to 11.55
(xvi) J W Wilson, *Residential and Industrial Demand for Electricity: An Empirical Analysis*, PhD Thesis, Cornell University (June 1969).	A. 25 regressions using electricity per household as $f(P_e)$ or f (typical monthly bill for 500 kWh) (elasticities for average price slightly less). B. 42 regressions using percentage of homes with certain electric appliances. B (i) cooker B (ii) water heater B (iii) clothes dryer B (iv) electric heating B (v) freezers B (vi) air conditioning	USA cross-section of 77 cities. No date given.	Equations use a variety of P_e, Y, also number of rooms per home, temperature. No lag.	Typical range: A −1·00 to −1·50 B (i) −1.20 to −1.70 B (ii) −2.00 to −3.00 B (iii) −0.90 to −2.00 B (iv) −3.5 to −6.0 B (v) −0.6 to −0.9 B (vi) 0.0		A. over 5 B (i) over 5 B (ii) over 5 B (iv) over 5 B (v) over 5 B (vi) under 2
(xvii) J W Howe. 'Lifeline Rates—Benefits for Whom ?', *Public Utilities Fortnightly* Vol 97, No. 3,29 January 1976.	Consumption per household as $f(P_e)$ current prices (fuel surcharge).	(a) Jacksonville USA, January 1973 to December 1974. (b) Orlando USA January 1973 to December 1974. Each disaggregated into 15 groups by consumption level.	Temperature, 1 month lagging of price.	Jacksonville Groups 1 – 5 (low consumption); below −0.1. Groups 6 – 9; −0.1 to −0.2. Groups 10 – 14; −0.2 to −0.3. Group 15; −0.1. Orlando Groups 1 – 9; below −0.1. Groups 10 – 15; −0.1 to −0.3.		

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
DOMESTIC ELECTRICITY (continued)						
(xviii) R G Hawkins, 'The Demand for Electricity: A Cross-Section Study of New South Wales and the Australian Capital Territory, *Economic Record*, March 1975.	Domestic electricity demand per consumer, as $f(P_e)$ (nominal average price).	Cross-section of 43 retailing authorities in New South Wales and the Australian Capital Territory 1971	Number of houses, number of unoccupied holiday houses, Y per head, black coal consumption, gas availability.		−0.55	4.47
(xix) A S Deaton, 'The Measurement of Income and Price Elasticities', *European Economic Review* (6), 1975.	Domestic electricity as $f(P_e)$.	United Kingdom, 1970, based on time series 1954 – 1972.	Y (a) conventional constant elasticity model. (b) 'simple non-additive model'	(a) −0.96 (b) −0.30		

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity* *Short run*	*Elasticity* *Long run*	*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
B. DOMESTIC GAS						
(i) K Wigley (See above page 21) (1968)	Domestic gas consumption per head of population as f(P_g) (market share model).	England and Wales quarterly time series 1955 (1) to 1965 (1)	Y, population. temperature. No lag.	1955: −1.87 1960: −1.94 1965: −1.86		
(ii) Department of Energy EcS Division. 'The Sensitivity of Domestic Purchase to Relative Fuel Prices – an Explanatory Analysis' (1974).	Gas as a percentage of the domestic fuel market (market share model) as f(P_g).	United Kingdom cross-section (Area Boards) 1971.	(a) average prices. (b) weighted average prices. (c) central heating market. elasticities of gas demand; A. in $Q_g + Q_{sf}$ market. B. in $Q_g + Q_e$ market. C. in $Q_g + Q_e$ market. D. in $Q_g + Q_{all}$ market. E. P_e, P_g, in Dec. of years (i) to (vi) 1 – 6 yr lags (vii) $P_t 0{\cdot}8^{1972-t}$ (viii) $P_t 0{\cdot}85^{1972-t}$ (ix) $P_t 0{\cdot}9^{1972-t}$ F. Central heating market i – ix as i – ix in E.	A (a) −1.40 (b) −1.90 (c) −1.78 B (a) −3.08 (b) −1.21 (c) −1.54 C. (b) −1.04 (c) −1.07 D. (b) −0.76 (c) −0.86	E. (i) −1.23 (ii) −1.23 (iii) −0.96 (iv) −0.80 (v) −0.72 (vi) −0.91 (vii) −1.40 (viii) −1.36 (ix) −1.33 F. (i) −1.51 (ii) −1.43 (iii) −1.28 (iv) −1.18 (v) −0.86 (vi) −0.97 (vii) −1.58 (viii) −1.59 (ix) −1.58	
(iii) A S Deaton (See above page 27) (1975)	Domestic gas as f(P_g).	United Kingdom, 1970, based on time series 1954 – 72.	Y (a) conventional constant elasticity model (b) 'simple non-additive model'.	(a) −2.64 (b) −2.90		
C. DOMESTIC SOLID FUEL						
(i) K Wigley (1968)	Domestic solid fuel consumption per head of population as f (P_{sf}), market share model	England and Wales quarterly time series 1955 (1) to 1965 (1).	Y, population temperature No lag.	1955: −0.83 1960: −1.03 1965: −1.24		

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient* (t = coefficient ÷ estimated standard error)
				Short run	*Long run*	
C. DOMESTIC SOLID FUEL (continued)						
(ii) A S Deaton (1974)	Domestic coal as f (P_c).	United Kingdom, 1970 based on time series 1954 – 1974.	Y (a) conventional constant elasticity model (b) 'simple non-additive model.'	(a) −0.32 (b) −2.18		
D. DOMESTIC OIL						
(i) K Wigley (1968)	Domestic oil consumption per head of population as f (P_{oil}), market share model.	England and Wales quarterly time series 1955 (1) to 1965 (1).	Y Population, temperature No lag.	1955: −2.07 1960: −2.01 1965: −1.97		
(ii) A S Deaton (1974)	Domestic 'other fuel' as f (P_{oil}).	United Kingdom. 1970 based on time series 1954 – 1974.	Y (a) conventional constant elasticity model (b) 'simple non-additive model'	(a) +0.54 (b) −2.73		
E. TOTAL DOMESTIC FUEL CONSUMPTION						
(i) Department of Energy, EcS Division (1975).	Total domestic fuel consumption in useful terms as: (i) f (P_f useful (real), weighted by region). (ii) f (P_f useful (real) national average).	United Kingdom cross-section (regional) (i) (a) 1971 (i) (b) 1972 (ii) 1971	Y, dummy variable for London. No lag.	(i) (a) −0.20 (i) (b) −0.28 (ii) −0.24		(i) (a) 0.54 (i) (b) 0.60 (ii) 0.86
(ii) Department of Energy, EcS Division (1975).	Total domestic fuel consumption in useful therms as; f (real marginal price).	Great Britain, annual time series 1965 – 72 and cross-section, (New Standard Planning Regions) pooled.	Y, temperature. Exponential lag. A. Using OLS method. B. Using Zellner technique, and dummy variable for GLC. C. Using OLS method and dummy variable for GLC. D. Using Zellner technique and dummy variable for all regions (Due to over-identification of the equations, elasticity estimates are a range.)		A. −0.65 to −0.89 B. −0.45 to −0.56 C. −0.96 to −1.10 D. −0.61 to −0.74	

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
TOTAL DOMESTIC FUEL CONSUMPTION (continued)						
(iii) OECD. *Energy Prospects to 1985. An Assessment of Long Term Energy Developments and Related Policies* Vol II (1974).	Total final energy consumption (heat supplied) as f (weighted average fuel price).	A. Projections for 1980 (i) USA (ii) Canada (iii) Europe (iv) Japan	Not derived by analysis, but 'based to a large extent' on elasticities in an Appendix to the National Petroleum Council, 'United States Energy Outlook', December 1972.		A. (i) −0.2 (ii) −0.2 (iii) −0.2 (iv) −0.3	Not applicable
		B. for 1985 (i) USA (ii) Canada (iii) Europe (iv) Japan			B. (i) −0.3 (ii) −0.3 (iii) −0.3 (iv) −0.4	
(iv) WD Nordhaus, 'The Demand for Energy: An International Perspective' in *Proceedings of the Workshop on Energy Demand.* International Institute for Applied Systems Analysis, Luxembourg/Austria. May 22-23 1975. Published 1976.	Total domestic *useful* energy consumption per head as f (P_t).	Time series, basically 1955-72. (a) France	Y, temperature (i) geometric lag (ii) and (iii) polynomial lags.	(a) (i) −0.16 (ii) −0.03 (iii) −0.08	(a) (i) not estimated (ii) +0.10 (iii) +0.06	(a) (i) 1.33 (ii) 0.33 (iii) 0.80
		(b) W Germany		(b) (i) −0.44 (ii) +0.30 (iii) +0.17	(b) (i) −0.89 (ii) +0.70 (iii) +1.46	(b) (i) 1.76 (ii) 1.58 (iii) 1.31
		(c) Italy		(c) (i) −0.33 (ii) −0.72 (iii) −0.75	(c) (i) −0.50 (ii) −1.30 (iii) −1.33	(c) (i) 1.38 (ii) 5.54 (iii) 6.82
		(d) Netherlands		(d) (i) −0.58 (ii) −0.68 (iii) −0.56	(d) (i) −0.81 (ii) −1.20 (iii) −1.56	(d) (i) 2.76 (ii) 3.58 (iii) 2.43
		(e) United Kingdom		(e) (i) −0.42 (ii) −0.42 (iii) −0.35	(e) (i) −0.49 (ii) −0.26 (iii) −0.31	(e) (i) 2.62 (ii) 3.00 (iii) 2.19
		(f) USA		(f) (i) −0.26 (ii) −0.50 (iii) −0.41	(f) (i) −0.57 (ii) −1.73 (iii) +1.94	(f) (i) 0.93 (ii) 2.63 (iii) 2.56
		(g) Composite of above		(g) −0.66	—	(g) 2.54
		(h) pooled estimate of (a)-(f) plus Belgium	for (h), (i) with dummy variables (ii) no dummy variables		(h) (i) −0.79 (ii) −0.71	(h) (i) 9.88 (ii) 7.89

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
F. INDUSTRIAL ELECTRICITY						
(i) R E Baxter and R Rees, 'Analysis of the Industrial Demand for Electricity,' *Economic Journal.* Vol. 78 (1968).	Industrial electricity (total) for each of 16 industrial groups f (P_e/P_w).	United Kingdom, annual time series 1954-64.	Temperature, IIP, seasonal dummy variable. Exponential lag.	Of 16 industrial groups 1 was +ve 3 were −0.5 to −1.0 7 were −1.0 to −2.0 5 were less than −2.0		
(ii) Electricity Council, R E Baxter, Appendix to *Economic Planning and Electricity Forecasting.* Prof Sir Ronald Edwards (1966)	Total Industrial electricity consumption as f (P_e/P_o).	England and Wales quarterly time series 1955(1) to 1965(1).	IIP, seasonal constants. (Author suggests price may be acting as a time variable.) Exponential lag.	−0.14	−0.59	3.6
(iii) J M Griffin, 'The Effects of Higher Prices on Electricity Consumption', *The Bell Journal of Economics and Management Science.* Autumn 1974.	Total industrial electricity consumption as f (P_e).	USA annual time series 1951-71.	Simultaneous equations of supply industry: 10 behavioural equations, 4 linking equations, 11 identities. Demand equations include Y, stock of air conditioning appliances. Polynomial lag distribution of P_e.	−0.04	−0.51	

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
INDUSTRIAL ELECTRICITY (continued)						
(iv) G J Doumenis (1965)	Total electricity consumption of various industries as f (P_e).	Great Britain annual time series 1948-61.	IIP. No lag.			
	1. All industries			1. −0.07		
	2. Gas, water etc			2. +0.33		
	3. Mining and quarrying			3. −0.55		
	4. Cement, glass, pottery			4. +1.05		
	5. Metal manufacture			5. −0.28		
	6. Chemicals and allied			6. −1.32		
	7. Shipbuilding and marine engineering			7. −7.77		
	8. Engineering and electrical goods			8. +0.25		
	9. Vehicles			9. +0.15		
	10 Textile, leather, clothing			10. −0.82		
	11. Food, drink and tobacco			11. +0.18		
	12. Paper and printing			12. +0.34		
	13. Construction			13. −1.40		
	14. Other industry.			14. +0.60		
(v) R Halvorsen, 'Demand for Electric Power in the United States', Discussion Paper No 73-13 presented at Winter Meeting of the Econometric Society, New York, (December 1973).	Total industrial electricity sales as f (P_e).	USA annual time series 1961-69 and cross-section (48 contiguous states) pooled	A. Simultaneous equations. Demand equations: P_g, P_w, temp, industrial value added, mineral production value added.		A. Using price equation type 1 using 2SLS method: −1.40	8.8
			Price equation (type 1): Qe per consumer (industrial), Qe total (all markets), $P_{generating\ fuel}$, P_w, pop. density, and % in rural areas.		Using price equation type II using 2SLS method: −1.24	7.0
					using OLS method (regardless of price equation type used): −1.40	11.3
			Price equation (type II): Qe per consumer (industrial)			
			B. Reduced Form: Y, P_g, P_w, temperature, population density. No lags.		B. Using OLS method: −2.37	4.3

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
INDUSTRIAL ELECTRICITY (continued)						
(vi) T D Mount, L D Chapman and T J Tyrrell, (June 1973)	Total industrial electricity consumption as f (P_e).	USA annual time series 1947-70 and cross-section (47 contiguous states) pooled.	Y, P_g (for C. only) population, temperature. Exponential lag.			
			A. Constant elasticity model, using OLS method.	A. −0.20	A. −1.79	A. 8.1
			B. Variable elasticity model, using OLS method, (for 1971).		B. −1.82	
			C. Variable elasticity model using instrumental variables method (for 1971).		C. −1.74	
(vii) J W Wilson (1969)	A. 6 regressions on kWh per $ value added, as f(P_e) or f(average bill for 400,000 kWh per month)	USA Cross section by Standard Metropolitan Statistical Areas) 1963.	Equations use a variety of; P_e, P(oil), P_g (average), P_g (marginal), capital intensity, Y (regional) (for B only: value added). No lag.	Typical range A. −1.70 to −2.40 B. −0.90 to −1.50		A. Over 5 B. Typically over 5
	B. 11 regressions on total consumption as f(P_e) or f(average bill for 400,000 kWh per month)					
(viii) D Blain (1974)	A. Modulated high voltage consumption as a proxy for industrial driving power. B. Continuous high voltage consumption as a proxy for electrolysis and specific industrial uses. As f(P_e), f(Δnominal price), f(nominal price), or f(Δ price relative to Δ wage rates).	France time series 1954-72.	Regressions on first differences.			
			A. (a) f(Δ real price). No lag.	A. (a) −0.38		A. (a) 1.73
			(b) f(Δ price relative to wage rates). No lag.	(b) −0.25		(b) Not given
			(c) as (a), 1 yr lag.		A. (c) −0.25	(c) 1.25
			(d) as (b), 1 yr lag.		(d) −0.26	(d) 2.17
			B. (e) f(Δnominal price). No lag.	B. (e) −0.04		B. (e) 0.16
			(f) f(Δ real price) No lag	(f) +0.20		(f) Not given
			(g) as (e), 1yr lag		B. (g) +0.09	(g) 0.38
			(h) as (f), 1yr lag.		(h) +0.41	(h) 0.98
			(i) f(nominal price level. No lag.	(i) −0.01		(i) 3.33

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient*
				Short run	*Long run*	(t = coefficient ÷ estimated standard error)
G. INDUSTRIAL OIL						
(i) Department of Energy, EcS Division (1974).	**Industrial oil consumption (excluding iron and steel) (i) per unit of output as $f(P_{oil}/P_e)$ (ii) as a proportion of total useful energy consumption as $f(P_{oil}/P_e)$**	**GB annual time series 1957-72.**	**(i) IIP. (ii) market shares. Exponential lag**	**(i) −0.24 (ii) −0.23**	**(i) −1.60 (ii) −1.53**	**(i) 2.14 (ii) 2.72**
(ii) H S Houthakker and M Kennedy 'Demand for Energy as a function of Price,' *Proceedings of Annual Meeting of American Association for the Advancement of Science. San Francisco* (1974)	**Residual fuel oil, all all markets, per head of population, as $f(P_{oil})$.**	**OECD annual time series 1965-70 and cross section (9 countries Europe and Japan) pooled.**	**Y, Exponential lag.**	**−1.05**	**−1.58**	**2.46**
(iii) H S Houthakker and M Kennedy, (1974).	**Distillate fuel oil all markets per head of population, as $f(P_{oil})$.**	**OECD annual time series 1965-70 and cross-section (9 countries Europe and Japan) pooled.**	**Y, Exponential lag.**	**−0.39**	**−0.76**	**2.01**
(iv) H S Houthakker and M Kennedy, (1974).	**Kerosene, all markets per head of population as $f(P_{oil})$.**	**OECD annual time series 1965-70 and cross-section (9 countries Europe and Japan) pooled.**	**Y, Exponential lag.**	**−0.17**	**−2.0**	

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
H. TOTAL INDUSTRIAL FUEL CONSUMPTION						
(i) Dept of Energy EcS Division, 'An Analysis of Industrial Demand for Energy in United Kingdom' (1976).	Total energy consumption of various industries as $f(P_{\text{heavy fuel oil}})$ deflated by relevant wholesale price index of industry inputs.	UK annual time series 1955-74.	6 forms of regression were used. (i) IIP. Exponential lag solved by ordinary least squares. (ii) As (i) solved assuming 1st order auto correlation. (iii) As (i) solved assuming 2nd order auto correlation. (iv) As (i) +t (v) As (ii) +t (vi) As (iv) +lagged value of IIP. *Industry groups:*	Range of elasticities		Typical values
			(a) Engineering and other industries	(a) +0.07 to −0.03	(a) +0.10 to −0.03	(a) Under 1
			(b) Food, drink and tobacco.	(b) −0.03 to −0.05	(b) −0.06 to −0.09	(b) 1.5
			(c) Chemicals and allied industries.	(c) +0.08 to −0.02	(c) +0.49 to −0.03	(c) 0.5
			(d) Textiles, leather and clothing.	(d) −0.12 to −0.15	(d) −0.23 to −1.02	(d) 3.0
			(e) Paper, printing and stationery.	(e) −0.13 to −0.14	(e) −0.50 to −0.68	(e) 5.5
			(f) Bricks, tiles, fireclay and other building materials (incl. cement).	(f) −0.02 to −0.19	(f) −0.03 to −0.39	(f) 2.0
			(g) China, earthenware and glass.	(g) +0.11 to +0.06	(g) +0.27 to −0.25	(g) 1.5
			(h) Total industry	(h) −0.01 to −0.05	(h) −0.03 to −0.26	(h) 1.0
(ii) OECD, *Energy Prospects to 1985 An Assessment of Long Term Energy Developments and Related Policies* Vol II (1974).	Projected elasticity	A. Projections for 1980	Not applicable.		A.	Not applicable
		(i) USA			(i) −0.3	
		(ii) Canada			(ii) −0.3	
		(iii) Europe			(iii) −0.3	
		(iv) Japan			(iv) −0.2	
		B. for 1985			B.	
		(i) USA			(i) −0.4	
		(ii) Canada			(ii) −0.4	
		(iii) Europe			(iii) −0.3	
		(iv) Japan			(iv) −0.3	

Study	Dependent variable and elasticity estimated	Area and time	Equation form and other variables	Elasticity		t value of short run coefficient (t = coefficient ÷ estimated standard error)
				Short run	Long run	
TOTAL INDUSTRIAL FUEL CONSUMPTION (contindued)						
(iii) W D Nordhaus (1976).	Total industrial (excluding energy industries) *useful* energy consumption per head of population as $f(P_I)$.	Time series basically 1955-72.	Y, temperature (i) geometric lag. (ii) and (iii) polynomial lag.	(a) (i) −0.47 (ii) −0.45 (iii) −0.39	(a) (i) −0.82 (ii) −0.38 (iii) −0.44	(a) (i) 3.62 (ii) 4.50 (iii) 4.88
		(a) France (b) W Germany (c) Italy		(b) (i) −0.11 (ii) +0.29 (iii) +0.04	(b) (i) −0.21 (ii) +1.03 (iii) +1.06	(b) (i) 0.38 (ii) 1.93 (iii) 0.31
		(d) Netherlands (e) United Kingdom (f) USA		(c) (i) −0.82 (ii) −0.60 (iii) −0.49	(c) (i) Not estimated (ii) −0.98 (iii) +0.45	(c) (i) 4.82 (ii) 4.29 (iii) 3.77
		(g) composite of above (lag form ii)		(d) (i) −0.51 (ii) −0.34 (iii) −0.29	(d) (i) −0.61 (ii) +0.01 (iii) +0.28	(d) (i) 1.89 (ii) 1.21 (iii) 0.78
		(h) pooled estimate of (a)-(f) plus Belgium.	for (h): (i) with dummy variables. (ii) with no dummy veriables.	(e) (i) −0.79 (ii) −0.79 (iii) −0.63	(e) (i) −0.88 (ii) −0.73 (iii) −0.95	(e) (i) 3.95 (ii) 4.65 (iii) 2.74
				(f) (i) −0.21 (ii) −0.09 (iii) −0.11	(f) (i) −0.33 (ii) −0.35 (iii) −0.47	(f) (i) 0.53 (ii) 0.50 (iii) 0.65
				(g) −0.30	—	(g) 1.30
					(h) (i) −0.52 (ii) −0.48	(h) (i) 3.06 (ii) 3.43

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
J. COMMERCIAL ELECTRICITY						
(i) R Halvorsen 'Demand for Electric Power in the United States.' (1973).	Total sales to commercial sector as f (P_e).	USA annual time series 1961-69 and cross-section (48 contiguous states) pooled.	A. Simultaneous equations Demand equation: P_g, P_w, Y temperature, population density, housing variables.		A. Using price equation type I Using 2SLS method −1.16	4.5
			Price equation (type I): Q_e (all markets) Q_e per consumer (commercial), P_w, $P_{generating\ fuel}$ population density and % in rural areas.		Using price equation type II Using 2SLS method −0.56	2.6
			Price equation (type II): Q_e per consumer (commercial), P_e (average).		Using OLS method (regardless of price equation type used) −0.94	5.5
			B. Reduced form equation Variables as in Demand equation. excluding temperature. No lag.		B. Using OLS method −0.94	4.4
(ii) T D Mount, L D Chapman and T J Tyrrell (June 1973)	Total commercial electricity consumption as f (P_e).	USA annual time series 1947-70 and cross-section (47 contiguous States) pooled.	Y, P_g, population, temperature, exponential lag.			
			A. Constant elasticity model, using OLS method.	A −0.20	A. −1.60	9.6
			B. Variable elasticity model, using OLS method (for 1971).		B. −1.36	
			C. Variable elasticity model, using instrumental variables method (for 1971).		C. −1.45	

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
K. TOTAL TRANSPORT FUEL CONSUMPTION						
W D Nordhaus	Total transport *useful*	Time series	Y, temperature.	(a) (i) −0.66	(a) (i) not estimated	(a) (i) 2.64
(1976)	energy consumption	basically 1955-72		(ii) −0 29	(ii) −0.15	(ii) 3.22
	per head of population		(i) Geometric lag	(iii) −0.18	(iii) −0.10	(iii) 2.25
	as f ($P_{\text{transport fuel}}$).	(a) France	(ii) and (iii)			
			polynomial lag	(b) (i) −0.13	(b) (i) −0.28	(b) (i) 0.93
		(b) W Germany		(ii) −0.55	(ii) −0.87	(ii) 6.11
				(iii) −0.53	(iii) −0.89	(iii) 7.57
		(c) Italy				
				(c) (i) −0.09	(c) (i) −0.23	(c) (i) 1.29
		(d) Netherlands		(ii) −0.24	(ii) −0.60	(ii) 0.92
				(iii) −0.17	(iii) +0.01	(iii) 0.40
		(e) United Kingdom		(d) (i) +0.05	(d) (i) +0.26	(d) (i) 0.50
		(f) USA		(ii) −0.49	(ii) −0.37	(ii) 2.13
				(iii) −0.38	(iii) −0.92	(iii) 2.71
		(g) Composite of				
		above (lag from		(e) (i) +0.02	(e) (i) +0.03	(e) (i) 0.17
		(ii))		(ii) −0.20	(ii) −0.15	(ii) 2.22
				(iii) −0.17	(iii) −0.16	(iii) 1.70
		(h) pooled estimate				
		of (a)-(f) plus		(f) (i) −0.22	(f) (i) −0.76	(f) (i) 1.57
		Belgium		(ii) −1.04	(ii) +0.13	(ii) 5 20
				(iii) −0.82	(iii) +1.88	(iii) 4.10
				(g) −0.39	(g) −0	(g) 3.25
					(h) (i) −0.3.36	(h) (i) 3.00
					(ii) −61.28	(ii) 21.33

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient*
				Short run	*Long run*	(t = coefficient ÷ estimated standard error)
L. ALL MARKETS NATURAL GAS						
P Balestra, *The Demand for Natural Gas in the United States* (1967) North-Holland.	Gas consumption per head of population as f (P_g).	USA annual time series for each of 36 States.	Y. No lag.	Generally + ve		
M. TOTAL PRIMARY ENERGY						
N Edmonson, 'Real Price and the Consumption of Mineral Energy in the United States', 1901-1968, *Journal of Industrial Economics*, March 1975.	Total mineral energy consumption per head of population as f (P_t).	USA annual time series 1901-1968.	A. Simultaneous equations. Demand equation: Y, Y_{t-1}, P_t, $P_{t,\,t-1}$, Q_t, $Q_{t,\,t-1}$, appliance stock. Supply equation: P_t, 5 variables describing specific autonomous forces of different periods.	A. −0.38 (from appliance stock change effect) −0.02 (from utilisation effect)	A. −0.49	3.57
			B. Due to problems of collinearity, model re-run hypothesising $\log P_t = a + b \log P_{t,\,t-1}$ and $\log Y = a + b \log Y_{t-1}$. Lag: long run element—exponential lag, short run element—one year lagging of variables.	B. −0.39 (total short run effect)	B. −0.48	4.12

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷estimated standard error)*
				Short run	*Long run*	
N. TOTAL USEFUL ENERGY CONSUMPTION						
W D Nordhaus (1976) (See above page 30.)	Total useful energy consumption as f (P_t).	Time series basically 1955-72. (a) France	Y, temperature. (i) Geometric lag. (ii) and (iii) Polynomial lag.	(a) (i) −0.16 (ii) −0.03 (iii) −0.08	(a) (i) not estimated (ii) +0.10 (iii) ÷0.06	(a)(i) 1.33 (ii) 0.33 (iii) 0.80
		(b) W Germany		(b) (i) −0.44 (ii) +0.30 (iii) +0.17	(b) (i) −0.89 (ii) +0.70 (iii) +1.45	(b) (i) 1.76 (ii) 1.58 (iii) 1.31
		(c) Italy		(c) (i) −0.33 (ii) −0.72 (iii) −0.75	(c) (i) −0.50 (ii) −1.30 (iii) −1.33	(c) (i) 1.38 (ii) 5.54 (iii) 6.82
		(d) Netherlands		(d) (i) −0.58 (ii) −0.68 (iii) −0.56	(d) (i) −0.81 (ii) −1.21 (iii) −1.56	(d) (i) 2.76 (ii) 3.58 (iii) 2.43
		(e) United Kingdom		(e) (i) −0.42 (ii) −0.42 (iii) −0.35	(e) (i) −0.49 (ii) −0.26 (iii) −0.31	(e) (i) 2.63 (ii) 3.00 (iii) 2.19
		(f) USA		(f) (i) −0.26 (ii) −0.50 (iii) −0.41	(f) (i) −0.57 (ii) −1.73 (iii) +1.94	(f) (i) 0.93 (ii) 2.63 (iii) 2.56
		(g) composite of above (lag form (ii))			(g) −0.66	(g) 2.54
		(h) pooled estimate of (a)-(f) plus Belgium.			(h) (i) −0.85 (ii) −1.16	(h) (i) 8.50 (ii) 11.50

Table 2 Petrol price-elasticity estimates

Study	*Dependant variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
A. PRIVATE DEMAND						
(i) J Ramsay, R Rosche, B Allen, *An Initial Analysis of the Private and Commercial Demand for Gasoline*, Department of Economics, Michigan State University (1974).	Total private petrol consumption as f (P_p).	USA annual time series 1945 – 69.	Y, railway travel price index, proportion of population aged 16 – 24. Simultaneous equation system. Lags: Y lagged 1 year.	−0.77 (1969 = −0.70)		
(ii) R G McGillivray, *Gasoline Use by Automobiles*, The Urban Institute, Washington DC Working Paper August 1974.	Private petrol consumption per head as f (P_p).	USA annual time series 1951 – 69.	Linear equation (i) New car registrations per head, retirement rate of cars, average consumption per car. (ii) As (i), excluding average consumption per car. (i) and (ii) Exponential lag.		(i) −0.23 (ii) −0.17	(i) 2.99 (ii) 1.38
(iii) H S Houthakker and L D Taylor, *Consumer Demand in the US 1929 – 70*, Harvard University Press (1966).	Total private petrol consumption as f(P_p).	USA annual time series 1929 – 61 (excluding war years).	Y. Exponential lag.	−0.16	−0.45	
(iv) L Phillips, 'A Dynamic Version of the Linear Expenditure Model', *Review of Economics and Statistics*, Vol 54, No 4, November 1972.	Total private petrol consumption as f(P_p).	USA annual time series 1929 – 67.		−0.68		
(v) W K O'Riordan, 'The Elasticity of Demand for Petrol in Ireland', *Economic and Social Review* (1972).	Total private petrol consumption as f(P_p).	Ireland annual time series. Post war.	Y, car stock $P_{public\ transport}$. No lags.	−1.00		
(vi) Interim report for the Environmental Protection Agency and the Council of Environmental Policy, *A Study of the Quarterly Demand for Gasoline and the Impact of Alternative Gasoline Bases* (1973)	Total private petrol consumption as f(P_p).	USA quarterly time series 1963 – 72.	Y. Exponential lag.	−0.09	−0.45	

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
B. COMMERCIAL DEMAND						
J Ramsay, R Rosche, B Allen, (1974)	Total commercial petrol consumption as f(P_p).	USA annual time series 1945 – 69.	Simultaneous equation model. $P_{diesel\ fuel}$, total ton miles of freight. No lag.	−3.8 (1968-: −2.8)		
C. TOTAL DEMAND						
(i) H S Houthakker, P K Verleger, D Sheehan (1973).	Total petrol consumption per head as f (P_p).	USA quarterly time series 1963 – 72 and cross-section (48 States) pooled	Y. Exponential lag.	−0.08	−0.24	5.76
(ii) H S Houthakker and M Kennedy (1974).	Total petrol consumption per head as f(P_p).	OECD, annual time series, 1962 – 72 and cross-section (12 countries Europe, Japan and USA pooled).	Y. Exponential lag.	−0.47	−0.82	4.42
(iii) J Fields, G Nolan, S Miller, *'Empirical Analysis of the Price Elasticity of Demand for Gasoline in Selected Foreign Countries and the United States'*, Federal Highway Administration, US Dept of Transport, Washington DC, July 1973.	Total petrol consumption per head as f(P_p).	USA annual time series.	Y. A. No lag. B. Exponential lag.	B. −0.04	A. +0.36	Insignificant in both cases.
(iv) C Chamberlain, *Models of Gasoline Demand*, Transportation Systems Center Cambridge Mass. (1973).	Total petrol consumption per head as f (P_p)	A. USA annual time series (using data of Fields *et al*)	A. Y, $P_{automobiles}$	A. −0.08		
		B. Europe annual time series.	B. Y. Exponential lag in both cases.	B. −0.12		

Study	*Dependent variable and elasticity estimated*	*Area and time*	*Equation form and other variables*	*Elasticity*		*t value of short run coefficient (t = coefficient ÷ estimated standard error)*
				Short run	*Long run*	
TOTAL DEMAND (continued)						
(v) Wildham *et al*, *How to Save Gasoline. Public Policy Alternatives for the Automobile*, Rand Corporation (1974).	Total petrol consumption per head as f (P_p)	A. USA annual time series and cross-section, pooled.	A. Y, average vehicle efficiency, vehicle stock per head, % of population in rural areas. No lag.	A. range of −0.10 to −0.18		
		B. USA annual time series.	B. Simultaneous equations (5), with variables; $P_{\text{used cars}}$, vehicle ownership per household, new car car demand per household, vehicle efficiency, vehicle miles per household. No lag.	B. −0.37		
(vi) OECD, *Energy Prospects to 1985* (1974) (See domestic fuel consumption above.)	Total consumption of transport gasoline as f (P_p).	A. Projections for 1980 (i) USA (ii) Canada (iii) Europe (iv) Japan B. for 1985 (i) USA (ii) Canada (iii) Europe (iv) Japan	Based on same sources as OECD total domestic fuel consumption elasticities quoted above.	A. (i) −0.3 (ii) −0.3 (iii) −0.3 (iv) −0.4 B. (i) −0.5 (ii) −0.4 (iii) −0.4 (iv) −0.4		Not applicable

ANNEX 2

Tabulation of estimated price and income elasticities of energy demand according to end-user, to fuel carriers, type of model and data.

Source: D R Bohi (1981) "Analysing Demand Behaviour - A Study of Energy Elasticities" John Hopkins University Press

TABLE 1. SUMMARY OF ESTIMATED PRICE AND INCOME ELASTICITIES OF RESIDENTIAL DEMAND FOR ELECTRICITY BY TYPE OF MODEL AND DATA

Research study	*Sample*[a]	*Price elasticity*[b]		*Income elasticity*[b]	
		Short-run	*Long-run*	*Short-run*	*Long-run*
I. Reduced-Form Models					
A. Static consumption models					
1. Aggregate level data					
(a) Average prices					
Fisher, Kaysen (1962)	Time series: states, 1946–57	−0.16 to −0.24		0.07 to 0.33	
Moore (1970)	Cross-section: 407 utilities, 1963		−1.02		
Wilson (1971)	Cross-section: 77 cities, 1966		−1.33		n.s.
Anderson (1973)	Cross-section: states, 1960, 1970		−1.07		1.06
			−1.28		0.67
CRA (1976)	Pooled: states, 1966–72		−1.20		0.48
Halvorsen (1978)	Pooled: states, 1961–69		−1.14		0.52
(b) Marginal prices					
Lacy, Street (1975)	Times series: Alabama Power Co., 1967–74	−0.45		1.87	
Wills (1977)	Cross-section: Mass. utilities, 1975	−0.08		−0.32	
Halvorsen (1978)	Pooled: states, 1961–69		−1.53		0.72
McFadden, Puig (1975)	Pooled: states, 1961–69		−0.48		0.99
2. Disaggregated level data					
(a) Average prices: none					
(b) Marginal prices					
Acton, Mitchell, Mowill (1976)	Pooled: monthly, Los Angeles County, 1972–74		−0.70		0.40
Hewlett (1977)	Cross section: household survey, 1973 & 1975	−0.14		0.07	
B. Dynamic consumption models					
1. Aggregate level data					
(a) Average prices					
Houthakker, Taylor (1970)	Time series: U.S., 1946–64	−0.13	−1.89	0.13	1.94
Uri (1976)	Time series: monthly, U.S., 1971–75	−0.35		2.00	
Griffin (1974)	Time series: U.S., 1951–71	−0.06	−0.52	0.06	0.88
Mount, Chapman, Tyrrell (1973)	Pooled: states, 1946–70 (3 versions)	−0.14	−1.21	0.03	0.30
		−0.14	−1.20	0.02	0.20
		−0.36	−1.24	0.06	0.21
Gill, Maddala (1976)	Pooled: monthly, TVA area, 1962–67 and 1968–72	−0.49	−0.57	0.10	0.12
		−0.34	−0.62	0.12	0.22
Cohn, Hirst, Jackson (1977)	Pooled: states, 1951–74 and 1969–74	−0.14	−1.16	0.02	0.16
		−0.14	−0.47	0.16	0.56
(b) Marginal prices					
Houthakker, Verleger, Sheehan (1974)	Pooled: states, 1960–71 (3 prices)	−0.09	−1.19	0.13	1.63
		−0.03	−0.44	0.14	2.20
		−0.09	−1.02	0.14	1.64
Taylor, Blattenberger, Verleger (1977)	Pooled: states, 1956–72	−0.08	−0.82	0.10	1.08
2. Disaggregated level data					
(a) Average prices: none					
(b) Marginal prices					
Hewlett (1977)	Pooled: household survey, 1973 and 1975	−0.16	−0.45	n.s.	n.s.

TABLE 1 *continued*

		Price elasticity[b]		*Income elasticity*[b]	
Research study	*Sample*[a]	*Short-run*	*Long-run*	*Short-run*	*Long-run*
C. Fuel shares models					
1. Static versions					
Chern (1976)	Pooled: states, 1971–72		−1.34		0.40
2. Dynamic versions					
Baughman, Joskow (1975)	Pooled: states, 1968–72	−0.19	−1.00	n.s.	n.s.
DOE (1978)	Pooled: regions, 1960–75	−0.18 to −0.54	−0.72 to −2.10	n.s.	n.s.
II. Structural Models					
A. Aggregate level data					
1. Average prices					
Fisher, Kaysen (1962)	Time series: states, 1946–57		n.s.		n.s.
Anderson (1973)	Cross-section: states,		−1.07		1.06
	1960 and 1970		−1.28		0.67
2. Marginal prices					
Taylor, Blattenberger, Verleger (1977)	Pooled: states, 1961–72	−0.16	−0.46	0.22	1.00
B. Disaggregated level data					
1. Average prices: none					
2. Marginal prices					
McFadden, Puig, Kirshner (1977)	Cross-section: household survey, 1975	−0.25	−0.66	0.21	0.39

[a] Observation periods are annual except where indicated otherwise.

[b] The estimates given are statistically significant at the 0.05 level. An entry of n.s. indicates not significant. A blank space means no estimate was attempted or reported.

TABLE 2. SUMMARY OF ESTIMATED PRICE AND INCOME ELASTICITIES OF COMMERCIAL DEMAND FOR ELECTRICITY

		Price elasticity[a]		*Income elasticity*[a]	
Research study	*Sample*	*Short-run*	*Long-run*	*Short-run*	*Long-run*
I. Reduced-Form Models					
A. *Static consumption models*					
Asher and Habermann (1978)	Pooled: monthly, 63 utility areas, 1971–76	−0.25	−1.20	n.s.	n.s.
Halvorsen (1978)	Cross-section: annual, states, 1969 (two price equations)		−1.16 −0.56		1.38 1.15
B. Dynamic consumption models					
Mount, Chapman, Tyrrell (1973)	Pooled: annual, states, 1946–70 (3 versions)	−0.20 −0.17 −1.18	−1.60 −1.36 −1.45	0.10 0.11 0.72	0.80 0.86 0.88
Uri (1976)	Time series: monthly, U.S., 1971–75	n.s.	n.s.	n.s.	n.s.
C. Fuel shares model					
DOE (1978)	Pooled: annual, 10 regions, 1960–75	−0.30 to −0.66	−0.94 to −1.54	n.s.	n.s.
II. Structural Models: none					

[a] The estimates given are statistically significant at the 0.05 level. An entry of n.s. indicates not significant. A blank space means no estimate was attempted or reported.

TABLE 3. SUMMARY OF AGGREGATE PRICE AND INCOME ELASTICITIES OF INDUSTRIAL DEMAND FOR ELECTRICITY

		Price elasticity[a]		*Output elasticity*[a]	
Research study	*Sample*	*Short-run*	*Long-run*	*Short-run*	*Long-run*
I. Static Consumption Models					
Asher, Habermann (1978)	Time series and Cross-section: 63 utilities, 1971–75	−0.20	−0.74	n.s.	n.s.
Halvorsen (1978)	Cross-section: states, 1969		−1.24		0.68
II. Dynamic Consumption Models					
Mount, Chapman, Tyrrell (1973)	Pooled: states,	−0.20	−1.79	0.08	0.73
	1946–70	−0.22	−1.82	0.06	0.51
	(3 versions)	−1.36	−1.74	0.51	0.65
CRA (1976)	Pooled: states, 1958–73	−0.10	−1.02	0.07	0.70
Uri (1976)	Time series: monthly, U.S., 1971–75	−0.12		0.87	
Griffin (1974)	Time series: annual, U.S., 1951–71	−0.04	−0.51		
III. Fuel Shares Models					
Baughman, Zerhoot (1975)	Pooled: annual, states, 1968–72	−0.11	−1.28		
DOE (1978)	Pooled: annual, states, 1960–75	−0.17	−0.75		

[a] The estimates given are statistically significant at the 0.05 level. An entry of n.s. indicates not significant. A blank space means no estimate was attempted.

TABLE 4. COMPARISON OF PRICE ELASTICITY ESTIMATES BY INDUSTRIAL CATEGORIES

		Study and sample period						
	Energy intensiveness	*(1)*	*(2)*	*(3)*	*(4)*[b]	*(5)*[b]	*(6)*	
		Fisher–Kaysen	*Fisher–Kaysen/*	*Anderson/CRA*	*Wilson*	*NERA*	*Halvorsen*	
Two-digit SIC industry	*in 1974*[a]	*(1956)*	*CRA(1971)*	*(1971)*	*(1963)*	*(1963)*	*(1962)*	*(1971)*
Food and kindred products	3.22	−0.78 (−1.9)	−0.46 (−2.1)	−0.36 (−1.6)	−1.09	n.e.	n.e.	−0.08 (−0.5)
Textile products	5.24	−1.62 (−14.5)	−2.08 (−5.7)	−0.76 (−1.3)	−1.22	−0.63	−0.42 (−5.5)	−0.41 (−3.6)
Pulp & paper products	10.05	−0.97 (−4.7)	−2.33 (−5.5)	−2.02 (−4.3)	−1.48	−0.56	−0.46 (−2.1)	−0.20 (−0.7)
Chemicals & products	7.71	−2.60 (−5.0)	−1.90 (−6.2)	−1.95 (−6.5)	−2.23	−0.91	n.e.	−0.68 (−4.0)
Stone, clay, glass	10.67	−1.74 (−1.4)	−1.55 (−4.8)	−1.82 (−3.6)	−1.08	n.e.	−0.38 (−2.3)	−0.31 (−1.2)
Primary metal products	11.24	−1.28 (−6.1)	−2.07 (−8.1)	−1.88 (−6.5)	−1.51	−0.98	−0.94 (−10.4)	−0.83 (−6.1)
Fabricated metal products	2.33	0.55 (1.1)	−0.42 (−1.9)	−0.39 (−1.5)	n.e.	n.e.	n.e.	−1.10 (−3.1)
Machinery, excluding electric	1.48	−1.33 (−3.1)	−0.74 (−2.3)	−1.02 (−2.7)	−1.16	n.e.	−0.72 (−6.0)	−0.79 (−7.1)
Electrical machinery	1.64	−1.82 (−4.1)	−0.71 (−2.3)	−0.66 (−1.9)	−1.76	n.e.	−0.76 (−34.4)	−0.27 (−3.6)
Transportation equipment	1.84	0.69 (1.1)	−0.37 (−1.5)	−0.51 (−1.9)	−1.01	n.e.	n.e.	−0.43 (−5.3)

n.e. = not estimated. *t* - statistics in parentheses.

[a] Energy cost as a percent of value added. From U.S. Bureau of Census, *Annual Survey of Manufacturers*, 1974.

[b] *t*-statistics are not reported, but the authors report that all price coefficients listed are significant at the 1 percent level.

TABLE 5 . SUMMARY OF ESTIMATED PRICE AND INCOME ELASTICITIES OF RESIDENTIAL AND COMMERCIAL DEMAND FOR NATURAL GAS

		Price elasticity[b]		Income Elasticity[b]	
Research study	*Sample*[a]	*Short-run*	*Long-run*	*Short-run*	*Long-run*
I. Reduced-Form Models					
A. Static consumption models					
1. Aggregate level data (average prices)					
Cohn, Hirst, Jackson (1977)	Cross-section: states, 1955, 1965, 1970, 1974 (residential)		−2.04 −1.54 −2.42 −2.23		2.18 1.59 1.88 1.77
2. Disaggregated level data (marginal prices)					
Hewlett (1977)	Cross-section: household survey, 1975 (residential)		−0.45		0.08
Olson, Robeson, Neri (1979)	Pooled: monthly, New York state customer survey 1976–77 (residential and commercial separate)	R: C:	−0.17 −1.04		0.12
B. Dynamic consumption models					
1. Aggregate level data (average prices)					
Balestra (1967)	Pooled: states, 1950–62 (residential + commercial)	−0.03	−0.70	0.003	0.62
MacAvoy, Pindyck (1973)	Pooled: states, 1964–70 (residential + commercial)	n.s.	n.s.	n.s.	n.s.
Berndt, Watkins (1977)	Pooled: Ontario and British Columbia 1959–74 (residential + commercial)	−0.16	−0.69	−0.03	0.13
Taylor, Blattenberger, Verleger (1977)	Pooled: states 1956–72 (residential)	−0.24 to −0.50	−0.48 to −1.02	n.s.	n.s.
Cohn, Hirst, Jackson (1977)	Pooled: states 1960–69, 1969–74 (residential)	−0.15 −0.39	−0.81 −0.89	n.s. n.s.	n.s. n.s.
2. Disaggregated level data (marginal prices)					
Hewlett (1977)	Pooled: household survey 1973, 1975 (residential)	−0.28	−0.37	0.05	0.07
C. Fuel shares models (aggregate level data)					
1. Static versions					
Chern (1976)	Pooled: states, 1971–72 (residential + commercial)		−1.26		n.s.
2. Dynamic versions					
Baughman, Joskow (1975)	Pooled: states, 1968–72 (residential + commercial)	−0.15	−1.01	n.s.	n.s.
DOE (1978)	Pooled: states, 1960–75 (residential, commercial separate)	R: −0.34 C: −0.32	−0.95 −1.06	n.s.	n.s.
II. Structural Models					
A. Aggregate level data (average prices)					
Anderson (1974)	Cross-section: states, 1970 (residential)	−0.3	−2.0		
B. Disaggregated level data: None					

[a] Observation periods are annual except where indicated otherwise.

[b] The estimates given are statistically significant at the 0.05 level. An entry of n.s. indicates not significant. A blank space means no estimate was attempted or reported

TABLE 6 SUMMARY OF OWN-PRICE AND CROSS-PRICE ELASTICITIES OF DEMAND FOR NATURAL GAS IN MANUFACTURING AND ELECTRIC UTILITIES

		Price elasticity[b]		Cross-price elasticity[a,b,c]	
Research study	*Sample*[a]	*Short-run*	*Long-run*	*Short-run*	*Long-run*
Manufacturing					
1. Fuel shares models (aggregate data)					
Baughman, Zerhoot (1975)	Pooled: states, 1968–72	−0.07	−0.81	O: 0.01 C: 0.01 E: 0.03	0.14 0.15 0.34
DOE (1978)	Pooled: states, 1960–75	−0.21	−0.45		
2. Static (two-digit) models					
Anderson (1971)	Cross-section: states, 1962 (primary metals industries		−1.41	n.s.	n.s.
Halvorsen (1978)[d]	Cross-section: states, 1971		−1.47	O: C: E:	0.44 0.25 0.35
Electric utilities					
Uri (1978)	Time series: monthly, U.S., 1972–76	−0.06		O: 0.05 C: 0.03	
Atkinson, Halvorsen (1976b)	Cross-section: power plants 1972		−1.43	O: C:	0.58 0.45

[a] Annual.

[b] The estimates given are statistically significant at the 0.05 level. An entry of n.s. indicates not significant. A blank space means no estimate was attempted or reported.

[c] The cross-price elasticities are for fuels as indicated, with O for oil, C for coal, and E for electricity.

[d] Halvorsen's estimates refer to a weighted average of two-digit product classes.

TABLE 7 SUMMARY OF PRICE AND INCOME ELASTICITIES OF DEMAND FOR GASOLINE

		Price elasticity[a]		*Income elasticity*[a]	
Research study	*Sample*	*Short-run*	*Long-run*	*Short-run*	*Long-run*
I. Reduced-Form Models					
A. Static versions: Aggregate level data					
Ramsey, Rasche, Allen (1975)	Time series: annual, U.S., 1947–70		−0.77		1.34
Greene (1978)	Pooled: annual, states, 1966–75	−0.19		0.24	
Adams, Graham, Griffin (1974)	Pooled: OECD countries, 1955, 1960, 1965, 1969		−0.40		0.72
B. Static versions: Disaggregated level data					
Archibald, Gillingham (1978)	Cross-section: Consumer Expenditure Survey, 1972–73		−0.60		0.40
C. Dynamic versions: Aggregate level data					
Verleger, Sheehan (1976)	Pooled: quarterly, states, 1963–72	−0.14	−0.32	0.45	1.03
Alt, Bopp, Lady (1976)	Time series: monthly, U.S., 1968–74	−0.19	−0.50	0.38	1.02
McGillivray (1976)	Time series: annual, U.S., 1951–69	−0.23	−0.77		
Philips (1972)	Time series: annual, U.S., 1929–67	−0.11	−0.68	0.58	1.54
Kouris (1978)	Pooled: annual, EEC countries, 1956–73	−0.23	−0.76	0.53	1.74
II. Structural Models					
Burright, Enns (1975)	Time series: annual, U.S., 1959–72	−0.41	−0.60		
Cato, Rodekohr, Sweeney (1976)	Time series: annual, U.S., dates unspecified	−0.24	−0.36	0.16	0.93

[a] The estimates given are significant at the 0.05 level. A blank space means no estimate was attempted or reported.

TABLE 8 ESTIMATES OF LONG-RUN PRICE AND INCOME ELASTICITIES OF DEMAND FOR TRANSPORTATION FUELS OTHER THAN GASOLINE

Fuel	*Price elasticity*	*Income elasticity*
Truck fuel demand	−0.545	1.740
Bus fuel demand	−0.474	0.285
Rail diesel fuel	−0.368	0.144
Airline passenger-miles[a]	−0.245	1.457

Source: DOE (1978, p. 69).

[a] Commercial jet fuel demand is equal to air passenger-miles adjusted for a load factor.

TABLE 9 SUMMARY OF PRICE AND INCOME ELASTICITIES OF RESIDENTIAL AND COMMERCIAL DEMAND FOR FUEL OIL

		Price elasticity[a]		*Income elasticity*[a]	
Research study	*Sample*	*Short-run*	*Long-run*	*Short-run*	*Long-ru*
I. Reduced-Form Models					
1. Dynamic consumption models					
Cohn, Hirst, Jackson (1977)	Pooled: annual, states, 1969–74 (Nos. 1–4 fuel oil)	−0.19	−0.51	0.50	1.33
Taylor, Blattenberger, Verleger (1977)	Pooled: annual, states, 1967–72 (all distillates and No. 2 separately)	n.s.	n.s.	n.s.	n.s.
Alt, Bopp, Lady (1976)	Time series: monthly, U.S., 1967–74 (all distillates)	−0.13	−0.27	1.26	1.70
2. Fuel shares models					
Baughman, Joskow (1975)	Pooled: annual, states, 1968–72 (all fuel oils)	−0.18	−1.12	n.s.	n.s.
Chern (1976)	Pooled: annual, states, 1971–72 (all distillates)		−1.61		n.s.
DOE (1978)	Pooled: annual, states, 1960–75 (all distillates; residential and commercial separated)	R: −0.7 C: −0.3	−1.50 −0.70	n.s.	n.s.
II. Structural Models					
Anderson (1974)	Pooled: annual, states, 1960–70 (all distillates)		−1.76		

[a] The estimates given are statistically significant at the 0.05 level. An entry of n.s. indicates not significant. A blank space means no estimate was attempted or reporte

TABLE 10 SUMMARY OF OWN-PRICE AND CROSS-PRICE ELASTICITIES OF DEMAND FOR FUEL OIL BY MANUFACTURING AND ELECTRIC UTILITIES

Research study	Sample	Own-price elasticity[a]		Cross-price elasticity[b]	
		Short-run	Long-run	Short-run	Long-run
I. Manufacturing Demand					
A. Aggregate level data					
Baughman, Zerhoot (1975)	Pooled: annual, states, 1968–72 (all oil)	−0.11	−1.32	G: 0.06	0.75
				C: 0.01	0.14
				E: 0.03	0.34
DOE (1978)	Pooled: annual, states, 1960–75 (distillates (D) and residual (R) separate)	D: −0.22	−0.54		
		R: −0.13	−0.73		
B. Product class data					
Anderson (1971)	Pooled: annual, states 1958, 1962 (primary metals)		−2.18	G:	1.42
Halvorsen (1978)	Cross section: annual, states, 1958, 1962, 1971 (weighted averages)	1958	−1.72	G (1971)	1.03
		1962	−0.77	C (1971)	0.63
		1971	−2.82	E (1971)	0.74
II. Electric Utilities					
Uri (1978)	Time series: monthly, ten regions, 1972–76	−0.10		C: 0.003	
Atkinson, Halvorsen (1976b)	Cross-section: annual, power plants, 1972		−1.50	G	0.76
				C	1.01

[a] The estimates given are statistically significant at the 0.05 level. A blank space means no estimate was attempted or reported.

[b] The cross-price elasticities are for fuels as indicated, with G for gas, C for coal, and E for electricity.

TABLE 11 SUMMARY OF ESTIMATED PRICE ELASTICITIES OF DEMAND FOR COAL BY ELECTRIC UTILITIES

Research study	Sample	Own-price elasticity[a]		Cross-price elasticity[b]	
		Short-run	Long-run	Short-run	Long-run
Reddy (1974)	Time series: annual, U.S., 1956–71	−0.46	−0.67	O: 0.26	0.38
				G. n.s.	n.s.
Uri (1978)	Time series: monthly, regions, 1972–76	−0.09		O: 0.02	
				G: n.s.	
Atkinson, Halvorsen (1976b)	Cross-section: annual, power plants, 1972		−1.15	O:	0.99
				G:	n.s.

[a] The estimates given are statistically significant at the 0.05 level. An entry of n.s. indicates not significant. A blank space means no estimate was attempted or reported.

[b] The cross-price elasticities are for fuels as indicated, with O for oil and G for gas.

TABLE 12 SUMMARY OF ESTIMATED PRICE ELASTICITIES OF DEMAND FOR COAL IN MANUFACTURING

Research study	Sample	*Own-price elasticity*[a]		*Cross-price elasticity*	
		Short-run	*Long-run*	*Short-run*	*Long-r*
I. Aggregate Level Data					
Reddy (1974)	Time series: annual, U.S., 1956–71				
	Coking coal	−0.25	−0.55		
	Steam coal	−0.49	−2.06		
Baughman, Zerhoot	Pooled: annual, states, 1968–72 (all coal)	−0.10	−1.14	O: 0.01	0.14
				G: 0.06	0.75
				E: 0.03	0.33
DOE (1978)	Coking coal: time series: annual, U.S., 1960–75		n.s.		
	Steam coal: pooled states, 1960–75	−0.28	−0.49		
II. Product Class Data					
Anderson (1971)	Pooled: annual, states, 1958, 1962 (primary metals)				
	Coking coal			O	3.06
			−1.14	E	−1.35
	Steam coal		n.s.	O	1.66
				G	1.03
Halvorsen (1978)	Cross-section: annual, states, 1971 (all coal)				
	Stone, glass, clay			O	0.83
			−2.22	G	1.27
	Primary metals		−1.53	O	1.92
				E	n.s.
	Fabricated metal products		−2.00	O	n.s.
				G	n.s.

[a] The estimates given are statistically significant at the 0.05 level. An entry of n.s. indicates not significant. A blank space means no estimate was attempted or repo

[b] The cross-price elasticities are for fuels as indicated, with O for oil, G for gas, and E for electricity.

References

Acton, J. P., B. M. Mitchell, and R. S. Mowill. 1976. *Residential Demand for Electricity in Los Angeles: An Econometric Study of Disaggregated Data.* Report R-1899-NSF (Santa Monica, Calif., Rand Corp.).

Adams, F. G., H. Graham, and J. M. Griffin. 1974. *Demand Elasticities for Gasoline: Another View.* Discussion Paper no. 279 (Philadelphia, Pa., University of Pennsylvania, Economic Research Unit).

Allen, R. G. D. 1938. *Mathematical Analysis for Economists* (London, Macmillan).

———. 1960. *Mathematical Economics* (London, Macmillan).

Almon, Shirley. 1965. "The Distributed Lag Between Capital Appropriations and Expenditures," *Econometrica* vol. 33, no. 1 (January) pp. 178–196.

Alt, Christopher, Anthony Bopp, and George Lady. 1976. "Short-Term Forecasts of Energy Supply and Demand," in A. Bradley Askin and John Kraft, eds., *Econometric Dimensions of Energy Demand and Supply* (Lexington, Mass., D. C. Heath).

Anderson, Kent P. 1971. *Toward Econometric Estimation of Industrial Energy Demand: An Experimental Application to the Primary Metals Industry.* Report R-719-NSF (Santa Monica, Calif., Rand Corp.).

———. 1973. *Residential Energy Use: An Econometric Analysis.* Report R-1296-NSF (Santa Monica, Calif., Rand Corp.).

———. 1974. *The Price Elasticity of Residential Energy Use.* Report P-5180 (Santa Monica, Calif., Rand Corp.).

Archibald, Robert, and Robert Gillingham. 1978. *Two Studies of Consumer Demand for Gasoline.* BLS Working Paper 83 (Washington, D.C., U.S. Department of Labor).

Asher, Harold, and Rudolph Habermann, Jr. 1978. *Analysis of Recent Fluctuations in Electricity Consumption.* Report CFESR-77-3 (Washington, D.C., General Electric Co., Center for Energy Systems).

Askin, A. Bradley, and John Kraft. 1976. *Econometric Dimensions of Energy Demand and Supply* (Lexington, Mass., D. C. Heath).

Atkinson, Scott, and Robert Halvorsen. 1976a. "Demand for Fossil Fuels by Electric Utilities," in A. Bradley Askin and John Kraft, eds., *Econometric Dimensions of Energy Demand and Supply* (Lexington, Mass., D. C. Heath).

———, and ———. 1976b. "Interfuel Substitution in Steam Electric Power Generation," *Journal of Political Economy* vol. 84, no. 5, pp. 959–978.

Averch, Harvey, and Leland L. Johnson. 1962. "Behavior of the Firm Under Regulatory Constraint," *American Economic Review* vol. 52, no. 5 (December) pp. 1052–1069.

Balestra, Pietro. 1967. *The Demand for Natural Gas in the United States* (Amsterdam, North-Holland).

———, and Marc Nerlove. 1966. "Pooling Cross Section and Time Series Data in the Estimation of a Dynamic Model: The Demand for Natural Gas," *Econometrica* vol. 34, no. 3 (July) pp. 585–612,

Barten, A. P. 1970. "Reflexions sur le construction d'un systeme empirique des fonctions de demande," *Cahiers du Seminaire d'Econometrice* no. 12.

Barzel, Yoram. 1964. "The Production Function and Technical Change in the Steam Power Industry," *Journal of Political Economy* vol. 72 (April) pp. 133–150.

Baughman, Martin, and Paul Joskow. 1975. *Energy Consumption and Fuel Choice by Residential and Commercial Consumers in the United States.* Report MIT-EL-75-024 (Cambridge, Mass., Massachusetts Institute of Technology Energy Laboratory).

———, and Frederick Zerhoot. 1975. *Interfuel Substitution in the Consumption of Energy in the United States, Part II: Industrial Sector.* Report MIT-EL-75-007 (Cambridge, Mass., Massachusetts Institute of Technology Energy Laboratory).

Berndt, Ernst R., and David O. Wood. 1975. "Technology, Prices, and the Derived Demand for Energy," *The Review of Economics and Statistics* vol. 57, no. 3 (August) pp. 259–268.

———, Melvin A. Fuss, and Leonard Waverman. 1977. *Dynamic Models of the Industrial Demand for Energy.* Report EPRI EA-580 (Palo Alto, Calif., Electric Power Research Institute).

———, and G. C. Watkins. 1977. "Demand for Natural Gas: Residential and Commercial Markets in Ontario and British Columbia," *Canadian Journal of Economics* vol. X, no. 1 (February) pp. 97–111.

———, C. J. Morrison, and G. C. Watkins. 1980. "Dynamic Models of Energy Demand: An Assessment and Comparison." Research Paper no. 49 (Vancouver, University of British Columbia).

Bohi, Douglas R., and Milton Russell. 1978. *Limiting Oil Imports: An Economic History and Analysis* (Baltimore, Md., Johns Hopkins University Press for Resources for the Future).

Brown, Alan, and Angus Deaton. 1972. "Surveys in Applied Economics: Models of Consumer Behavior," *The Economic Journal* vol. 82, no. 328 (December) pp. 1145–1236.

Burright, Burke K., and John H. Enns. 1975. *Econometric Models of the Demand for Motor Fuel.* Report R-1561-NSF/FEA (Santa Monica, Calif., Rand Corp.).

Carlson, M. T. 1974. "The 1972-73 Consumer Expenditure Survey," *Monthly Labor Review* vol. 97, no. 12 (December) pp. 16–23.

Cato, Darriel, Mark Rodekohr, and James Sweeney. 1976. "The Capital Stock Adjustment Process and the Demand for Gasoline: A Market-Share Approach," in A. Bradley Askin and John Kraft, eds., *Econometric Dimensions of Energy Demand and Supply* (Lexington, Mass., D. C. Heath).

Chang, Hui S., and Wen S. Chern. 1978. "A Study in Electricity Demand and Variation in the Price Elasticity of Demand for Manufacturing Industries." Draft (Oak Ridge, Tenn., Oak Ridge National Laboratory).

Charles River Associates, Inc. (CRA). 1976. *Long-Range Forecasting Properties of State-of-the-Art Models of Demand for Electric Energy.* Report EA-221 (Palo Alto, Calif., Electric Power Research Institute).

Chase Econometrics, Inc. 1974. *The Effect of Tax and Regulatory Alternatives on Car Sales and Gasoline Consumption.* Prepared for the U. S. Council on Environmental Quality, Contract No. EQ4AC004.

Chern, Wen S. 1976. *Energy Demand and Interfuel Substitution in the Combined Residential and Commercial Sector.* Report RM-5557 (Oak Ridge, Tenn., Oak Ridge National Laboratory).

———, and William Lin. 1976. "Energy Demand for Space Heating: An Econometric Analysis," in American Statistical Association, *1976 Proceedings of the Business and Economics Section,* pp. 250–254.

Chow, Gregory. 1957. *The Demand for Automobiles in the United States* (Amsterdam, North-Holland).

Christensen, L. R., and W. H. Greene. 1976. "Economies of Scale in U.S. Electric Power Generation," *Journal of Political Economy* vol. 84, part 1 (July/August) pp. 655–676.

———, Dale Jorgenson, and Lawrence Lau. 1973. "Transcendental Logarithmic Production Frontiers," *The American Economic Review* vol. 51, no. 1 (February) pp. 28–45.

———, ———, and ———. 1975. "Transcendental Logarithmic Utility Functions," *The American Economic Review* vol. 65, no. 3 (June) pp. 367–383.

Cohn, Steve, Eric Hirst, and Jerry Jackson. 1977. *Econometric Analyses of Household Fuel Demands.* Report ORNL/CON-7 (Oak Ridge, Tenn., Oak Ridge National Laboratory).

Data Resources, Inc. 1973. *A Study of the Quarterly Demand for Gasoline and Impacts of Alternative Gasoline Taxes.* Prepared for the Environmental Protection Agency and the Council on Environmental Quality.

Deaton, A. S. 1974. "A Reconsideration of the Empirical Implications of Additive Preferences," *The Economic Journal* vol. 84 (June) pp. 338–348.

Department of Energy (DOE). 1978. *Draft Documentation Report on the Regional Demand Forecasting Model, 1977 Version.* Prepared by Synergy, Inc., Washington, D.C.

Dhrymes, Phoebus, and Mordechai Kurz. 1964. "Technology and Scale in Electricity Generation," *Econometrica* vol. 32, no. 3 (July) pp. 287–315.

Diewert, W. E. 1974. "Applications of Duality Theory," in M. D. Intriligator and D. A. Kendrick, eds., *Frontiers of Quantitative Economics,* volume 2 (Amsterdam, North-Holland).

Energy Modeling Forum (EMF). 1978. *Coal in Transition: 1980–2000.* EMF Report 2, volumes 1 and 2 (Stanford, Calif., Stanford University).

Erickson, Edward, Robert Spann, and Robert Ciliano. 1973. "Substitution and Usage in Energy Demand: An Econometric Estimation of Long-Run and Short-Run Effects," in Milton Searl, ed., *Energy Modeling* (Washington, D.C., Resources for the Future).

Farrell, M. J. 1954. "The Demand for Motor Cars in the United States," *Journal of the Royal Statistical Society,* series A, vol. 117, no. 2 (February) pp. 171–193.

Federal Energy Administration (FEA). 1976. *National Energy Outlook* (Washington, D.C., GPO).

———. 1974. *Project Independence Report* (Washington, D.C., GPO).

Fisher, Franklin M. 1966. *The Identification Problem in Econometrics* (New York, McGraw-Hill).

———, and Carl Kaysen. 1962. *A Study in Econometrics: The Demand for Electricity in the United States* (Amsterdam, North-Holland).

Fuss, Melvin A. 1971. "Factor Substitution in Electricity Generation: A Test of the Putty-Clay Hypothesis." Research Discussion Paper no. 185 (Cambridge, Mass., Harvard Institute of Economic Research).

Galatin, Malcolm. 1968. *Economies of Scale and Technological Changes in Thermal Power Generation* (Amsterdam, North-Holland).

Gill, G. S., and G. S. Maddala. 1976. "Residential Demand for Electricity in the TVA Area: An Analysis of Structural Change," in American Statistical Association, *1976 Proceedings of the Business and Economic Statistics Section,* pp. 315–319.

Gorman, W. M. 1953. "Community Preference Fields," *Econometrica* vol. 21 (January).

———. 1959. "Separable Utility and Aggregation." *Econometrica* vol. 27, no. 3 (July) pp. 469–481.

Greene, David L. 1978. *Econometric Analysis of the Demand for Gasoline at the State Level.* Report ORNL/TM-6326 (Oak Ridge, Tenn., Oak Ridge National Laboratory).

Griffin, James M. 1974. "The Effects of Higher Prices on Electricity Consumption," *The Bell Journal of Economics and Management Science* vol. 5, no. 2 (Autumn) pp. 515–539.

Griliches, Zvi, ed. 1971. *Price Indexes and Quality Change* (Cambridge, Mass., Harvard University Press).

Halvorsen, Robert. 1975. "Residential Demand for Electric Energy," *Review of Economics and Statistics* vol. 57, no. 1 (February) pp. 12–18.

———. 1978. *Econometric Models of U.S. Energy Demand* (Lexington, Mass., D. C. Heath).

Hartman, Raymond S. 1978. *A Critical Review of Single Fuel and Interfuel Substitution Residential Energy Demand Models.* Report MIT-EL-78-003 (Cambridge, Mass., Massachusetts Institute of Technology Energy Laboratory).

Hewlett, James G. 1977. "Changing Patterns of Households' Consumption of Energy Commodities," in American Statistical Association, *1977 Proceedings of the Business and Economic Statistics Section* (Part 1) pp. 99–108.

Hicks, J. R. 1939. *Value and Capital* (Oxford, Oxford University Press, reprinted 1974).

Houthakker, H. S. 1951. "Electricity Tariffs in Theory and Practice," *The Economic Journal* vol. 61, no. 241 (March) pp. 1–25.

———, and Lester D. Taylor, 1970. *Consumer Demand in the United States: Analyses and Projections* (Cambridge, Mass., Harvard University Press).

———, Philip K. Verleger, Jr., and Dennis Sheehan. 1974. "Dynamic Demand Analyses for Gasoline and Residential Electricity," *American Journal of Agricultural Economics* vol. 56, no. 2 (May) pp. 412–418.

Iulo, William. 1961. *Electric Utilities: Costs and Performance* (Pullman, Wash., Washington State University Press).

Johnson, Terry R. 1978. "Aggregations and the Demand for New and Used Automobiles," *Review of Economic Studies* vol. 45, no. 2 (June) pp. 311–327.

Johnston, J. 1972. *Econometric Methods* (New York, McGraw-Hill).

Khazzoom, J. Daniel. 1977. "An Application of the Concepts of Free and Captive Demand to the Estimating and Simulating of Energy Demand in Canada," in William D. Nordhaus, ed., *International Studies of the Demand for Energy* (Amsterdam, North-Holland).

Komiya, Ryutaro. 1962. "Technological Progress and the Production Function in the United States Steam Power Industry," *The Review of Economics and Statistics* vol. 44, no. 2 (May) pp. 156–166.

Kouris, George J. 1978. "Price Sensitivity of Petrol Consumption and Some Policy Indications: The Case of the EEC," *Energy Policy* vol. 6, no. 3 (September) pp. 209–216.

Koyck, L. M. 1954. *Distributed Lags and Investment Analysis* (Amsterdam, North-Holland).

Kuh, Edwin. 1976. "Preliminary Observations on the Stability of the Translog Production Function: in J. D. Khazzoom, ed., *Proceedings of the Workshop on Modeling the Interrelationships Between the Energy Sector and the General Economy*. Special Report no. 45, chap. 16 (Palo Alto, Calif., Electric Power Research Institute).

Lacy, A. W., and D. R. Street. 1975. "A Single Firm Analysis of the Residential Demand for Electricity." (Auburn, Alabama, University of Alabama, Department of Economics).

Lawrence, A. G. 1972. "Inter-Fuel Substitution: Steam Electric Generation's Demand for Fuels." Research Discussion Paper no. 8 (Washington, D.C., U.S. Bureau of Labor Statistics).

Leontief, Wassily. 1936. "Composite Commodities and the Problem of Index Numbers," *Econometrica* vol. 4.

Ling, Suilin. 1964. *Economies of Scale in the Steam-Electric Power Generating Industry: An Analytical Approach* (Amsterdam, North-Holland).

Lomax, K. S. 1952. "Cost Curves for Electricity Generation," *Econometrica* vol. 19, no. 74 (May) pp. 193–197.

Lucas, Robert E., Jr. 1976. "Econometric Policy Evaluation: A Critique," in Karl Brunner and Allan H. Meltzer, eds., *The Phillips Curve and Labor Markets*; supplementary series to the *Journal of Monetary Economics*, vol. 1 (Amsterdam, North-Holland).

MacAvoy, Paul, and Robert S. Pindyck. 1973. "Alternative Regulatory Policies for Dealing with the Natural Gas Shortage," *The Bell Journal of Economics and Management Science* vol. 4, no. 2 (Autumn) pp. 454–498.

Malinvaud, Edmund. 1972. *Lectures on Microeconomic Theory* (Amsterdam, North-Holland).

McFadden, Daniel. 1964. "Notes on the Estimation of the Elasticity of Substitution." Working Paper no. 57 (Berkeley, Calif., University of California Institute of Business and Economic Research).

———, and Carlos Puig. 1975. "An Econometric Model of the Demand for Electricity," in *Economic Impact of Water Pollution Control on the Steam Electric Industry*. Report EED-12 (Washington, D.C., Teknekron, Inc.).

———, ———, and Daniel Kirshner. 1977. "Determinants of the Long-Run Demand for Electricity," in American Statistical Association, *1977 Proceedings of the Business and Economic Statistics Section* (Part 2) pp. 109–117.

McGillivray, R. G. 1976. "Gasoline Use by Automobiles," in *Transportation Energy Conservation and Demand* (Washington, D.C., National Academy of Sciences, National Research Council) pp. 45–56.

Moore, Thomas G. 1970. "The Effectiveness of Regulation of Electric Utility Prices," *Southern Economic Journal* vol. 36, no. 4 (April) pp. 365–375.

Mount, T. D., L. D. Chapman, and T. J. Tyrrell. 1973. *Electricity Demand in the United States: An Econometric Analysis*. Report ORNL-NSF-EP-49 (Oak Ridge, Tenn., Oak Ridge National Laboratory).

National Economic Research Associates, Inc. (NERA). 1977. *Consideration of the Price Elasticity of Demand for Electricity: Topic 2*. Prepared by NERA, New York, N.Y.

Nerlove, Marc. 1968. "Returns to Scale in Electricity Supply," in Arnold Zellner, ed., *Readings in Economic Statistics and Econometrics* (Boston, Little, Brown) pp. 409–439.

———. 1971. "Further Evidence on the Estimation of Dynamic Economic Relations from a Time Series of Cross Sections," *Econometrica* vol. 39, no. 2 (March) pp. 359–382.

Newman, D. K., and D. Day. 1975. *The American Energy Consumer* (Cambridge, Mass., Ballinger).

Olson, Charles E., Franklin E. Robeson, and John A. Neri. 1979. *The Demand for Gas: A Study of Residential and Commercial User Characteristics in New York State*. A report to the New York Gas Group, prepared by H. Zinder and Associates, Washington, D.C.

Pearce, I. F. 1964. *A Contribution to Demand Analysis* (Oxford, Oxford University Press).

Phlips, Louis. 1972. "A Dynamic Version of the Linear Expenditure Model," *Review of Economics and Statistics* vol. 54, no. 4 (November) pp. 450–458.

Prais, S. J., and H. S. Houthakker. 1955. *The Analysis of Family Budgets* (Cambridge, Cambridge University Press).

Ramsey, J. B., R. Rasche, and B. Allen. 1975. "An Analysis of the Private and Commercial Demand for Gasoline," *Review of Economics and Statistics* vol. 57, no. 4 (November) pp. 502–507.

Reddy, Nallapu N. 1974. "The Demand for Coal in the United States: An Econometric Analysis," in *Proceedings of the Council of Economics*, AIME Annual Meeting, Dallas, Texas.

Resek, Robert W. and Robert K. Springer. 1977. "Time Lags in the Demand for Gasoline: Effects of a Durable Good," in American Statistical Association, *1977 Proceedings of the Business and Economic Statistics Section* (Part 2) pp. 476–480.

Samuelson, Paul A. 1965. *Foundations of Economic Analysis* (New York, Atheneum).

———. 1974. "Complementarity: An Essay on the 40th Anniversary of the Hicks-Allen Revolution in Demand Theory," *Journal of Economic Literature* vol. 12, no. 4 (December) pp. 1255–1289.

Schneider, A. M. 1977. "Elasticity of Demand for Gasoline Since the 1973 Oil Embargo," *Energy: The International Journal* vol. 2, no. 1 (March) pp. 45–52.

Schultz, Henry. 1938. *The Theory and Measurement of Demand* (Chicago, University of Chicago Press).

Schurr, Sam H., Joel Darmstadter, Harry Perry, William Ramsay, and Milton Russell. 1979. *Energy in America's Future: The Choices Before Us* (Baltimore, Md., Johns Hopkins University Press for Resources for the Future).

Stanford Research Institute. 1972. *Patterns of Energy Consumption in the United States* (Washington, D.C., GPO).

Strotz, Robert H. 1959. "The Utility Tree—A Correction and Further Appraisal," *Econometrica* vol. 27, no. 3 (July) pp. 482–488.

Sweeney, James. 1975. "Passenger Use of Gasoline." Mimeo (Washington, D.C., Federal Energy Administration).

Taylor, L. D. 1975. "The Demand for Electricity: A Survey," *The Bell Journal of Economics and Management Science* vol. 6, no. 1 (Spring) pp. 74–110.

———. 1977. "The Demand for Energy: A Survey of Price and Income Elasticities," in William D. Nordhaus, ed., *International Studies of the Demand for Energy* (Amsterdam, North-Holland).

———, G. R. Blattenberger, and P. K. Verleger, Jr. 1977. *The Residential Demand for Energy*, vol. 1. Report EA-235 (Palo Alto, Calif., Electric Power Research Institute).

Theil, Henri. 1971. *Principles of Econometrics* (New York, Wiley).

Uri, Noel D. 1976. "Short-Run Variations in the Demand for Electrical Energy," in American Statistical Association, *1976 Proceedings of the Business and Economic Statistics Section*, pp. 618–621.

———. 1978. "Regional Interfuel Substitution by Electric Companies: The Short-Term Prospects," *Annals of Regional Science* vol. 12, no. 2 (July) pp. 4–15.

Verleger, Philip K., Jr., and Florinda Iascone. 1977. *The Residential Demand for Energy: Estimates of Residential Stocks of Energy Using Capital.* Report EA-235 (Palo Alto, Calif., Electric Power Research Institute).

———, and Dennis Sheehan. 1976. "A Study of the Demand for Gasoline," in Dale Jorgenson, ed., *Econometric Studies of U.S. Energy Policy* (Amsterdam, North-Holland).

Wills, J. 1977. *Residential Demand For Electricity in Massachusetts.* Working Paper no. MIT-EL-77-016WP (Cambridge, Mass., Massachusetts Institute of Technology).

Wilson, John W. 1971. "Residential Demand for Electricity," *The Quarterly Review of Economics and Business* vol. 11, no. 1 (Spring) pp. 7–19.

———. 1974. "Electricity Consumption: Supply Requirements, Demand Elasticity and Rate Design," *American Journal of Agricultural Economics* vol. 56, no. 2 (May) pp. 419–427.

Wykoff, F. C. 1973. "A User Cost Approach to New Automobile Purchases," *Review of Economic Studies* vol. 40, no. 123 (July) pp. 377–390.

ANNEX 3

Tabulation of estimated price and income elasticities of energy demand according to end-user and fuel carriers.

Source: D R Bohi and M B Zimmerman (1984) "An Update on Econometric Studies of Energy Demand Behaviour" Annual Review of Energy 9:105-54

Table 1 Residential electricity

Study (date)	Sample[a]	Price elasticity[b]		Income elasticity		Regression procedure[c]	Other variables[d]
		Short	Long	Short	Long		
Reduced-form, static							
Agg., ave. price							
Lyman (1978)	1959–68, P; 10 regions						
	(utility)	−0.13 to −1.36		−2.14 to 0.55		MLE	PNGas, D, W, YDIst
Smith (1980)	1957–72, T; 27 utilities						
	(utility)	−0.07 to −1.56		0.59 to 1.76		OLS	W, PNGas
		−0.11 to −1.57		0.21 to 1.62		TSLS	
Agg., marg. price							
Houthakker (1979)	1964–76; P; US (state)	−1.18		1.39		WLS	W, IMC, APNGas
	1964–76; P;						
	Northeast states	n.s.		1.67			
	1964–76; P;						
	N. Central states	n.s.		1.45			
	1964–76; P;						
	Southern states	−1.07		1.58			
	1964–76; P;						
	Western states	−0.56		1.79			
Wills (1981)	1975; C;						
	Massachusetts						
	(Lypteal customer)	n.s.	−0.27	n.s.		WLS	IMC, PNGas, W, H (all customers)
			−0.18				(electric heating customers)
			−0.52				(others)
Disagg., ave. price							
Hirst et al (1982)	1978–79; C; US						
	(household)		−0.71[e]		0.12[e]		H, W, D (linear model)
			−0.67		0.16		(log model)
Disagg., marg. price							
Iowa (1982)	1977–80; P; Iowa						
	(non-farm household)	−0.55 to −0.71		0.13		–	W, D, AElec (monthly observations)
Garbacz (1983)	1978–79; C; US						
	(household)		−0.05		0.14	–	APElec, D, G, PFuel
Reduced-form, dynamic							
Agg., ave. price							
Uri (1978)	1971–75; T; US (US)	−0.35	−0.35	2.00	2.04	SDR	W, E, No. of customers (monthly observations)
Beierlein et al (1981)	1967–77; P:						
	Northeast (state)	−0.11	−1.87	n.s.	n.s.	OLS	APNGas, POIl
		−0.11	−2.20	n.s.	n.s.	EC	
		−0.09	−2.19	n.s.	n.s.	EC-SUR	
Maddigan et al (1983)	1969–78; P; N.E. states						
	(rural state)	−0.20	−0.47	0.42	0.98	TSLS	POIl, W, no. of customers, farming activity, G
	S.E. states	−0.22	−0.50	0.32	0.70		
	N. central states	−0.21	−0.93	n.s.			
	S.W. states	−0.16	−0.74	n.s.			
	Western states	−0.13	−0.26	0.18	0.37		
	1969–78; P; N.E. states						
	(total state)	−0.18	−0.62	0.19	0.66		PNGas, W, no. of customers
	S.E. states	n.s.		n.s.			
	N. central states	−0.25	−0.71	n.s.			
	S.W. states	−0.10	−0.26	0.30	0.76		
	Western states	n.s.		0.24	1.23		
Agg., marg. price							
Houthakker (1979)	1964–76; P; US (state)	−0.11	−1.42	0.14	1.78	WLS	W, Y-IMC, APNGas
	1964–76; P;						
	N.E. states	−0.14	−0.67	0.62	3.00		
	1964–76; P;						
	N. central states	−0.11	−2.50	n.s.	0.32		
	1964–76; P;						
	Southern states	−0.08	−1.11	0.15	2.01		
	1964–76; P;						
	Western states	−0.11	−1.12	0.15	1.50		

Table 1 *(continued)*

Study (date)	Sample[a]	Price elasticity[b]		Income elasticity		Regression procedure[c]	Other variables[d]
		Short	Long	Short	Long		
Blattenberger et al (1983)	1960–75; P; US (state)	−0.10	−1.05	0.08	0.80	VC	IMC, PNGas, POil, W, gas supply
		−0.09	−1.21	0.06	0.74		IMC, PNGas, POil, W, gas supply, E
Reduced-form, end-use							
Agg., marg. price							
Hartman & Werth (1981)	1960–75; P; US (state)	n.s.		n.s.		RE, PE	IMC, AElec, no. of customers
Disagg., ave. price							
Parti & Parti (1980)	1975–76; C; San Diego County (household)	−0.58		0.15		TSLS	H, W, AElec, D (weighted ave., of monthly observations)
Disagg., marg. price							
Acton et al (1980)	1972–74; P; Los Angeles (meter book)	−0.70		0.40		WLS	PGas, IMC, AElec, ANGas, H, D, W (bi-monthly observations)
	1972–73; P; Los Angeles	−0.52		0.31			
	1973–74; P; Los Angeles	−0.20		0.42			
	1972–74; P; Los Angeles	−0.35		0.38			
Barnes et al (1981)	1972–73; C; 23 metro areas (household)	−0.55		0.20		IV	IMC, AE, W, H, G, D
		−0.88		0.21		OLS	
Archibald et al (1982)	1975; C; US (household)	−0.40		0.11		OLS	D, W, H, AElec, Y-IMC (weighted ave. of monthly observations)
		−0.47[f]					(Peak)
		−0.32					(Off-peak)
Structural							
Disagg., ave. price							
Garbacz (1983)	1978–79; C; US (household)	−0.19	−1.40	0.10	0.41	TSLS	PFeul, AElec, W, D, G
Disagg., marg. price							
Garbacz (1982)	1978–79; C; US (household)	−0.67	−1.51	0.13	0.36	TSLS	AElec, W, D, PFuel, G, IMC
Dubin & McFadden (1982)	1975; C; US (household)	−0.20		0.03		OLS	(all electric)
		0.02		0.08			(other)
		−0.16		0.06			(total)
		−0.31		0.01		IV	(all electric)
		0.04		0.02			(other)
		−0.20		0.01			(total)

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[a] The term in parentheses refers to the unit of observation. T = time-series data; C = cross-sectional data; P = pooled data.

[b] n.s. = not significant at the 5% level.

[c] MLE = maximum likelihood estimation; OLS = ordinary least squares; GLS = generalized least squares, WLS = weighted least squares, EC = error components; VC = variable components, RE = random effects; FE = fixed effects; SUR = seemingly unrelated regressors; TSLS = two-stage least squares; IV = instrumental variables.

[d] PElec = price of electricity; APElec = average price of electricity; PNGas = price of natural gas; APNGas = average price of natural gas: POil = price of oil; PGas = price of gasoline, PCoal = price of coal; PFuel = price of local alternative fuel; IMC = inframarginal charge; AElec = stock of electricity-using appliances; AGas = stock of gasoline-using appliances; Auto = stock of automobiles; Truck = stock of trucks, CPI = consumer price index; YDist = income distribution; POP = population; D = demographic variables; H = housing stock and characteristics, W = weather variables, G = geographic variables (including regional dummies); E = embargo dummy, Employ = rate of (un)employment, Tax = import tax on equipment stock.

[e] The authors interpret long run estimates as lower bound values due to inclusion of housing stock variables.

[f] −0.47 and −0.27 are reported for peak and off-peak months respectively. The authors' averages are not weighted by monthly consumption, however.

Table 2 Residential natural gas

Study (date)	Sample[a]	Price elasticity[b]		Income elasticity		Regression procedure[c]	Other variables[d]
		Short	Long	Short	Long		
Reduced-form, static							
Disagg., marg. price							
Bloch (1980)	1971–76, P; Twin Rivers, New Jersey (household)	−0.60				OLS	W (monthly observations)
		−0.22					W, time
		−0.24					W, CPI
		−0.22					W, CPI, time
Reduced-form, dynamic							
Agg., ave. price							
Beierlein et al (1981)	1967–77; P; N.E. states (state)	−0.23	−2.79	n.s.		OLS	PElec, POil
		−0.24	−3.17	n.s.		EC	
		−0.35	−3.44	n.s.		EC-SUR	
Agg., marg. price							
Blattenberger et al (1983)	1961–70; P: US (state)	−0.05	−0.33	0.11	0.77	VC	APNGas, PElec, POil, W
	1961–74	−0.032[e]	−0.26	0.06	0.48		APNGas, PElec, POil, W, gas supply
Reduced-form, end-use							
Agg., ave. price							
Hartman & Werth (1981)	1960–75; P: US (state)	n.s.		n.s.		WLS	ANGas
		n.s.		n.s.		FE	
		n.s.		n.s.		RE	

[a–d] See Table 1 notes.

[e] The figure is reported as −0.32, but is assumed to be a typographical error.

Table 3 Residential, fuel oil

Study (date)	Sample[a]	Price elasticity[b]		Income elasticity		Regression procedure[c]	Other variables[d]
		Short	Long	Short	Long		
Reduced-form, dynamic							
Agg., marg. price							
Blattenberger et al (1983)	1964–74; P: US (state)	−0.19	−0.67[e]	0.12	0.44	VC	PElec, PGas, W, gas supply
		−0.18	−0.62	0.10	0.34 to 0.37		PElec, PGas, W

[a–d] See Table 1 notes.

[e] The figure reported in this study of −0.618 is inconsistent with the reported lag coefficient.

Table 4 Commercial electricity

Study (date)	Sample[a]	Price elasticity[b]		Income elasticity		Regression procedure[c]	Other variables[d]
		Short	Long	Short	Long		
Reduced-form, static							
Agg., ave. price							
Lyman (1978)	1961–68, P; 10 regions (utility)	−0.27 to −4.56		not reported		MLE	PGas, D, W, G
Disagg., ave. price							
Hirst et al (1980)	1977–78, C, Minesota (building)		−1.05			–	PFuels, D, H (institutional buildings)
Reduced-Form, dynamic							
Agg., ave. price							
Uri (1978)	1971–75; T: US	n.s.[e]		n.s.		SUR	W, E, no. of customers (monthly observations)
Beierlein et al (1981)	1967–77; P; N.E. states (state)	n.s.		n.s.		OLS	PGas, POil
		n.s.		−0.15	−1.73	EC	
		n.s.		n.s.		EC-SUR	

[a–d] See Table 1 notes.

[e] The author regards the short-run estimate of −0.15 as significant (p. 239), but the standard error is reported as 0.96.

Table 5 Industrial electricity

Study (date)	Sample[a]	Price elasticity[b] Short	Price elasticity[b] Long	Income elasticity Short	Income elasticity Long	Regression procedure[c]	Other variables[d]
Reduced-form, static							
Agg., ave. price							
Lyman (1978)	1961–68, P; 10 regions (utility)	−0.27 to −3.52		not reported		MLE	PGas, D, W, G
McRae & Webster (1982)	1962–73; P; Canada (region)	−0.43				TSLS	PElec, PNGas, POil, PLPG, PCoal, PGas
	1962–76; P; Canada	0.00				2SLS	(All from single equation)
	1962–73; P; Quebec	−0.54					
	1962–76	−0.18					
	1962–73; P; Ontario	−0.65					
	1962–76	−0.18					
	1962–73; P; prairies	−0.60					
	1962–76	−0.18					
	1962–73; P; British Columbia	−0.55					
	1962–76	−0.18					
Disagg., ave. price							
Kenney & Kershner (1980)	1972; C; New York State (upstate) (plant)		−1.83		0.33	—	Income = manufacturing employment
	1975; C, New York State		−1.59		0.39		
	1978; C; New York State		−1.54		0.42		
Reduced-form, dynamic							
Agg., ave. price							
Uri (1978)	1971–75, T, US	−0.12	−0.12	0.87	0.87	SUR	W, E, no. of customers (monthly observations)
Beierlein et al (1981)	1967–77; P; N.E. states (state)	−0.10	[e]	n.s.	[e]	OLS	PGas, POil OLS
		−0.12	−3.55	n.s.		EC	
		−0.12	−2.97	0.04	1.00	EC-SUR	
Reduced-form, end-use							
Disagg., ave. price							
Kenney & Kershner (1980)	1972; C; New York State (upstate) (plant)		−1.09		1.04	—	For process heat
	1975; C; New York State		−1.34		0.95		
	1978; C; New York State		−1.02		0.89		
	1972; C; New York State (upstate) (plant)		−1.38		0.62		For driving motors
	1975; C; New York State		−1.44		0.66		
	1978; C; New York State		−1.77		0.62		
	1972; C; New York State (upstate) (plant)		−0.61		0.36		For lighting and space conditioning
	1975; C; New York State		−0.66		0.33		
	1978; C; New York State		−0.83		0.30		

[a–d] See Table 1 notes.

[e] Reported estimate of lag coefficient does not appear plausible and is inconsistent with text references.

Table 6 Commercial natural gas

Study (date)	Sample[a]	Price elasticity[b] Short	Price elasticity[b] Long	Income elasticity Short	Income elasticity Long	Regression procedure[c]	Other variables[d]
Reduced-form, dynamic							
Agg., ave. price							
Beierlein et al (1981)	1967–77; P; N.E. states (state)	n.s.		n.s.		OLS	PElec, POil
		−0.28	−1.86	n.s.		EC	
		−0.37	−2.27	n.s.		EC-SUR	

[a–d] See Table 1 notes.

Table 7 Industrial natural gas

Study (date)	Sample[a]	Price elasticity[b] Short	Price elasticity[b] Long	Income elasticity Short	Income elasticity Long	Regression procedure[c]	Other variables[d]
Reduced-form, static							
Agg., ave. price							
McRae & Webster (1982)	1962–73; P; Canada (region)		−1.30			TSLS	PElec, POil, PCoal, PLPG, PNGas, PGas
	1962–76		−0.71				
	1962–73; P; Quebec		−2.30				
	1962–76		−1.74				
	1962–73; P; Ontario		−1.56				
	1962–76		−1.15				
	1962–73; P; prairies		−1.44				
	1962–76		−1.02				
	1962–73; P; British Columbia		−1.75				
	1962–76		−1.33				
Reduced-form, dynamic							
Agg., ave. price							
Beierlein et al (1981)	1967–77; P; N.E. states (state)	−0.61	−2.40	0.78	3.08	OLS	POil, PElec
		−0.63	−2.51	0.75	2.95	EC	
		−0.62	−2.54	0.70	2.86	EC-SUR	
Fuel share							
Agg., ave. price							
Chern & Just (1980)	1971, 1974, P, 19 states (state)		−2.16			GLS	POil, PCoal, manufac. costs ("marked share")
			−2.92				("total" or "conventional")

[a–d] See Table 1 notes.

Table 8 Commercial fuel oil

Study (date)	Sample[a]	Price elasticity[b] Short	Price elasticity[b] Long	Income elasticity Short	Income elasticity Long	Regression procedure[c]	Other variables[d]
Reduced-form, dynamic							
Agg., ave. price							
EIA DOE (1980)	1973–77; –; US		−0.7				P = wholesale (distillate)
			−0.7				(residual)

[a–d] See Table 1 notes.

Table 9 Industrial fuel oil

Study (date)	Sample[a]	Price elasticity[b] Short	Price elasticity[b] Long	Income elasticity Short	Income elasticity Long	Regression procedure[c]	Other variables[d]
Reduced-form, static							
Aggregated							
McRae & Webster (1982)	1962–73; P; Canada (region)	−0.23				TSLS	PElec; PNGas; PGas; PLPG; PCoal; POil
	1962–76	−0.36					
	1962–73; P; Quebec	−0.87					
	1962–76	−0.43					
	1962–73; P; Ontario	−1.07					
	1962–76	−0.43					
	1962–73; P; prairies	−1.51					
	1962–76	−0.32					
	1962–73; P; British Columbia	−0.92					
	1962–76	−0.85					
Reduced-form, dynamic							
Aggregated							
EIA DOE (1980)	1973–77; –; US		−0.7				P = wholesale (distillate)
			−0.5				(residual)
Fuel-share							
Aggregated							
Chern & Just (1980)	1971, 1974; P; 19 states (state)		−1.28			GLS	PCoal, PNGas, wage, manufacturing costs (market share)
			−1.57				(Total)

[a–d] See Table 1 notes.

Table 10 Gasoline

Study (date)	Sample[a]	Price elasticity[b]		Income elasticity		Regression procedure[c]	Other variables[d]
		Short	Long	Short	Long		
Reduced-form, static							
Agg., domestic							
Greene (1979)	1966–75; P; US (state)	−0.34		0.36		LSDV	G, auto, truck, D
Berzeg (1982)	1972–76, P; US (state)	−0.17		0.36		GEC	POP
Reduced-form, dynamic							
Agg., domestic							
Kwast (1980)	1963–77; P; US (state)	−0.07	−1.59	0.03	0.76	EC	G, E, POP
Berzeg (1982)	1972–76; P; US (state)	n.s.	n.s.	−0.18	−0.34	OLS	CPI, POP
		−0.15	0.14	0.42	0.40	GEC	CPI, POP
International							
Dahl (1982)	1970–78; P; 41 countries (country)	−0.13	−0.76	0.06	0.35	OLS	Auto
		−0.20	−1.00[e]	0.10[f]	0.50		Auto (low-price countries dropped)
Reduced-form, end-use							
Agg., static							
Reza & Spiro (1979)	1969–76; T; US (US)	−0.21	−0.33	0.60	1.44	GLS	Auto, D, E, MPG pollution, PAutos
Wheaton (1982)	1972; C; 25 countries		−0.74		1.26	OLS	Auto, MPG, T, D, G
Dahl (1979)	1936–41; 1947–72; 1975; T; US (US)	−0.44		not reported		2SLS	PAuto, auto, T, pollution, MPG
Disagg., static							
Archibald & Gillingham (1980)	1972–73; C; metro areas (household, residential)	−0.43		0.29		GLS	Auto, 1-car households
		−0.43		0.56			Auto, multi-car households
Archibald & Gillingham (1981)	1972–73; C; metro areas (household, residential)	−0.77		0.29		OLS	Auto, D, pollution, employ, 1-car households
		−0.22		0.56			Multi-car households
Agg., dynamic							
Paxson (1982)	1975–81; T; US (US)	−0.17		1.20		GLS	Auto, employ (1-year adjust)
		−0.07		0.91			Nonauto, employ (1 year)
		−0.14		0.56			Total (weighted average)

[a–d] See Table 1 notes.
[e] Value of −0.98 reported in text (p. 377) is not consistent with reported lag coefficient (p. 376).
[f] Value of 0.11 reported in text (p. 377) is not consistent with that reported in the text (p. 376).

Table 11 Decomposition of gasoline demand elasticities

Study (date)	Short-run gas price elast.			Long-run price elast.			Short-run income elast.			Long-run income elast.		
	MILES	STOCK	MPG	MILES	STOCK	MPG	MILES	STOCK	MPG	MILES	STOCK	MPG
Reza & Spiro (1979)	−0.21			−0.20	−0.13		0.60			0.83[a]	0.61	
Wheaton (1982)												
25 countries, nominal				−0.50	n.s.	0.32				0.54	1.38	−0.21
25 countries, deflated				−0.54	n.s.	0.33				0.46	1.89	−0.20
42 countries, nominal				−0.55	n.s.	0.26				0.33	1.43	−0.12
Archibald & Gillingham (1981)												
One car	−0.61		0.16				0.23		−0.06			
Multi-car	−0.16		0.06				0.47		−0.08			
Paxson (1982)												
One year	−0.14						0.56					
Dahl (1979)												
MILES econometrically estimated												
(1936–72 data)	−0.08		0.21									
(1936–74 data)	−0.2[b]		0.08									
MILES not econometrically estimated												
(1936–72 data)	−0.23		0.21									

[a] The figure of 1.44 reported in Reza & Spiro (59), p. 312, is for total miles traveled: this figure is adjusted for the change in the capital stock to obtain a miles-per-automobile figure and for consistency with the other studies.

[b] Assumed from statement in text, p. 430.

Table 12 Consensus estimates of price elasticities (in absolute value)

	Electricity Short/long	Natural gas Short/long	Fuel oil Short/long	Gasoline Short/long
Residential	0.2/0.7	0.2/0.3	uncertain	
Commercial	uncertain	uncertain	uncertain	
Industrial	uncertain	uncertain	uncertain	
Transportation				0.2/ < 1.00

Literature Cited

1. Taylor, L. D. 1975. The Demand for Electricity: A Survey. *Bell. J. Econ.* 6(1): 74–110
2. Hartman, R. S. 1979. Frontiers in energy demand modeling. *Ann. Rev. Energy* 4: 433–66
3. Bohi, D. R. 1981. *Analyzing Demand Behavior*. Baltimore, Md: Johns Hopkins Univ. Press for Resources for the Future
4. Kopp, R. J., Hazilla, M. 1982. *Substitution Between Energy and Other Factors of Production: U.S. Industrial Experience 1958–1974*, rep. EA 1475-1. Palo Alto, Calif: Electric Power Res. Inst.
5. US Dept. Energy, Energy Inf. Admin. 1980. *Residential Energy Consumption Survey: Conservation*, Rep. DOE/EIA-0207/3 (Feb.). Washington DC
6. Newman, D. K., Day, D. 1975. *The American Energy Consumer*. Cambridge, Mass: Ballinger
7. Hirst, E., Hermans, R., Eastes, C. 1980. Energy use in Minnesota institutional buildings. *Energy Systems and Policy* 4(4): 295–316
8. Electric Power Res. Inst. (EPRI). 1977. *Forecasting and Modeling Time-of-Day and Seasonal Electricity Demands*, rep. EPRI EA 578-SR. Palo Alto, Calif: EPRI
9. Fisher, F. M., Kaysen, C. 1962. *A Study in Econometrics: The Demand for Electricity in the United States*. Amsterdam: North-Holland
10. Stapleton, D. C. 1981. Inferring long-term substitution possibilities from cross-section and time-series data. In *Modeling and Measuring Natural Resource Substitution*, ed. E. R. Berndt, B. C. Field, pp. 93–118. Cambridge, Mass: MIT Press
11. Berndt, E. R., Morrison, C. J., Watkins, G. C. 1981. Dynamic models of energy demand: an assessment and comparison. See Ref. 10, pp. 259–89
12. Fisher, F. M. 1966. *The Identification Problem in Econometrics*. New York: McGraw-Hill
13. Sargent, T. J. 1981. Interpreting economic time series. *J. Polit. Econ.* 89(2): 213–48
14. Epple, D., Hansen, L. P. 1981. An econometric framework for modeling exhaustible resource supply. In *The Economics of Exploration for Energy*, ed. J. Ramsay. Greenwich, Conn: JAI Press
15. Epple, D. 1983. *The Econometrics of Exhaustible Resource Supply: A Theory and An Application*, discussion paper D-82R. Washington DC: Resources for the Future
16. Roberds, W. 1982. *A Dominant Firm Model of an Exhaustible Resource Industry: Theory and Estimation*, unpubl. working paper 12-81-82. Providence, RI: Brown Univ.
17. Christensen, L. R., Jorgenson, D. W., Lau, L. J. 1973. Transcendental logarithmic production frontiers. *Rev. Econ. Stat.* 55(1): 28–45
18. Brown, A., Deaton, A. 1972. Surveys in applied economics: models of consumer behaviour. *Econ. J.* 82(328): 1145–236
19. Kuh, E. 1976. Preliminary observations on the stability of the translog production function. In *Workshop Modeling Interrelationships Between Energy Sector and Gen. Econ.* spec. rep. 45, ed. J. D. Khazzoom, ch. 16. Palo Alto, Calif: Electric Power Res. Inst.
20. Berndt, E. R., Fuss, M. A., Waverman, L. 1977. *Dynamic Models of the Industrial Demand for Energy*, rep. EPRI EA-580. Palo Alto, Calif: Electric Power Res. Inst.
21. Theil, H. 1971. *Principles of Econometrics*. New York: Wiley
22. Nordin, J. A. 1976. A proposed modification of Taylor's demand analysis: comment. *Bell J. Econ.* 7(2): 719–21
23. Natl. Econ. Res. Assoc. 1982. *Aggregate Residential Electricity Demand: Methods for Integrating Over Declining Block Rates*, rep. EPRI EA-2767. Palo Alto, Calif: Electric Power Res. Inst.
24. Lyman, R. A. 1978. Price elasticities in the electric power industry. *Energy Systems and Policy* 2(4): 381–406
25. Smith, V. K. 1980. Estimating the price elasticity of U.S. electricity demand. *Energy Econ.* 2(2): 81–85
26. Houthakker, H. S. 1979. *Electricity Demand Revisited*, Harvard Inst. Econ. Res. discussion paper 711. Cambridge, Mass: Harvard Univ. Press
27. Wills, J. 1981. Residential demand for electricity. *Energy Econ.* 3(4): 249–55
28. Garbacz, C. 1983. *Electricity Demand and the Elasticity of Infra-Marginal Price*. Rolla, Mo: Univ. Missouri-Rolla. Unpublished manuscript
29. Hirst, E., Goeltz, R., Carney, J. 1982. Residential energy use: analysis of disaggregate data. *Energy Econ.* 4(2): 74–82
30. Iowa State Commerce Comm., Rates Res. & Policy Div. 1982. *Estimated Household Response to Inverted Electric Rates: An Empirical Analysis*. Presented at Inst. Public Util., Mich. State Univ., 14th ann. conf. "Adjusting to Regulatory, Pricing, and Marketing Realities," Dec., Williamsburg, Va. Des Moines: Iowa State Commerce Comm.
31. Beierlein, J. G., Dunn, J. W., McConnon, J. C. Jr. 1981. The demand for electricity and natural gas in the Northeastern United States. *Rev. Econ. Stat.* 63(3): 403–8
32. Maddigan, R. J., Chern, W. S., Rizy, C. G. 1983. Rural residential demand for electricity. *Land Econ.* 59(2): 150–61
33. Blattenberger, G. R., Taylor, L. D., Rennhack, R. K. 1983. Natural gas availability and the residential demand for energy. *Energy J.* 4(1): 23–45
34. Uri, N. D. 1978. The demand for electrical energy in the United States. *Energy Systems and Policy* 2(3): 233–44
35. Hartman, R. S., Werth, A. 1981. Short-run residential demand for fuels: a disaggregated approach. *Land Econ.* 57(2): 197–212
36. Parti, M., Parti, C. 1980. The total and appliance-specific conditional demand for electricity in the household sector. *Bell J. Econ.* 11(1): 309–21
37. Acton, J. P., Mitchell, B. M., Sohlberg, R. 1980. Estimating residential electricity demand under declining-block tariffs: an econometric study using micro-data. *Appl. Econ.* 12(2): 145–61
38. Barnes, R., Gillingham, R., Hagemann, R. 1981. The Short-run residential demand for electricity. *Rev. Econ. Stat.* 63(4): 541–52
39. Archibald, R. B., Finifter, D. H., Moody, C. E. Jr. 1982. Seasonal variation in residential energy demand: evidence from survey data. *Appl. Econ.* 14(2): 167–81
40. Garbacz, C. 1983. A model of residential demand for electricity using a national household sample. *Energy Econ.* 5(2): 124–28
41. Garbacz, C. 1982. *In Search of Residential Electricity Demand*. Paper presented at meet. Int. Assoc. Energy Econ., Nov., Denver, Colo. Rolla, Mo: Univ. Missouri-Rolla
42. Dubin, J. A., McFadden, D. 1982. An econometric analysis of residential electric appliance holdings and consumption. In *Proc. End-Use Models and Conservation Anal.*, rep. EPRI EA-2509, res. proj. 1050, prep. by Univ. Ariz. Eng. Exp. Station for EPRI. Palo Alto, Calif: Electric Power Res. Inst.
43. Amemiya, T. 1981. Qualitative response models: a survey. *J. Econ. Lit.* 19(4): 1483–536
44. Bloch, F. E. 1980. Residential-demand

for natural gas. *J. Urban Econ.* 7(3): 371–83

45. McRae, R. N., Webster, A. R. 1982. The robustness of a translog model to describe regional energy demand by Canadian manufacturing industries. *Resources and Energy* 4(1): 1–26
46. Kenney, J. M., Kershner, T. R. 1980. *The Industrial Demand for Electricity in New York State: A Survey Analysis.* Schenectady, NY: Union Coll. Unpublished manuscript, Aug.
47. Chern, W. S., Just, R. E. 1980. A generalized model for fuel choices with application to the paper industry. *Energy Systems and Policy* 4(4): 273–94
48. Baughman, M. L., Joskow, P. L. 1976. Energy consumption and fuel choice by residential and commercial customers in the United States. *Energy Systems and Policy* 1(4): 305–23
49. US Dept. Energy, Energy Inf. Admin. 1980. *Income and Price Effects on Petroleum Consumption—An International Comparison,* rep. DOE/EIA-0183/16. Washington DC
50. Uri, N. D. 1978. Regional interfuel substitution by electric companies: the short-term prospects. *Ann. Regional Sci.* 12(2): 4–15
51. Paxson, D. L. 1982. *Short-term Motor Gasoline Demand Forecasting.* Paper presented at meet. Int. Assoc. Energy Econ., Nov. 18, Denver, Colo. Washington DC: Short-Term Inf. Div., Off. Energy Markets and End-Use, Energy Inf. Admin. US Dept.
52. Dahl, C. A. 1982. Do gasoline demand elasticities vary? *Land Econ.* 58(3): 373–81
53. Greene, D. L. 1979. State differences in the demand for gasoline: an econometric analysis. *Energy Systems and Policy* 3(2): 191–212
54. Mehta, J. S., Narasimham, G. V. L., Swamy, P. A. V. B. 1976. Estimation of a dynamic demand function for gasoline with different schemes of parameter variation. *J. Economet.* 7: 263–79
55. Kraft, J., Rodekohr, M. 1978. Regional demand for gasoline: a temporal cross-section specification. *J. Regional Sci.* 18(1): 45–56
56. Berzeg, K. 1982. Demand for motor gasoline: a generalized error components model. *So. Econ. J.* 49(2): 462–71
57. Kwast, M. L. 1980. A note on the structural stability of gasoline demand and the welfare economics of gasoline taxation. *So. Econ. J.* 46(4): 1212–20
58. Dahl, C. A. 1979. Consumer adjustment to a gasoline tax. *Rev. Econ. Stat.* 61(3): 427–32
59. Reza, A. M., Spiro, M. H. 1979. The demand for passenger car transport services and for gasoline. *J. Transport Econ. and Policy* 13(3): 304–19
60. Wheaton, W. C. 1982. The long-run structure of transportation and gasoline demand. *Bell J. Econ.* 13(2): 439–54
61. Archibald, R., Gillingham, R. 1980. An analysis of the short-run consumer demand for gasoline using household survey data. *Rev. Econ. Stat.* 62(4): 622–28
62. Archibald, R., Gillingham, R. 1981. A decomposition of the price and income elasticities of the consumer demand for gasoline. *So. Econ. J.* 47(4): 1021–31
63. US Dept. Labor, Bureau Labor Stat. 1977. *Consumer Expenditure Survey Series: Interview Survey, 1972–1973,* report 455-4. Washington DC
64. Deaton, A. S. 1974. A reconsideration of the empirical implications of additive preferences. *Econ. J.* 84: 338–48

ANNEX 4

Analysis and estimation of energy elasticities in South Africa

Source: "The Outlook for Energy in South Africa" Dept of Planning and the Environment, 1977

APPENDIX A : THE USE OF ECONOMETRICS AS AN AID IN THE FORECASTING OF ENERGY DEMAND[*]

1. Introduction

Economic and other forecasting can be enhanced through techniques employed in econometrics. Owing to the fact that a large number of parameters and variables can be included in econometric models the flexibility and meaningfulness of forecasts can be substantially increased. It would thus be profitable to explore the possibilities offered by econometrics in the forecasting of energy demand. The results so obtained could be used as a control and a supplement to results obtained by other methods. Some preliminary results of an econometric investigation into the demand for energy carriers are subsequently discussed.

2. The General Framework

When considering the demand for energy and energy carriers, one should keep in mind that it is but one element of a whole complex system of functional relationships among interdependent economic variables. Consumers demand energy along with many other goods and services in order to satisfy their wants, while producers demand energy as an input in the production of intermediary and final goods. Neither the consumer nor the producer will demand energy regardless of what happens in the world in which he lives. There are indeed many factors which influence the demand for energy. As production and income per head increase the demand for energy in general will also increase. The rate at which this increase takes place will depend on many things. It will be influenced by the state of technology, by the distribution of income, by relative prices, and many other variables.

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As the world advances on its time path technology, income, production and relative prices do not remain unchanged. They will vary along with changes in other endogenous variables of the economic system, as well as with exogenous factors. These changes will of cource influence the demand for energy and energy carriers, while the latter will in turn cause changes in the rest of the economic system, including income and prices.

These considerations urge us to study any of the mutually dependent functional relationships in the context of an all-embracing model of the entire economy. Such a model will contain as many equations as there are relationships among the economic variables and will include the demand and supply equations of the various energy carriers.

Let Y be a vector whose elements Y_i $i=1,2 \ldots,n$ represent the endogenous variables of the economic system. Let X be a vector whose elements X_i $i=1,2 \ldots,m$ represent the exogenous variables which bear an influence upon the economic system, but are not themselves dependent upon changes in the system. A model of the economic system will now be represented by n equations in the elements of Y and X, each equation reflecting a specific structural property of the economic system:

$$f_i(Y_1, Y_2, \ldots\ldots Y_n, X_1, X_2, \ldots\ldots X_m, U_i) = 0 \quad i=1,2 \ldots,n$$

The variable U_i represents the influence of random factors.

Some of the f_i $i=1,2 \ldots\ldots,n$ will reflect direct consumption activities such as the demand for motor fuel, while others will reflect productive activities, such as industrial or mining production. The latter will give rise to an industrial demand for energy carriers, owing to the fact that energy is usually quite an important input in the production process.

Let $Y_{v+1} = \sum_{i=1}^{v} Y_i$ denote the total value of final consumption, and let Y_1, Y_2 and Y_3 denote the demand for electricity, petroleum and coal respectively. Furthermore, let Y_{pi} denote the total value of production in the i-th production sector and Y_{Eji} the value of the j-th energy carrier required by the i-th production sector.

Y_{pi} will now be a function of Y_{Eji} $j=1,2 \ldots,q$, namely

$Y_{pi} = f_{pi}\ (Y_{E1i}, Y_{E2i}, \ldots.\ Y_{Eqi})$ where q represents the total number of energy carriers. If there are W production sectors, the total value of production is

$$\sum_{i=1}^{W} Y_{pi}.$$

The total demand for the j-th energy carrier is $\sum_{i=1}^{W} Y_{Eji}$, which must be equal to the total supply, Y_{Ej}.

If we let Y_d be equal to the total value of intermediary inputs and Y_{dr} be equal to the total value of non-energy intermediary inputs, then

$$Y_d = \sum_{i=1}^{W} \sum_{j=1}^{q} Y_{Eji} + Y_{dr},$$

and $Y_t = \sum_{i=1}^{W} Y_{pi} - Y_d$ will denote the final value of production.

Our model, which accounts for the interdependence among the various economic variables and explicitly contains the various demand for energy carrier equations, now takes the following form.

$$\begin{aligned}
Y_1 &= Y_1(Y_2, Y_3, \ldots\ Y_n; X_1, X_2, \ldots.X_m;\ U_1) \\
Y_2 &= Y_2(Y_1, Y_3, \ldots\ Y_n; X_1, X_2, \ldots X_m;\ U_2) \\
&\vdots \\
Y_A &= Y_A(Y_1, Y_2, \ldots\ Y_n; X_1, X_2, \ldots X_m\ ;\ U_A) \\
Y_{AH} &= Y_{AH}\ Y_1, Y_2, \ldots\ Y_n; X_1, X_2, \ldots X_m\ ;\ U_{AH}) \\
&\vdots \\
Y_v &= Y_v(Y_1, \ldots.\ Y_n; X_1\ \ldots.X_m;\ U_v) \\
Y_{v+1} &= \sum_{i=1}^{v} Yi
\end{aligned}$$

$$\vdots$$

$$Y_{p1} = Y_{p1}(Y_1, \ldots Y_{E11}; \ldots, Y_{nj}X_1, \ldots, X_m; U_{p1})$$

$$Y_{p2} = Y_{p2}(Y_1, \ldots Y_{E12}; \ldots, Y_n; X_1, \ldots, X_m; U_{p2})$$

$$Y_{E11} = Y_{E11}(Y_1, Y_2, \ldots, Y_n; X_1, \ldots, X_m; U_{E11})$$

$$\vdots$$

$$Y_{E_{qw}} = Y_{E_{qw}}(Y_1, Y_2, \ldots, Y_n; X_1, \ldots X_m; U_{qm})$$

$$Y_t = \sum_{i=1}^{W} Y_{pi} - Y_d$$

$$Y_d = \sum_{i=1}^{W} \sum_{j=1}^{q} Y_{Eji} + Y_{dr}$$

$$Y_{E_j} = \sum_{i=1}^{W} Y_{Eji}$$

$$\vdots$$

$$Y_n = Y_n(Y_1, Y_2, \ldots Y_{n-1}; X_1, X_2 \ldots X_m; U_n)$$

Some of the Y_{pi} $i=1,2, \ldots, w$ will represent the production functions of energy carriers being produced or extracted domestically, while other carriers are of course being imported, represented by some of the other Y_1 $i=1,2, \ldots, n$.

Such well-known relationships as the investment function, the demand for money and the supply of labour will also feature in the model. The most prominent property of the model is the fact that all the variables are related to each other, directly or indirectly.

This model represents the ideal framework within which the demand for fuel, coal and electricity or any other energy carrier should be studied. When faced by the actual task of obtaining empirical results, one usually has to reduce the ideal situation to manageable proportions, keeping one's eye on the availability of suitable data. Certain simplifications were therefore made in the present study as well. The precise way in which this was done will be dealt with in later sections. In the meantime, it is worthwhile to remember that the sophisticated model serves as a fixed point towards which one strives.

3. The general form of the energy carrier demand functions and the aggregation problem

No matter how many energy carriers we distinguish and how many consumers there are, we would find but two general types of energy carrier demand functions, namely final demand functions and intermediary demand functions.[1] The first relates to consumers and the second to producers. The properties of both these types of demand functions are well-established in economic theory, but it might serve a useful purpose to review them briefly.

3.1 Final demand functions

The most general property which all final demand functions should display is that they are functions of prices and consumer's income. When one specifies a demand function for the purpose of econometric study it is not possible to include each and every price in such a function. The minimum number of variables to be included would be the consumer's income, the product's own price and the price of its most important substitute and/or complement. By studying the circumstances relevant to a specific function one would get an idea of what other prices to include in the function. If $P_1, P_2, \ldots P_n$ are representations of final prices and Y denotes income the final demand for the i-th product will be represented by

$$Q_i = Q_i(p_1, p_2, \ldots p_i \ldots p_n; Y)$$

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1) cf. Samuelson, P A, Foundations of Economic Analysis,

Of course, not all of the p_i $i=1,2,...n$ will actually feature in a specific formulation of the demand function.

It is normally required that this demand function be homogeneous of degree zero in prices and income so that the same percentage increase in all prices and income would leave the amount demanded unaffected:

$Q_i(kp,ky) = Q_i(p,Y)$.

When money illusion is present this property may be violated.

In the case of a linear demand function the following form would display the homogeneity property:

$$Q_i = a+b_1\frac{p_1}{p} + b_2\frac{p_2}{p} + \ldots.\ b_n\frac{p_n}{p} + c\frac{Y}{P}$$

where $P = \sum_{i=i}^{n} a_i p_i$, representing some general price index.

In empirical work one frequently finds demand functions which are linear in the logarithms of the variables:

$$Q_i = A\left(\frac{p_1}{p}\right)^{b_1} \cdot \left(\frac{p_2}{p}\right)^{b_2} \cdot \ldots\ldots \cdot \left(\frac{p_n}{p}\right)^{b_n} \cdot \left(\frac{Y}{p}\right)^{C}$$

The homogeneity property could be retained if the function takes the form

$$Q_i = A\,p_1^{b_1}\,p_2^{b_2} \ \ldots\ldots\ p_n^{b_n}\ Y^C \text{ and } \sum_{i=1}^{n} b_i + C = 1$$

Once again, the presence of money illusion may cause

$\sum_{i=1}^{n} b_i + C$ to deviate from 1.

One of the most fundamental properties of final demand functions is that the quantity demanded must be negatively related to product's own price, unless one deals with so-called Giffen products:

$$\frac{\partial Q_i}{\partial p_i} < 0 \quad \text{unless} \quad \frac{\partial Q_i}{\partial Y} < 0$$

Owing to the unsatiability of consumer wants, income will normally have a positive influence on the quantity demanded:

$$\frac{\partial Q_i}{\partial Y} > 0.$$

We shall therefore require our final demand functions to be dependent upon prices and income. The quantity demanded and the own price should influence each other negatively, while income must have a positive influence on the quantity demanded. Unless money illusion exists, the functions should be homogeneous of degree zero in prices and in income. These properties do assume that the consumer acts rationally and consistently, but we have at least no evidence to support the opposite view.

3.2 The intermediary demand function

If one assumes that the producer minimises his cost for any given level of output, one can deduce the demand for any of his inputs, including energy carriers, given the production function. Should the latter be represented by

$$X = X(Z_1, Z_2, \ldots\ldots Z_n), \text{ then}$$

the demand for the i-th input will be represented by

$$Z_i = Z_i\ (W_1, W_2, \ldots . W_n, X)$$

where X = production

Z_i i=1, ...,n = inputs

W_i i=1, ...,n = prices of the inputs

The properties of the input demand function will, in general, be analogous to that of the final demand function, except for some minor differences. As long as Z_i is not an inferior input we shall have

$$\frac{\partial Z_i}{\partial W_i} < 0$$

In the case of constant or decreasing returns to scale

$$\frac{\partial z_i}{\partial x} \geqslant 0$$

The input demand function will also be homogeneous of degree zero in input prices for any given output.

As was the case with final demand functions one can find several empirical forms which will actually display the desired properties:

$$Z_i = b + A_1\frac{W_1}{W} + A_2\frac{W_2}{W} + \ldots + A_n \frac{W_n}{W} + dX$$

where $W = \sum_{i=1}^{n} k_i W_i$

or $\quad Z_i = bW_1^{a_1} W_2^{a_2} \;.....\; W_n^{a_n} X^d$

with $\sum_{i=1}^{n} a_i = 1$

Once again, owing to practical considerations only a subset of the $W_1, W_2, \ldots W_n$ will be included when one specifies a form which is actually to be used for estimation purposes.

3.3 The aggregation problem

The general properties of the final and intermediary demand functions are deduced from individual behavioural assumptions and it is not always clear whether the same properties can be attributed to the macro functions. The latter reflect the result of the simultaneous action of many individual subjects and the aggregation problem, which deals with the transition from the micro to the macro level, is certainly not yet finally settled. Nevertheless enough progress regarding insight into the problems has been made to allow one to proceed with research at the macro level, as long as one keeps an eye for the many pitfalls which may be encountered.

In this study, we shall always deal with the demand for a homogeneous product, namely one or other energy carrier, so that the problem is one of aggregating over individuals. Since most solutions to the aggregation problem are particular to the specific form of the functional relationship involved, the way in which the difficulty is surmounted in this study will be dealt with when we arrive at the estimations themselves.

4. The demand for energy carriers in South Africa

4.1 Introduction

We distinguish three types of energy carriers, namely coal, petroleum and electricity, and four subject groups, namely households, industry, mining and transport. Although it was argued previously that the demand for the various energy carriers should actually be studied in the context of an all-embracing econometric model of the South African economy, it is impossible to achieve this ideal at present. Such a model does not exist and it would certainly take much more than a mere study of energy demand to construct such a model. As we needed the best results possible under the circumstances, we proceeded to study the demand for energy within the context of a submodel consisting of demand and supply equations for the various energy carriers. Variables which would be determined elsewhere in the complete model, such as income, population and prices other than those of the energy carriers, are considered as exogenous to the submodel and therefore treated as being predetermined. Making these simplifications, the price and quantity of energy can be determined by simultaneously solving these variables in the following systems

$$Q = Q(P,A)$$
$$P = P(Q,B)$$

where the first equation represents the demand for energy and the second equation its supply. Q and P are the quantity traded and the price respectively, while A and B are the sets of other (predetermined) variables entering the demand and supply equations. For practical considerations an even further abstraction from reality proved necessary. Owing to the very special circumstances which surround the supply of each type of energy carrier and the fact that the construction of the supply function would indeed be a study in its own right the supply of each carrier was considered to be infinitely elastic at a given price. As a first approximation it is certainly not too unrealistic to think of the price of energy carriers in our country to be fixed at levels on account of factors which have little to do with purely economic considerations. Broadly speaking, the prices of fuel, for example, are determined outside the country. Once the price is fixed we can usually obtain as much of the energy carrier as we whould like to have, as long as we are prepared to pay the price. It should be mentioned, however, that we intend to look into the supply question more closely in future.

With the price being predetermined our model now takes the following form :

$Q = Q(P,A)$

$P = \overline{P}$, where $P = \overline{P}$ represents the supply function in the form of an exogenously determined price.

One does of course lose a certain amount of information through the lack of complete interdependence; yet our results indicated that one may still gain much insight into the demand for energy despite the simple nature of the model.

4.2 The form of the estimated demand functions

The functions which have been estimated so far are all linear in the logarithms of the variables, which is the form used in many similar studies abroad. They usually contain the own price, the price of a substitute or complement, income or production and an approximation of it, and the lagged value of the dependent variable as explanatory variables, while the quantity demanded is the dependent variable.

$$=\frac{\ln A+a_1}{1-kL}\frac{1}{1-kL}\ln P_{1t}+a_2\frac{1}{1-kL}\ln P_{2t}+b_1\frac{1}{1-kl}\ln X_t$$

where L is the lag operator

$$\ln Q_t-k\ln Q_{t-1}=\ln A+a_1\ln P_{1t}+a_2\ln P_{2t}+b_1\ln X_t$$

$$\ln Qt=\ln A+a_1\ln P_{1t}+a_2\ln P_{2t}+b_1\ln X_t+k\ln Q_{t-1}$$

$$\text{or } Qt = A.P_{1t}^{a_1}.P_{2t}^{a_2}.X_t^{b_1}.Q_{t-1}^{b_2} \quad \text{where } b_2 = k$$

It is well known that a Koyck lag in the explanatory variables may be the result of at least two possible behavioural structures. One such structure would be a true geometrically declining influence of the explanatory variables on the dependent variable, while another would be a dependence upon expected values of the explanatory variables, these expected values being determined by a geometrically declining series of observed values.

4.3 Aggregation of the demand function over individuals

If we assume that the parameters are more or less the same with regard to all the individual units demanding a certain energy carrier, we can easily aggregate in terms of geometric averages and obtain

$$Q^G = A.P_1^{a_1}P_2^{a_2}X^{Gb_1}.Q_{-1}^{Gb_2} \quad \text{where}$$

the superscript G indicates that one deals with the geometric average of the relevant variables.1) The variables P_1 and P_2 are of course exogenously determined and the same for all individuals, so that they can be treated as constants in the present problem. As long as the variables are normally distributed in their logarithms, which is indeed a natural assumption in our case, a proportionate relationship exists between geometric and arithmetic means,1) so that we may write

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1) Klein, L R, Macroeconomics and the theory of rational behaviour, Econometrica, April 1946

$$Q = A.P_1^{a_1} P_2^{a_2} \; X^{b_1} \; Q_{-1}^{b_2}$$

or $$\ln Q = \ln A + a_1 \ln P_1 + a_2 \ln P_2 + b_1 \ln X + b_2 \ln Q_{-1}$$

Q = quantity demanded

P_1 = own price

P_2 = price of substitute

X = income (in the case of final demand)

production (in the case of intermediary demand)

Q_{-1} = one period lag in quantity demanded.

We note that the function does meet the requirements which we set out in the general discussion of demand functions. The presence of all variables except Q_{-1} was adequately explained then, so that we need to elaborate here only as far as Q_{-1} is concerned.

The most straightforward interpretation of Q_{-1} would be that it represents the influence which previous standards of living or levels of production have on the present demand. A more sophisticated explanation would be that it represents the presence of a Koyck lag in the logarithms of the other explanatory variables.

let $$Q_t = A.P_{1t}^{a_1k^o} . P_{1t-1}^{a_1k^1} . P_{1t-2}^{a_1k^2} . \ldots . P_{2t}^{a_2k^o} . P_{2t-1}^{a_2k^1} . P_{2t-2}^{a_2k^2} \ldots . X_{t.}^{b_1k^o} \; X_{t-1.}^{b_1k^1} \; X_{t-2}^{b_1k^2} \ldots$$

$$= A . \prod_{i=1}^{\infty} P_{1t-i}^{a_1k^i} . \prod_{i=1}^{\infty} P_{2t-i}^{a_2k^i} . \prod_{i=1}^{\infty} X_{t-i}^{b_1k^i}$$

Then $$\ln Q_t = \ln A + a_1 \sum_{i=1}^{\infty} k^i \ln P_{1t-i} + a_2 \sum_{i=1}^{\infty} k^i \ln P_{2t-i} + b_1 \sum_{i=1}^{\infty} k^i \ln X_{t-i}$$

$$Q^A = B.P_1^{a_1}P_2^{a_2}X^{Ab_1}.Q_{-1}^{Ab_2}$$

where A indicates that we deal with arithmetic averages and B is the previous constant A multiplied by the factor of proportion between geometric and arithmetic averages.

Owing to the homogeneity property of our functional relationship, we may even get rid of the arithmetic averages and work with total values. If there are T individual subjects over which we aggregate we have

$$B.P_1^{a_1}P_2^{a_2}.(X^T)^{b_1}.(Q_{-1}^T)^{b_2}$$

$$= B.P_1^{a_1}P_2^{a_2}(TX^A)^{b_1}.(TQ_{-1}^A)^{b_2}$$

$$= B.P_1^{a.}P_2^{a_2}(X^A)^{b_1}.(Q_{-1}^A)^{b2}\,T^{b_1+b_2}$$

$$= Q^A.T^{b_1+b_2}$$

where X^T and Q^T represents the total values, summed over all individual subjects. Using this relationship and the fact that

$$Q^T = \sum_{i=1}^{T} Q_i = Q^A.T$$

$$= Q^A.T^{b_1+b_2}.T^{1-b_1-b_2}$$

we finally find that

$$Q^T = B.P_1^{a_1}P_2^{a_2}(X^T)^{b_1}(Q_{-1}^T)^{b_2}.T^{1-b_1-b_2}$$

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1) Cramer, J S, Empirical Econometrics, North-Holland, Amsterdam, 1971, p. 180.

Incorporating the term $T^{1-b_1-b_2}$ into the constant term, we have

$$Q^T = C.P_1^{a_1}P_2^{a_2}(X^T)^{b_1}(Q_{-1}^T)^{b_2}$$

Apart from the constant term, in which we are at any rate not much interested, the parameters of the aggregate function are exactly those of the individual functions. We may proceed thus to estimate at the macro level.

4.4 Empirical results

Although further research is still being carried out, it may serve a useful purpose as far as the gaining of insight into the structure of energy demand in South Africa is concerned, to present some of the better results already available.

4.4.1 Households

Electricity

$$\ln E_t = -1.40 + 0.82\ln E_{t-1} - 0.30\ln P_{Et} + 0.37\ln P_{St} + 0.3_1\ln N_t$$

$$(0.51)(0.04) \quad (0.14) \quad (0.16) \quad (0.18)$$

$R^2 = 0.9984$

D.W. = 1.93

Period of fit: 1934-1973

E_t = demand for electricity by households

P_{Et} = price of electricity paid by households

P_{St} = price of coal paid by households

N_t = total population of the RSA

Petroleum products

$$\ln O_t = -2.36 + 0.71\ln O_{t-1} - 0.23\ln P_{Ot} + 0.83\ln N_t$$

$$(0.42)\ (0.06) \quad (0.05) \quad (0.15)$$

$R^2 = 0.9962$

D.W. = 1.39

Period of fit: 1934-1973

O_t = demand for petroleum products by households

B_{Ot} = price of petroleum products paid by households

N = population of the RSA

We have not yet succeeded in obtaining presentable results regarding the household demand for coal. This ought not to be surprising, because the distribution of income, rather than the absolute level, should be of prime importance in this case owing to the fact that a relatively large amount of coal consumption by households is accounted for by the lower income groups. In fact, one might even argue that the distribution of income should feature in the two functions which we do present above as well. We are therefore exploring these and other possibilities.

In the meanwhile, one may make some important observations. In all the electricity and petroleum demand functions that we tried out the own price effect was invariably negative, a fact which conforms to basic theory. It will also be noted that the form of the function suggests a Koyck type of geometrically declining influence by the explanatory variables, giving substance to the theory that consumers do not react once and for all after a price or income change.

A very important result, which is also borne out by the other less acceptable attempts not actually shown here, is that the own price elasticities of the household demand for electricity and petroleum products are significantly smaller than one. This implies that a one per cent increase in the price of these two energy carriers will lead to a considerably less than one per cent decrease in the demand for the carrier. As this property is also displayed by the estimations not shown here it may be regarded as quite reliable.

It will be noted that we have no income variable in the equations. It is very difficult to obtain figures which are reliable over the whole estimation period. We were compelled, therefore, to find approximations for personal disposable income. It appeared that total population has about the same variability as disposable income. N_t must thus be regarded as a substitute for income. Once again, the regression results are in accordance with basic theory, income having a positive influence on demand, but we note again the low value of the elasticity.

One would observe that there are no price variables other than the own price, P_{ot} in the demand function for petroleum products. This does not come as a surprise, because motor fuel comprises most of this item and there is no real direct substitute for it.

4.4.2 The Industrial Sector

Electricity

$$\ln E_t = -0.23 - 0.06 \ln P_{Et} + 0.39 \ln P_{St} + 0.84 \ln E_{t-1}$$

(0.15) (0.17) (0.18) (0.05)

$R^2 = 0.9931$

D.W. = 2.64

Period of fit: 1934-1972

E_t = quantity of electricity demanded by Industrial Sector

P_{Et} = price of electricity paid by Industrial Sector

P_{St} = price of coal paid by Industrial Sector

P_{Ot} = price of petroleum products paid by Industrial Sector

Coal

$$\ln S_t = 0.42 - 0.45 \ln P_{St} + 0.75 \ln P_{Ot} + 0.21 \ln NBBP_t$$

(0.23) (0.59) (0.22) (0.20)

$$+ 0.52\ln S_{t-1} + 0.45\ln P_{St-1}$$
$$(0.11) \qquad (0.54)$$

$R^2 = 0.9651$

D.W. = 1.98

Period of fit: 1935-1972

S_t = quantity of coal demanded by Industrial Sector

P_{St} = price of coal paid by Industrial Sector

P_{Ot} = price of petroleum paid by Industrial Sector

NBBP = Industrial sector's contribution to GNP

Petroleum

$$\ln O_t = -0.19 - 0.24\ln P_{Ot} + 0.28\ln NBBP_t + 0.83\ln O_{t-1}$$
$$(0.16) \; (0.12) \qquad (0.13) \qquad (0.09)$$

$R^2 = 0.9893$

D.W. = 1.64

Period of fit: 1934-1972

As was the case with households, one notes once again the low value of the own price elasticities, while the functions turn out to be in accordance with basic demand theory.

4.4.3 Transport Sector

Electricity

$$\ln E_t = -0.46 - 0.28\ln P_{Et} + 0.35\ln P_{St} + 0.26\mathrm{lb}\,Spton + 0.68\ln E_{t-1}$$
$$(0.37) \; (0.18) \qquad (0.19) \qquad (0.16) \qquad (0.10)$$

$R^2 = 0.9895$

D.W. = 1.82

Period of fit: 1935-1972

E_t = quantity of electricity demanded by Transport Sector

P_{Et} = price of electricity paid by Transport Sector

P_{St} = price of coal paid by Transport Sector

Spton = railway tonnage

Railway tonnage is taken as a measure of the production level in the transport sector.

Coal

$$\ln S_t = \underset{(0.20)}{0.11} + \underset{(0.15)}{0.22}\ln P_{Et} + \underset{(0.10)}{0.06}\ln \text{Spton} - \underset{(10.18)}{0.27}\ln P_{St} + \underset{(0.07)}{0.94}\ln S_{t-1}$$

$R^2 = 0.9414$

D.W. = 2.12

Period of fit: 1935-1972

S_t = quantity of coal demanded by Transport Sector

P_{Et} = price of electricity paid by Transport Sector

P_{St} = price of coal paid by Transport Sector

Spton = railway tonnage

4.5 The use of the present model

The fact that all the demand functions are linear in the logarithms permits us to read the elasticities of demand with respect to the various prices, income and production directly as the price coefficients in the logarithmic form. It was noted above that the price elasticities are invariably smaller than one, suggesting a highly price-inelastic energy demand structure. Yet the own price effects are always negative, so that an increase in the price must lead to a decrease in the demand, however small it may be.

If we take the demand functions for the Industrial Sector, we can clearly observe the substitution effects among the various carriers.

$$\ln E_t = -0.23 - 0.06\ln P_{Et} + 0.39\ln P_{St} + 0.84\ln E_{t-1}$$

$$\ln S_t = 0.42 - 0.45\ln P_{St} + 0.75\ln P_{Ot} + 0.21\ln NBBP_t$$
$$+ 0.52\ln S_{t-1} + 0.45\ln P_{St-1}$$

$$\ln O_t = -0.19 - 0.24\ln P_{ot} + 0.28\ln NBBP_t + 0.83\ln O_{t-1}$$

Should the price of petroleum increase one will get a decrease in the amount of petroleum demanded and an increase in the amount of coal demanded, indicating a substitution of coal for petroleum as an energy carrier. When the price of coal rises one gets a decrease in the demand for coal and an increase in the demand for electricity, leading to a substitution of electricity for coal.

It is interesting to note that an increase in the price of electricity will lead to a very small decrease in the demand for electricity (the price elasticity of electricity is a meagre 0,06), while no increase in the demand for coal or petroleum takes place. This is the case because P_{Et} does not figure in any of the other two demand functions. As a matter of fact, none of the various regressions which were investigated showed up with the effect of E_t being significantly different from zero. A possible explanation may be that once a firm uses electricity it is reluctant to switch back to more primitive forms of energy carriers. For this reason an increase in the electricity price does not lead to an increased demand for coal or petroleum and it leads to a very small decrease in the amount of electricity demanded. It is most probable that the firm uses its electricity more effectively rather than switching to other energy carriers when the price rises.

The coefficients of the income and production variables or their approximations are invariably positive, implying that the demand for all types of of energy carriers increases as the world progresses on its time path with income, population and production steadily increasing.

Although the structure of the model within which the demand functions for the various energy carriers were estimated is at this stage quite simple, we achieved reasonable success in forecasting exercises. If one obtains predictions about prices, income and production from elsewhere, long-term EDP projections for instance, one may use them period for period, together with the last period's predicted value with respect to the dependent variable, to predict the demand for each future period. One may also repeat the exercise, varying prices and income in order to study the effect of all possible future levels of these variables on the demand for each energy carrier. The formula to be used is simply

$$\ln Q^f = \ln A + a_1 \ln P_1 + a_2 \ln P_2 + b_1 \ln X + b_2 \ln Q^f_{-1},$$

where the superscript f denotes a predicted value.

Such an exercise was carried out ex post in the case of households for the period 1934-1972. The actual observed values of the exogenous values, namely prices, income and production in each year, were used as inputs together with the previous period's predicted value for demand.

The predicted values of the dependent variable, namely quantity demanded, were then compared with the actual observed values in order to assess the accuracy of the model's predictive performance. Although the prediction error accumulates rapidly in such an ex post prediction 1) the forecast values follow the general fluctuating pattern, especially during the early years. (See Figure 1 and Table 1.)

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1) Klein, L R, A Textbook of Econometrics, Prentice-Hall, Englewood Cliffs, N J, p. 278.

TABLE 1: HOUSEHOLDS

Years	$O_t = 2.36 + 0.71\ O_{t-1} - 0.23\ P_{Ot} + 0.83\ N_t$	Observed values	Prediction error: $\sqrt{\frac{1}{T}\sum_{i=1}^{T}(x_i-y_i)^2}$ x_i = estimated value y_i = actual value
1934	424,00	424,00	0,0
1935	461,85	475,00	13,150
1936	492,63	546,00	38,867
1937	538,76	627,00	60,021
1938	587,74	664,00	64,465
1939	634,34	714,00	67,777
1940	680,04	703,00	62,578
1941	680,16	721,00	59,957
1942	670,41	728,00	59,666
1943	658,66	667,00	56,323
1944	658,83	664,00	53,457
1945	666,25	670,00	50,982
1946	735,56	722,00	48,968
1947	821,46	825,00	47,058
1948	894,97	964,00	48,955
1949	962,93	1 052,00	52,590
1950	994,70	1 095,00	56,759
1951	1 020,64	1 142,00	62,438
1952	1 046,69	1 181,00	68,440
1953	1 082,51	1 251,00	77,018
1954	1 122,11	1 302,00	85,165
1955	1 181,27	1 382,00	93,949
1956	1 183,42	1 465,00	109,678
1957	1 270,39	1 597,00	127,060
1958	1 356,28	1 739,00	146,883
1959	1 429,30	1 849,00	166,606
1960	1 536,92	2 027,00	189,546
1961	1 650,98	1 846,00	189,751

TABLE 1: HOUSEHOLDS (CONTINUED)

Years	$O_t = 2.36 + 0.71\ O_{t-1} - 0.23\ P_{Ot} + 0.83\ N_t$	Observed values	Prediction error: $\sqrt{\frac{1}{T}\sum_{i=1}^{T}(x_i-y_i)^2}$ x_i = estimated value y_i = actual value
1962	1 766,58	1 938,00	189,127
1963	1 899,87	2 195,00	193,750
1964	2 045,33	2 370,00	199,503
1965	2 205,01	2 558,00	206,245
1966	2 376,40	2 777,00	214,995
1967	2 541,70	2 910,00	221,207
1968	2 724,19	3 029,00	224,112
1969	2 927,22	3 247,00	227,404
1970	3 192,99	3 529,00	231,111
1971	3 375,63	3 776,00	237,279
1972	3 533,81	3 808,00	238,323
1973	3 677,42	3 977,00	240,089

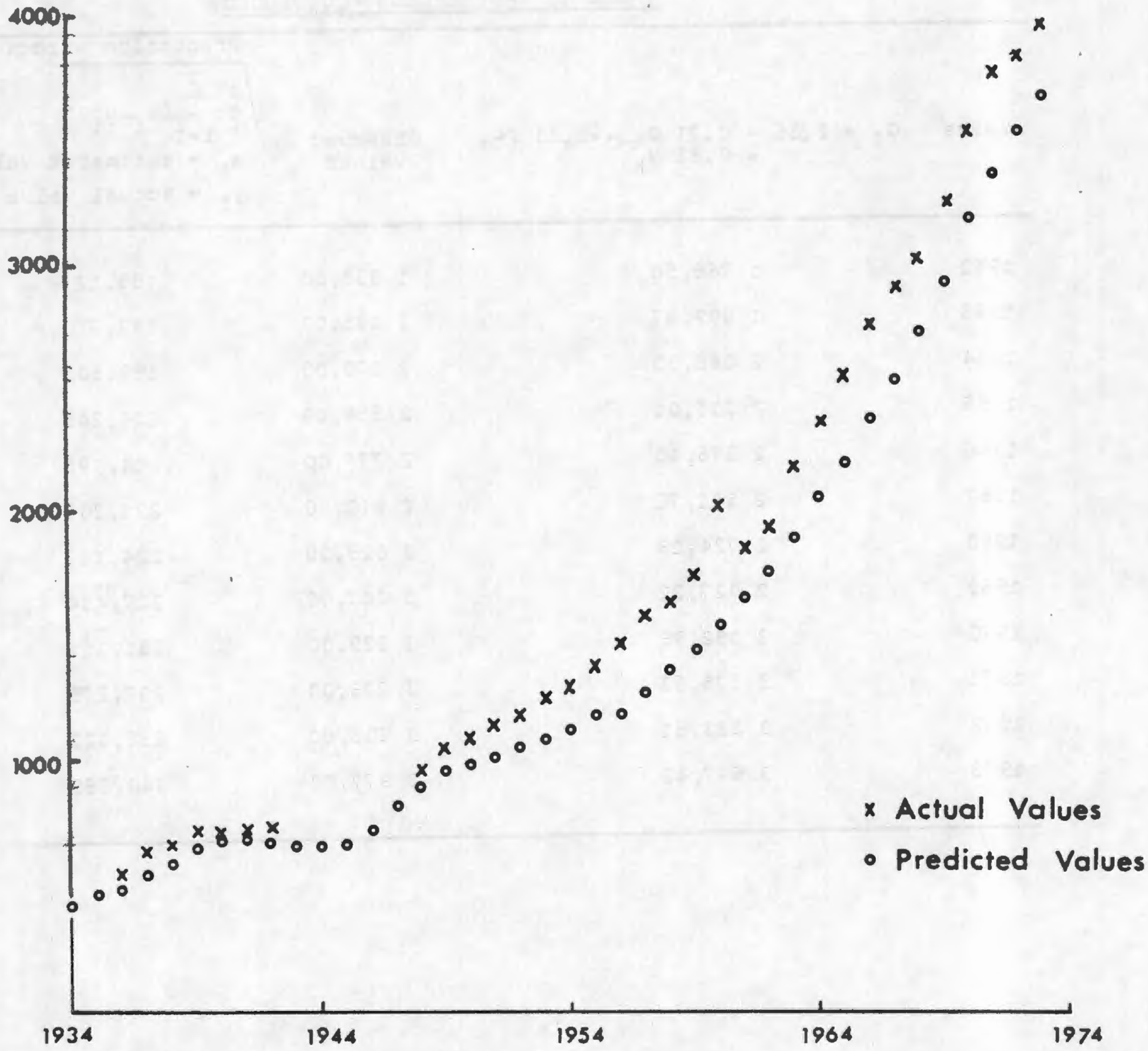

FIGURE 1 Actual and Predicted Values of Energy Demand

ANNEX 5

Price and income elasticities of electricity demand in South Africa

Source: South African Journal of Science, vol 82, June 1986

Price and income elasticities of electricity demand in South Africa

Anastassios Pouris

Energy elasticities, although important for policy formulation and forecasting, have not been examined in a South African context. In this paper a model of electricity demand is developed which indicates that the demand is price elastic and is only marginally affected by changes in economic activity. These findings suggest that forecasting models currently used tend to overestimate the long-term demand for electricity and that price is a useful tool for energy policy implementation.

IDENTIFYING the factors affecting the demand for electricity and quantifying their effects are important for energy forecasting and policy. Accurate forecasts can prevent scarce capital from being invested in idle capacity, or conversely electricity 'blackouts' to interrupt the country's economic activity. In addition, the identified factors can be evaluated and used as instruments for the implementation of energy policy (e.g. in regard to conservation, exploitation of indigenous resources, etc.).

Price has been recognised in the energy literature as one of the most important factors affecting the demand for electricity.[1-3] In South Africa, however, electricity forecasts are usually based on some form of trend extrapolation, or on a functional relationship between the demand for energy and the level of economic activity.[4-6] Both approaches neglect the impact of price on the demand for electricity and have been criticized in a recent survey[7] as being inadequate and inappropriate for 'energy planning, policy making activities and forecasting in a fast-changing environment'. An isolated attempt to investigate the effects of price on the demand for electricity in South Africa[8] assumed *a priori* a geometrically declining influence of price on the demanded quantity (Koyck's formulation), neglected the long-term price elasticity of demand and, on the basis of the short-term, statistically insignificant elasticity, concluded that an increase in the price of electricity leads to a meagre decrease in the demand.

In this article an econometric model of the demand for electricity is developed incorporating the long-term effects of price on the demand. An additional novelty is that no restrictive assumptions are made about the form of the influence that price has on the demand. The model indicates that the demand for electricity in South Africa is price elastic and that changes in the economic activity affect only marginally the demand for electricity. Important implications for electricity pricing policy, energy conservation and improvements of the forecasting models currently used stem from these findings.

The model

The assumption made for the development of the model is that the demand for electricity is a function of current economic activity and current and past electricity prices only. Persistently low or high electricity prices should have a strong influence on the demand in the long run. Higher electricity prices would, in general, induce consumers to switch to more efficient equipment, set into motion electricity saving technological progress, and possibly lead to substitution of electricity for other factors of production (labour, capital, etc.). The explicit incorporation of other factors such as habits, preferences, climatic conditions and competitive pricing of other fuels, which may have an impact on electricity sales, may be neglected in an econometric analysis of electricity demand as a result of the special conditions prevailing in South Africa.* For example, variation in temperature may affect the demand for electricity exhibited by the residential sector. Residential consumption, however, is only a small portion of the total demand. Similarly, any variation in the price of coal, the most important primary fuel in South Africa, would be reflected at least partially in the price of electricity. Most of the electricity in South Africa is generated by coal-fired power stations, and legislation determines that Escom should provide electricity at the lowest possible cost and operate, as far as practicable, at neither profit nor loss (Electricity Act 1922).

In line with this set of assumptions, the following function has been tested empirically:

$$E_t = f(Q_t, P_t, P_{t-1}, \ldots, P_{t-n}, e_t) \quad (1)$$

where E_t is the electricity sold in year t; Q_t is the gross domestic product in year t deflated to 1975 prices; P_t is the average electricity price in year t deflated by the consumer price index (base 1975); and e_t is an error term.

The estimated version of Equation (1) has been structured in a percentage change form. Under such formulation the constant term should capture any existing autonomous growth parameter. In addition, the transformation of variables into percentage changes rather than levels also ensures that the expected multicollinearity† and serial correlation among the independent variables are lessened and the resulting elasticities are more robust.

A general distributed lag formulation of the type:

$$E_t = \sum_{i=0}^{n} a_i P_{t-i} + Q_t + U_t \quad (2)$$

has been adopted and no restriction has been imposed on the impact of lagged prices. This formulation has the disadvantage of reducing the number of observations because of the presence of lagged variables. However, it does not violate any of the assumptions of the regression model and it is not restrictive to predetermine the impact of past prices, as the usual incorporation of Koyck's transformation in the model does. The Koyck lag formulation is one of the most popular approaches[9-12] in the estimation of elasticities, as it results in the loss of only one joint observation and it reduces the number of parameters to be estimated. However, it creates serious estimation problems (bias, consistency, etc.) and, more importantly, it assumes that the impact of past prices declines successively in a geometric way. Undoubtedly that is not the case with the adjustment in energy consumption. While, in the short run, a change in the price of electricity could affect the use of electrical appliances, the bulk of adjustment will take place sometime in the future, depending on the time required for new, more efficient machinery to be de-

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* Operational considerations such as the limited number of reliable observations, available degrees of freedom and multicollinearity among the independent variables, limit the number of explanatory variables that can be included in a regression.

† Multicollinearity is a term used in econometrics to denote the linear relationships among independent variables in linear regressions. When multicollinearity is present, the precision of estimation falls so that it becomes difficult to disentangle the relative influence of the various independent variables. In general, however, multicollinearity will conceal the presence of only the less strong effects. The use of lagged time-series prices inevitably leads to multicollinearity, as the same time series with the change of only two data (the first and the last) is used many times.

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veloped, the age profile of the electricity using durable goods, and the growth in the demand for electrical equipment.[‡]

The number of lagged prices contained in the regression was kept generous in order to capture any long-term effects. Fourteen annual lagged prices and a contemporaneous one were included in the regression. However, the number of lags was restricted *ad hoc* to 14, in order to conserve adequate data for the regression. The inclusion of 15 prices inevitably causes multicollinearity despite the appropriate transformation of the variables. To overcome this problem, the number of lagged prices was reduced in a stepwise manner after enforcing the variable denoting the changes in economic activity[*] in the regression.

The stepwise regression procedure, outlined by Draper,[14] is a standard technique embodied in all BMDP statistical software. The procedure is valuable for selecting the minimum number of variables necessary to predict a dependent variable when other predictors can be ignored. The important property of the stepwise regression is that each predictor gets credit for some variance, which several subsequent variables might be able to predict, plus any variance which only this particular variable can predict. Additional explanatory variables are added until their ability to 'predict' or 'explain' additional variance in the dependent variable is exhausted.

In estimating elasticities the procedure will give reliable estimates of the size of the total variance that can be explained by the total lag structure. However, attention should be paid to the fact that the size of the coefficients of the individual lags is only indicative, as variance that could be explained by other excluded variables is incorporated in the coefficients of the lags that are finally included in the regression. All variables in the model were estimated in natural logarithms and hence differences in logarithms represent rates of change in absolute values. As all variables were expressed in logarithms, the coefficients represent elasticities.[14] The estimated version of Equation (1) has been applied to data covering the period 1950-1983.[†] The results were as follows:

$$\begin{aligned} & E_t - E_{t-1} \\ &= 0{,}075 + \underset{(1{,}49)}{0{,}178}\,(Q_t - Q_{t-1}) \\ &\quad - \underset{(-2{,}55)}{0{,}097}\,(P_t - P_{t-1}) \\ &\quad - \underset{(-3{,}59)}{0{,}125}\,(P_{t-3} - P_{t-4}) \\ &\quad - \underset{(-7{,}19)}{0{,}304}\,(P_{t-6} - P_{t-7}) \\ &\quad - \underset{(-4{,}12)}{0{,}484}\,(P_{t-9} - P_{t-10}). \end{aligned} \tag{3}$$

$R^2 = 0{,}89$; F-ratio $= 21{,}52$; standard error of estimate $= 0{,}0099$; serial correlation of residuals $= -0{,}14$; degrees of freedom $= [5;13]$; t-ratios in parenthesis.

These results indicate that the price of electricity can explain up to 89% of the changes in electricity demand with a first year impact (i.e. short-run price elasticity) of −0,097 and a long-term (14 years) price elasticity of −1,01 (sum of price coefficients). The high ratios, quoted in parenthesis, also indicate high statistical reliability. In other words, it can be said with confidence that a doubling in the real price of electricity would reduce in half the demand for electricity assuming all other factors being equal or constant.

The estimated short-term income elasticity is found to be 0,178.[§] This figure represents the short-term impact and can be interpreted as representing the effects of capacity utilization on the demand for electricity. The constant term has a value of 0,075, implying that the demand for electricity exhibits an autonomous growth of 7,5% per year. The nature and character of this autonomous growth are not conspicuous. It can be argued, however, that, at least partially, this growth stems out of the enlarged market share of the Electricity Supply Commission (approximately 1% per year during the period under examination) and the enlarged share of electricity in total energy usage (approximately 3% per year during the period under examination). Other factors such as displacement of other forms of energy by electricity, other forms of production, etc. can also be considered as contributing to the size of the autonomous growth.

Conclusions

Price and income elasticities of electricity demand, although important for energy forecasting and energy policy implementation, have not been examined in a South African context. In this article an effort was made to estimate the impact of price and income changes on the demand for electricity, placing emphasis on the long-term effects of price changes. Analysis revealed a long-run price elasticity of demand of −1,01, a short-run price elasticity of −0,097, a short-run income elasticity of 0,178 and an autonomous growth of the demand for electricity of 7,5% per year.

Important policy implications stem from these results. First, price appears to have a sizeable impact on the demand for electricity. Price can, therefore, be used as a policy instrument for the manipulation of demand and promotion of conservation. The current policy of determining the price of electricity according to its production cost removes a powerful instrument from the hands of policy-makers. In addition, although the current pricing system constrains the monopolist producer to make abnormal profits openly, it does not support the consumers' interests. The monopolist can always represent profits as costs. Moreover, the lack of the profit incentive undermines competition and, in combination with the legislatively imposed monopolistic market structure, impairs productivity, innovativeness and efficiency. The myth that electricity generation is a natural monopoly is increasingly being challenged abroad,[15] so it should be recognised that only additional competition in the generation stage could result in downward pressure on rates; price should be used as a policy instrument.

Longer-term forecasts and planning should also take into account the detected impact of price changes on the demand for electricity. With increasing electricity prices, the omission of price from the set of determinant variables in forecasting will cause the overestimation of the long-term demand. As a result scarce capital would be invested in idle capacity with adverse repercussions for the price of electricity, Escom's financial position, the national balance of payments and the country's economic growth. Forecasts which exclude price effects can only be useful under the restrictive assumption of a stable or slowly changing environment.

A caveat should be mentioned here. Long-run energy price adjustments appear to be ten times greater than adjustments occurring over the immediate period after the price change. In other words, conservation motivated by price rises can continue to increase for many years after prices stop rising. Therefore, utilities opting for equilibrium in the short term will find themselves

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[‡] An analysis and model of the way that improvements are diffused in a system is provided in ref. 13.

[*] BMDP statistical software, converted for use on Sperry 1100 series computers by the University of Utah Computer Center, has been used.

[†] The data sources are as follows: Annual GDP figures deflated in 1975 prices are obtained from various issues of *International Financial Statistics*, published by the International Monetary Fund. Electricity sold by Escom in MWh and the annual average price of electricity in South Africa are obtained from Escom Annual Reports. The average price of electricity was deflated to 1975 values using the consumer price index as given by the Department of Statistics, Pretoria.

[§] It is possible that multicollinearity distorts the size of the income coefficient. However, in the first step of the regression when only the changes in the GDP were regressed on the changes of electricity sold, the coefficient received a value of 0,52. As new independent variables were introduced in the regression, the coefficient was gradually reduced to 0,178. The income elasticity of demand for electricity in any case remains well below unity.

with an overcapacity in the future, while utilities opting for long-run equilibrium can face capacity shortages in the short term. A policy accommodating both short-term requirements is required.

Another important finding is that the electricity demand exhibits an autonomous growth of 7,5% per year, if price and GDP remain constant. It is important to identify the factors determining this growth. It is suggested that, at least partially, this growth stems out of the enlargement of Escom's market and the greater share of electricity in total energy consumption. However, as Escom has no competitors and the share of electricity in the total energy usage approaches saturation levels, the autonomous growth will be curtailed in the future.

It should be emphasised that socio-economic studies do not possess the robustness of science. Past behaviour is not always a good guide for the future. However, high long-term price impact represents the current international 'paradigm', the favoured scientific belief. Forecasters, researchers and energy policy authorities should take into account and consider the usefulness of pricing as a policy instrument.

1. Taylor L.D. (1975). The demand for electricity: a survey. *Bell J. Econ.* 6, 74 – 110.
2. Pindyck R. (1979). The characteristics of energy demand. In *Energy Conservation and Public Policy*, edit. J. Sawhill. Prentice Hall, Englewood Cliffs.
3. Bohi D.R. (1981). *Analysing Demand Behaviour – A Study of Energy Elasticities*. Johns Hopkins University Press, Baltimore.
4. Kotze D.J. (1970). *Analysis of the South African energy economy with special reference to its forecasting*. PhD thesis, University of Cape Town.
5. Norman H.B. (1977). Electricity supply for the next half century. *Trans. S. Afr. Inst. Elec. Engr.*, 110 – 125.
6. Norman H.B. (1977). Future electricity demand and supply. *RSA 2000* 4(1), 32-44.
7. Pouris A. (1986). Demand for electricity in South Africa – survey. *S. Afr. Mech. Engr.* 36, 14 – 20.
8. De Wet G.L. and Chown I. (1977). The use of econometrics as an aid in the forecasting of energy demand. In *The Outlook for Energy in South Africa*. Department of Planning and the Environment, Pretoria.
9. Department of Energy (1977). *Report of the Working Group on Energy Elasticities*. Energy Paper no. 17, HMSO, London.
10. Mount T.D., Chapman L.D. and Tyrrell J.J. (1973). Electricity Demand in the United States – An Econometric Analysis. Oak Ridge National Laboratory, Tenn.
11. Kouris G. (1981). Elasticities – science or fiction. *Energy Economics* 3(2).
12. Kouris G. (1983). Fuel consumption for road transport in the USA. *Energy Economics* 5(2).
13. Pouris A. (1985). Forecasting system thermal efficiencies in technology importing countries. *Technological Forecasting and Social Change* 28(4).
14. Draper N.R. and Smith H. (1966). *Applied Regression Analysis*. John Wiley, New York.
15. Sant R.W., Bakke D.W. and Naill R.F. (1984). *Creating Abundance: America's Least-Cost Energy Strategy*. McGraw-Hill, New York.

New developments in the control of eutrophication

D.C. Grobler and D.F. Toerien

Excessive enrichment of water bodies with plant nutrients, such as phosphorus and nitrogen, has undesirable effects on the structure and functioning of freshwater ecosystems and results in serious water quality problems for potable and recreational use. Phosphorus is usually the growth-limiting plant nutrient in fresh water, and because it is the easiest to control, legislation was introduced in 1980 to limit the orthophosphate concentration in effluents discharged to seven sensitive catchments to 1 mg per litre. Local authorities and industries in the catchments were given five years (that is, until August 1985) to comply with the standard.

The uniform phosphorus standard has been criticized[1] on the grounds that the capacity of certain water bodies to absorb increased phosphorus loads without experiencing a deterioration in water quality is ignored, with the result that the standard may in some cases be enforced where it is not required, whereas in other cases it may not be stringent enough to prevent excessive eutrophication. The Directorate of Water Pollution Control, realizing this, is prepared to issue permits for phosphorus concentrations in effluents to exceed the standard in cases where it can be shown that enforcement will have little or no effect on the quality of the receiving waters. However, the Directorate is also considering the introduction of additional phosphorus control measures in catchments where the 1 mg P/l standard is likely to be insufficient to protect water quality.

The Water Research Commission (WRC) funded an initial assessment, carried out jointly by the Institute of Environmental Sciences of the University of the Orange Free State and the Hydrological Research Institute of the Department of Water Affairs, of the impact the phosphorus standard is expected to have on the trophic status of 19 reservoirs in sensitive catchments. A modification of a simple steady-state eutrophication model, which was developed for water bodies in North America and Europe, was used for the initial assessment. A report entitled *Impact of Eutrophication Control Measures on the Trophic Status of South African Impoundments*, which is available from the WRC, concluded that responses to the introduction of the phosphorus standard can be expected to range from insignificant to significant. For example, in some cases the contribution of the point sources (controlled by the standard) to the total phosphorus load is negligible compared with the contribution of non-point sources. In others the reservoirs are already so overloaded with phosphorus from point sources that introduction of the standard will be insufficient to cause a notable response.

There is some uncertainty associated with these predictions, partly because the effects of the highly variable hydrology characteristic of semi-arid regions were ignored in the steady-state modelling approach adopted in the assessment. Nevertheless, the Directorate of Water Pollution Control decided to postpone implementation of the phosphorus standard in those catchments where its impact was predicted to be small. This decision will result in large savings to local authorities and industries and should be welcomed in the present restricted economic climate. An exception was made in the case of the Vaal Dam catchment, where the standard will be enforced, despite predictions that it will have little effect on the water quality of the impoundment, South Africa's most important water resource. This was done to avoid any risk of deterioration in its water quality.

The next phase of the research, also funded by the WRC and carried out jointly by the CSIR's National Institute for Water Research (NIWR) and the Hydrological Research Institute, is directed at refinement of the eutrophication modelling approach. A Reservoir Eutrophication Model (REM model), which avoids the steady-state assumptions and accommodates the effects of hydrological variability on the trophic response of reservoirs, has been developed. The REM model consists of sub-models for simulating phosphorus export contributed by point and non-point sources and runoff from catchments, the fate of phosphorus in reservoirs and their trophic status. The model is now being implemented on a microcomputer and will in future be used for predicting the effects of phosphorus control measures on the trophic status of South African reservoirs.

The NIWR is also carrying out research on Hartbeespoort Dam which emphasises the functioning of the reservoir as an ecosystem and has led to the development of an ecological model of the reservoir. It is hoped that the REM and ecosystem models will prove to be valuable tools for water resources managers faced with the challenge of protecting and improving the quality of our water resources at the lowest economic, social and environmental costs.

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1. Pretorius W.A. (1983). Should the phosphate concentration in sewage effluents by restricted? *IMIESA* 8, 23-29.

ANNEX 6

The price elasticity of electricity demand in South Africa

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THE PRICE ELASTICITY OF ELECTRICITY DEMAND IN SOUTH AFRICA

INTRODUCTION

The term price elasticity of demand is coined by Alfred Marshall (1885, 1890), and refers to the percentage change in quantity demanded divided by the percentage change in price. It is a convenient way of summarising how changes in price or quantity consumed affect each other and it is valuable in a wide variety of applications involving forecasting and pricing decisions. For example, an estimate of the price elasticity of demand would make apparent the effectiveness of an excise tax in reducing gasoline consumption or the necessity to include price as an explanatory variable in a forecasting model.

In the energy field a variety of studies have been published providing estimates of energy elasticities. Bohi (1981, 1984), reviewing more than 80 studies, concluded that energy elasticities in general and electricity elasticities in particular, are different than zero.

In South Africa, electricity forecasts are based on some form of trend extrapolation or on a functional relationship between the demand for electricity and the level of economic activity (Kotze et al 1985, Norman 1977). Such approaches neglect the impact of price on the demand for electricity and as it was argued in the previous chapter are inappropriate for energy planning, policy making activities and forecasting in a fast changing environment.

In this chapter, the long run effect of price on the demand for electricity in South Africa is estimated, and the forecasting and policy consequences are outlined. First the modelling approach and the model specification are discussed. Then the results are presented and the chapter ends with concluding remarks and policy implications.

MODELLING APPROACH

An unconstrained distributed lag model is adopted for the estimation of the effects of price changes on the demand for electricity. In such a model, the independent variable or variables are lagged consecutively up to some preselected number of periods, eg ($Y_t = b + a_0X_t + a_1X_{t-1} + ... + a_nX_{t-n}$) and the coefficients are estimated without restrictions. This model was one of the first distributed lag models to be estimated econometrically. Subsequently, it lost favour because each lagged term uses up a degree of freedom and therefore larger samples are required for reliable estimates. The model came in favour again with Granger's and Sims' (Granger 1969, Sims 1972) works on causality. They suggested that causality between two variables X and Y can be tested by examining the statistical significance of the group of coefficients of the unconstrained distributed models which incorporate lags of either the independent and/or the dependent variables. A variety of causal relationships have been examined with this method and been reported in the literature. Some of the relationships investigated include the relationships between money and prices (Sargent et al 1973), wages and prices (Mehra 1977), wholesale and consumer prices (Silver et al 1980), exports and growth (Jung et al 1985), etc. This modelling approach therefore provides the first step for a test of one way causality of the effects of price changes on the demand for electricity.

The unconstrained distributed lag model is conceptually preferable to the simple contemporaneous correlation based models that are usually employed to investigate the electricity price-demand relationship. While electricity consumers may adjust the rate of utilization of their electricity using equipment immediately after a change in the price of electricity, (eg. switch off the lights) the bulk of the adjustment will take place sometime in the future depending on the rate of rotation of the capital stock, the success of the price induced innovative activity, the consumers′ habits and expectations etc. Contemporaneous correlations ignore such lagged adjustments and consequently provide limited information. The model is also preferable to models using Koyck′s (1954) transformation, as it does not require the strong assumption of geometrically declining price impact on the demand neither the largest response to occur in the first period. The Koyck-lag mechanism has gained popularity in electricity demand literature (mainly due to its simplicity) despite its restrictiveness (Grilicher 1967). Among the serious restrictions and shortcomings imposed by Koyck′s transformation are: the assumption of identical adjustment elasticities of the independent variables in the model, the introduction of serial correlation in the residuals even if they are independently distributed in their original form and the introduction of bias due to the presence of the lagged dependent variable. Most importantly, researchers (Coghlan 1978, Boughton 1981) have found Koyck′s lag mechanism to be partly responsible for the conclusion reached in several studies that the money demand function is structurally unstable. Transferring this finding to the research on electricity demand functions, which also have been criticized as unstable (Dept of Energy 1977, Sutherland 1983), we can infer that Koyck's transformation may be a source of instability in the electricity demand functions as well.

The disadvantages of the unconstrained model are that it requires the estimation of many coefficients, its definition of causality (when it is used as a causality test) is not equivalent to many philosophical notions of causation, and the length of the lag has to be balanced against the number of control variables that are required to be included in the model. If a long lag length is incorporated in the model, the number of control variables is usually restricted in order to conserve degrees of freedom.

As far as the degree of aggregation is concerned, the national level of aggregation is adopted. Such an aggregation would capture the full effect of a change in electricity price on the demand for it. A sectorial aggregation usually hides the more esoteric interactions taking place among different sectors of the economy (Sweeney 1984). Increasing electricity prices can increase the relative price of commodities embodying higher than average electric energy intensity and motivate substitution away from these commodities, thereby reducing electricity demand in the economy. If, however, the substituted and substituting commodities belong to different sectors and are modelled separately, the price induced impact will not be defected as such. An example is the substitution between transportation and telecommunication services. As electricity prices rise, transportation costs may rise relative to telecommunication costs, firms may substitute telecommunication for transportation and overall electricity demand in the economy decreases. If transport and telecommunication are modelled separately, the price effect through the structural change will not be detected. This interaction implies that the sum of the weighted elasticities, of all individual industries or sectors, would be smaller that the elasticity of the entire economy and therefore sectorial analyses will give elasticities for the total economy which are biased downwards (Taylor 1977).

In addition it can be argued that the higher level of aggregation could provide more stable relationships. Ehrenberg (1975) has argued that the advances of physical sciences are to a great extent due to the fact that simple relationships (laws) are attainable because they typically describe the aggregate behaviour of many million entities. This suggests that success in finding laws in the social sciences is most likely in the fields where the behaviour of a large number of objects is aggregated.

Within this framework, the following general model is formulated:

$$E_t = a + \sum_{0}^{n} b_i P_{t-i} + C_t V_t + U_t \qquad (2)$$

where E_t is the demand for electricity

P_t is the price of electricity in period t

V_t is a vector of other relevant predictors

U_t is the random error term

a, b_i, C_t are parameters

At this point a decision has to be made concerning the length of the lag (n) to be considered and the predictors to be included in the vector V_t. Inevitably, the decision has to be a compromise between the availability of data and econometric considerations.

Annual averages are the only readily available data on price and consumption of electricity in South Africa. Therefore annual time increments and average prices had to be used. In addition, the credibility of data deteriorates for the period prior to 1950. The Electricity Supply Commission (ESCOM) generated only 71% of the electricity consumed in the country during the year 1950 and the proportion was even lower in the preceding years. The rest of the electricity was produced by individual municipalities and different companies (eg mining companies) and data from these sources are not available. The time coverage, therefore, is restricted to the period 1950-1983 although longer time-series would have been desirable.

All variables were expressed in first differences in order to lessen serial correlation in the residuals. The existence of lags in the regression is expected to cause multicollinearity and therefore the F-statistic would have to be used to detect the significance of the group of coefficients. As the F-statistic is affected by serial correlation in the residuals, it is important that the assumption of serially uncorrelated residuals be accurate.

With these considerations, it was decided to use a lag of 12 years (n=12). A longer lag would be desirable as it has been suggested that the "rate of adjustment to the long-run levels of energy utilization is slow enough for the price changes to have an impact on energy demand for the next twenty years" (Landberg 1980). However, the need to conserve adequate degrees of freedom for the regression led to this decision.[1]

Concerning the explanatory variables to be included in the vector V_t, changes in the Gross Domestic Product, changes in weather conditions (temperatures) and changes in the price of fuels competing with electricity are the traditional variables incorporated in the models of electricity demand and were initially considered. The GDP is usually incorporated in this kind of analysis in order to account for the effects of varying economic activity, growth in population etc on the demand for electricity. Gross Domestic Product is preferred to Gross National Product as the former does not include the net factor of income originating in overseas enterprises and investments. Real GDP (deflated) is used in the analysis in order to account for real economic activity net of monetary considerations.

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[1] A statistical approach in the choice of the length of the lag to be considered, is to use the "Final Prediction Error" (FPE) criterion. The FPE criterion for a total of n lags on the independent and lagged dependent variable is defined as $FPE_{(n)} = [(T + n + 1) / (T - n - 1)]\ [SSR / T]$ where T is the number of observations and SSR is the sum of squared residuals. If $FPE_{(n+1)} > FPE_{(n)}$, then the n+1 lag is dropped from the model (H Akaike "Fitting Autoregressions for Prediction" Annals of the Institute of Statistical Mathematics pp 243-47, 1969).

However, this technique is also **ad hoc** in the sense that it is not supported by economic theory. There is also the possibility that the FPE criterion will prematurely terminate the selection process just because one lag is not important while subsequent lags are. In addition, if the FPE improves with the incorporation of very long lags the process would have again to be terminated in an **ad hoc** basis in order to conserve adequate degrees of freedom for the regression and estimation of SSR.

On the other hand, in demand analysis it is essential to specify the period of adjustment. "It is vain to search for the elasticity of demand" (H S Houthakker, "New Evidence on Demand" Econometrica 33(2), 1965). Therefore we can specify that the effort in this chapter is to estimate the 12-year elasticity of electricity demand.

Changes in temperatures are incorporated in studies examining the demand for electricity in order to account for seasonal variation in the demand, mainly for the heating of the residential sector. Variation in temperatures has less explanatory power in studies using annual data from countries with small residential sectors. Obviously there is a larger temperature variation between seasons than between years and industrial and mining electricity demand is less sensitive than residential demand on the variation of temperature. In addition, when aggregate data are used there is the possibility that variation in one sector of the economy is neutralised by opposite variation in other sectors. Lower temperatures, for example, could increase the demand for electricity in the residential sector (eg for heating) but could decrease the demand in the mining sector where electricity can be used to cool underground mining areas (Dept of Planning and the Environment, 1978). In South Africa the residential sector consumes only a small part of the total electricity consumed in the country. It has been reported that the residential and the agricultural sectors combined consume only 17% of the country's total electricity consumption (Venter et al 1986). In addition, the variation of the annual mean temperatures is negligible. The standard deviation of annual mean temperatures has been reported (Weather Bureau 1965), to be 0.76° F (over 100 years) and 0.88° F (over 56 years) for the Cape Town and Johannesburg areas respectively. The average temperatures over the same periods were 62.7°F and 60.2°F respectively. Presumably such a small variation in temperatures cannot explain adequately any part of the variation in the demand for electricity. On these grounds, temperature was dropped from the set of explanatory variables.

The prices of competing fuels are often incorporated in demand functions to account for the rational consumer who observes prices and substitutes one fuel for another. This process assumes that different fuels are substitutes and can easily replace each other. This theoretical conjecture, however, is not easily acceptable in the case of electricity and as Stone (1945) has argued, specific factors, peculiar to a given commodity in a given epoch, and social factors controlling changes in tastes and habits, are of paramount importance. Conjectures stemming from theoretical economics should not blindly be accepted. Doubts about the explanatory value of the price of competing fuels in electricity demand functions have also been cast by Bohi (1981), who, reviewing the relevant literature, concluded that "Cross price effects (of competing fuels) are found to be insignificant, and where significant, are typically small".

The reasons for the insignificant effect of changes in the price of competing with electricity fuels are as follows: Firstly, electricity has unique characteristics. It is the cleanest of all fuels for the end user, it is versatile, easily transferable, susceptible to fractional use, and offers precision of a kind that it is difficult or impossible for fossil fuel processes to match. These unique characteristics cast doubts about the ability of other fuels to replace electricity.

Secondly, rational consumers will observe not only the price of the fuel as such but will also take into account the expenditure to utilize this fuel. Thus the rate of substitution towards or against a fuel is constrained not only by the relative cost of different fuels but also by the relative cost of technologies utilizing different fuels and the availability of such technologies. Since the fuel cost is generally a relative low proportion of overall costs (Thomas et al 1982), marginal changes in the relative price of electricity are unlikely on their own to stimulate a change in production process. A solution would be to incorporate the relative costs of different technologies in the demand function. Unfortunately data availability precludes this solution.

Finally, a peculiarity particular to the South African energy system which weakens the importance of the prices of fuels competing with electricity, is the fact that the price of coal (the most important and the only indigenous primary fuel in South Africa) is in an indirect way legislatively linked with the price of electricity. Most of the electricity in South Africa is generated by coal-fired power stations (98% in 1983 according to ESCOM's Annual Report) and legislation determines that ESCOM should provide electricity at the lowest possible cost and operate as far as practicable at neither profit nor loss (Electricity Act 1922). As coal cost is approximately 25-30% of the final price of electricity, any variation in the price of coal would be reflected at least partially in the price of electricity. In order to verify this conjecture we estimated the correlation coefficient between the price of electricity and the price of coal over the period 1950-1983. The estimated correlation coefficient was found to be 0.989.

For the above reasons we decided not to use changes in the price of coal as explanatory variable. Instead, the consumer price Index is used as a general surrogate and the price of electricity is expressed in constant (deflated) Rands. The Consumer Price Index incorporates not only changes in the price of coal but also changes in the price of wages, capital, etc. Therefore the index would account for changes in the prices of different factors of production, different fuels and general level of living.

THE ELECTRICITY DEMAND MODEL AND THE EMPIRICAL RESULTS

Based upon the foregoing discussion, the estimated electricity demand function takes the following form:

$$E_t = a + \sum_{0}^{n} b_i \; P_{t-1} + C_t \; W_t + U_t \qquad (3)$$

where E_t denotes the change in the electricity sold from previous year in GWh

P_t denotes the change in the average price of electricity from the year t-1 to the year t in constant 1975 c/KWh;

W_t denotes change in the Gross Domestic Product in millions of constant 1975 Rands.

U_t is the random error term

a, b_i, C_t are parameters to be estimated

Data for the consumption of electricity (GWh sold by ESCOM) and the price of electricity (average price charged by ESCOM) for the period 1950-1983 were obtained from the "Annual Report of the Electricity Supply Commission 1983". The GDP in 1975 prices was obtained from various issues of the "International Financial Statistics" and the Consumer Price Index from various issues of the "South African Statistics". All data are listed in Appendix 1.

TABLE 1 Estimated Characteristics of the regression

$$E_t = a + \sum_{0}^{n} b_i P_{t-i} + C_t W_t + U_t$$

VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	t-STATISTIC
Intercept	3413.61	-	-
P_t	-59.83	3975.99	-0.01
P_{t-1}	1024.22	3846.67	0.26
P_{t-2}	9242.74	5270.94	1.75
P_{t-3}	-4840.07	5723.11	-0.84
P_{t-4}	12526.46	4779.87	2.62
P_{t-5}	-6569.94	4470.28	-1.47
P_{t-6}	-8353.31	8423.26	-0.99
P_{t-7}	22536.23	19749.85	1.14
P_{t-8}	-28092.70	24304.79	-1.15
P_{t-9}	6686.68	24399.06	0.27
P_{t-10}	-19636.93	12449.62	-1.57
P_{t-11}	-22271.68	13283.48	-1.67
P_{t-12}	-10700.66	10065.92	-1.06
W_t	0.71	0.69	1.03

Multiple R	0.9823
Multiple R^2	0.9650
F-ratio	11.82*
Serial Correlation of residuals	0.0038
Degrees of Freedom	[14,6]

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* F-ratio is statistically significant at the 0.01 level.

The results of the regression are listed in Table 1. A high coefficient of determination (R^2) and a high F-statistic indicate that the group of independent variables have significant explanatory power. The coefficient of determination indicates that 96.5% of the change in the dependent variable is explained by changes in the values of independent variables. The calculated F-statistic is 11.82 with 14 and 6 degrees of freedom and it is significant at the 0.01 level of significance. The serial correlation of residuals is 0.0038. The high F-statistic and the low serial correlation in the residuals indicate that the hypothesis that prices affect the demand for electricity should be accepted.

The large standard errors of the estimated coefficients in conjunction with the high values of R^2 and F-statistic indicate the presence of multicollinearity. This was expected as a variable is likely to be correlated with its lagged values. Multicollinearity precludes obtaining reliable estimates of the individual coefficients but interest here is in the sum of coefficients (long-run elasticity)[2]. As shown by Maddala (1977), the sum of the lagged coefficients is not highly sensitive to the length of lag selected, even though the individual coefficients are highly unstable. The total impact is given by the sum of all coefficients, $b_o + b_1 + b_2 + \ldots + b_k$. The long-run price elasticity can then be calculated by multiplying the price response by the ratio of the price to the quantity sold (Bohi et al 1984).

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[2] The long run price elasticity of demand has been estimated similarly by Griffin (1974) and Sutherland (1983).

The average electricity sold during the period under examination[3] was 52699 GWh and the average real price was 0.976 c/KWh. Therefore, using the response (-48506) derived by regression (3), the 12-year price elasticity of electricity in South Africa is estimated to be -0.90

THE DEMAND FOR ELECTRICITY IN THE YEAR 2000

To show the impact of the estimated elasticity, the demand for electricity for the year 2000 is estimated under two alternative assumptions. The first is that the real price of electricity remains unchanged as in the year 1983. The second assumption is that the price increases and becomes 30 % higher, that in 1983, and its full effect materializes by the year 2000.

The forecasting model has the form:

$$Q_t = a \, P^b_{t-12} \, W^c_t \, e^u \qquad (4)$$

or the equivalent:

$$\ln Q_t = \ln a + b \ln P_{t-12} + c \ln W_t + u \qquad (5)$$

where Q_t is the demand for electricity in period t

P_t is the average real price of electricity in period t

W_t is the real Gross Domestic Product in period t

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[3] The average electricity sold and the average real price, due to lagged formulation, correspond to 1963-1983 and 1950-1983 periods respectively.

b is the 12-year long-run price elasticity of demand

c is the income elasticity of demand

u is the error term

The GDP is assumed to have a constant growth of 5% per year in real terms and the previously estimated price elasticity of demand is used as an extraneous estimator.

The choice of a growth of 5% is made in order our forecasts to be comparable in this aspect with the assumptions of the studies reviewed in Chapter 1, and therefore the price effect could become immediately apparent.

The technique of extraneous estimators is used by economic statisticians in order to overcome the harmful effects of using highly collinear time series observations on regression and correlation estimates, and in order to obtain "structurally" more accurate estimates of income elasticities of demand (Kuh et al 1957).

When multicollinearity makes impossible to disentangle the relative influence of the various independent variables, the extraneous estimator technique suggests the use of prior knowledge of the size of some of the coefficients in order to estimate the rest of them[4]. In this case the extraneous information is the price elasticity of electricity demand. In order to utilize this prior information, the price elasticity of demand is multiplied by the time series of

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[4] While a variety of techniques use this concept, the rationale is fully explained in each of the following sources: (i) Durbin, 1953; (ii) Stone, 1954; and (iii) Wold et al 1953.

aggregate price and the product is subtracted from the time series of the annual quantity demanded to form a new dependent variable. The new dependent series is then regressed against the time series of the Gross Domestic Product to obtain an estimate of the income elasticity of demand.

Following Wold (1953) we use absolute series (not differences) and we did not remove any trend effect. Such formulation yields essentially long run estimates (Kuh et al 1957) and therefore the structure is commensurable with the structure yielding the extraneous estimator (long run).

The regression[5] gives a statistically significant estimate of the long-run income elasticity of demand of 1.64[6] with a multiple correlation coefficient of 0.92 and an F-ratio of 95.

With the estimated parameters of the model, the predicted demand for electricity for the year 2000 are 226 386 GWh and 178 732 GWh for unchanged (as in 1981) and increasing (30 percent higher than 1983) prices respectively. The effect of the price elasticity of demand is profound from these figures.

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[5] $$\ln Q_t - (-0.9) \ln P_{t-12} = -5.73 + \underset{(9.7)}{1.64} \ln W_t + U$$

where Q_t is the demand for electricity in period t
P_t is the average real price of electricity in period t
W_t is the real GDP in period t
t-statistic in parenthesis

[6] The magnitude of the income elasticity of electricity demand is comparable with the elasticities estimated by Houthakker & Taylor (1970) (1.9), Federal Energy Administration (1976) (1 to 1.63), and Lacy & Street (1975) (1.87), who also used time series analyses.

CONCLUDING REMARKS AND POLICY IMPLICATIONS

The purpose of this study has been to investigate the effects of price changes on the demand for electricity in South Africa, with emphasis on the long-run impact.

The long-run (12 years) own price elasticity of electricity demand is estimated to be -0.90. Taking into account the fact that more than 70% of the electricity in South Africa is consumed by the industrial and mining sectors, the estimated elasticity is in accordance with Bohi's (Bohi et al 1984) conclusion (from his extensive review), that the empirical evidence indicates that the long-run elasticity on industrial demand appears to fall somewhere between -0.5 and -1.0. Important implications for South African energy policy formulation and forecasting electricity demand stem out of this finding.

Firstly, price can be used as a policy instrument for the manipulation of demand and promotion of energy conservation. Determining the price of electricity according to its production cost (the current policy) removes a powerful instrument from the hands of policy makers. In addition it is doubtful whether the current policy serves the interests of the consumers. Enforcing the monopolistic utility to sell its product without profits, does not necessarily mean that the consumer pays the lowest possible price. The monopolist can present profits as costs and inevitably inefficiency builds in a system where costs are rewarded and profits through savings are not allowed.

A second implication of the non-zero price elasticity of electricity demand concerns the forecasting of, and planning for, the long-term demand. As discussed in Chapter 1, all electricity forecasting models used in South Africa, explicitly or implicitly, assume a zero price elasticity of electricity demand. Such models are deficient in fast changing environments. For example, with increasing electricity prices, the omission of price from the set of determinant variables will cause the overestimation of the long-term demand by the model. As a result scarce capital would be invested in idle capacity with adverse repercussions for the price of electricity, the utility's financial position and the country's balance of payments. In an environment of falling prices, demand will be underestimated, generating capacity will not be built and black-outs could constrain the country's economic activity and growth. Forecasts which exclude the price effects can only be useful under the restrictive assumption of a stable or slowly changing environment.

REFERENCES

Bohi D R (1981) Analysing Demand Behaviour - A Study of Energy Elasticities John Hopkins University Press for the Resources for the Future Inc, London

Bohi D R and Zimmerman M B (1984) "An Update on Econometric Studies of Energy Demand Behaviour" Annual Review on Energy 9, pp 105-54

Boughton J M (1981) "Recent Instability of the Demand for Money - An International Perspective" Southern Economic Journal 47, pp 579-97

Coghlan R T (1978) "A Transactions Demand for Money" Bank of England Quarterly Bulletin 18, pp 40-60

Department of Energy (1977) Report of the Working Group on Energy Elasticities Energy Paper 17, HMSO, London

Department of Planning and the Environment (1978) Energy Utilization in South Africa vol 3, p 25

Ehrenberg A S C (1975) Data Reduction: Analysing and Interpreting Statistical Data Wiley-Interscience, London

Durbin J (1953) "A Note on Regression When There is Extraneous Information About One of the Coefficients" Journal of the American Statistical Association XLVIII, pp 799-808

Federal Energy Administration (1976) "1976 National Energy Outlook" Washington DC

Granger C W J (1969) "Investigating Causal Relations by Econometric Models and Cross Spectral Methods" Econometrica 37, pp 424-38

Griffin J M (1974) "The Effects of Higher Prices on Electricity Consumption" Bell Journal of Economics and Management Science 5(2), pp515-539

Grilicher Z (1967) "Distributed Lags: A Survey" Econometrica 35, pp 16-49

Houthakker H S and Taylor L D (1970) Consumer Demand in the United States: Analyses and Projections Harvard University Press, Cambridge, Mass

Jung W S and Marshall P J (1985) "Exports, Growth and Causality in Developing Countries" Journal of Development Economics 18, pp 1-12

Kotze D J and Cooper C J (1985) Energy Projections for South Africa Institute for Energy Studies, Rand Afrikaans University, RSA

Koyck L M (1954) Distributed Lags and Investment Analysis, North-Holland, Amsterdam

Kuh E and Meyer J R (1957) "How Extraneous are Extraneous Estimates?" Review of Economics and Statistics 39(4) pp380-393

Lacy A W and Street D R (1975) A Single Firm Analysis of the Residential Demand for Electricity Department of Economics, Auburn University

Landberg H H (1980) Selected Studies on Energy Ballinger Publishing Company

Maddala G S (1977) Econometrics Mc Graw-Hill, New York, pp 194-201

Marshall A (1885) "On the Graphic Method of Statistics" Jubilee Volume of the Statistical Society, Royal Statistical Society, pp 251-260, Stanford, London

Marshall A (1890) Principles of Economics 9th edition, vol 2, McMillan, New York & London

Mehra Y P (1977) "Money, Prices and Causality" Journal of Political Economy 85, pp 1227-1244, December

Norman H B (1977) "Electricity Supply for the next half Century" in Transactions of the SA Institute of Electrical Engineers, pp 110-125, May

Pindyck R (1979) "The Characteristics of Energy Demand" in Energy Conservation and Public Policy edited by J Sawhill, Englewood Cliffs, N J Prentice Hall

SA Weather Bureau (1965) "Climate of South Africa" WB Report no 28, Department of Transport, Pretoria SA

Sargent T J and Wallace N (1973) "Rational Expectations and the Dynamics of Hyperinflation" International Economic Review 14, pp 328-350, June

Silver J L and Wallace D T (1980) "The Lag Relationship between Wholesale and Consumer Prices" Journal of Econometrics 12, pp 375-387

Sims C A (1972) "Money, Income and Causality" American Economic Review 62, pp 540-552

Stone R (1945) "The Analysis of Market Demand" Journal of the Royal Statistical Society 108, pp 286-391

(1954) The Measurement of Consumers' Expenditure and Behaviour in the United Kingdom 1920-1938 Cambridge University Press, UK

Sutherland R J (1983) "Instability of Electricity Demand Functions" Energy Economics, pp 267-272, October

Sweeney J L (1984) "The Response of Energy Demand to Higher Prices. What have we Learned?" The American Economic Review 74(2), pp31-37

Taylor L D (1975) "The Demand for Electricity: A Survey" Bell Journal of Economics 6(1), pp 74-110

Taylor L D (1977) "The Demand for Energy: A Survey of Price and Income Elasticities" in W D Nordhaus (ed) International Sudies of the Demand for Energy, North-Holland, New York

Thomas S and MacKerron G (1982) "Industrial Electricity Consumption in the UK" Energy Policy, pp 275-94, December

Venter G N P and Basson J A (1986) "Quo-Vadis, National Non-nuclear Energy Research in South Africa" paper presented in the South African National Committee of the World Energy Conference, CSIR Pretoria, 9-10 June

Wold H and Jureen L (1953) Demand Analysis New York

APPENDIX 1

YEAR	ELECTRICITY SOLD BY ESCOM (GWH)	AVERAGE PRICE OF ELECTRICITY (C/KWH)	GROSS DOMESTIC PRODUCT 1975 PRICES (R MILL)	CONSUMER PRICE INDEX
1950	6910	0.2741	7 745	34.4
1951	7456	0.2922	8 585	36.9
1952	8080	0.3115	8 818	40.2
1953	8732	0.3542	9 276	41.6
1954	9676	0.3808	9 895	42.4
1955	10964	0.4139	10 451	43.7
1956	12019	0.4285	10 996	44.5
1957	12763	0.4478	11 483	45.8
1958	13602	0.4733	11 737	47.4
1959	14724	0.4951	12 197	48.1
1960	16094	0.5079	12 605	48.8
1961	17013	0.5155	13 123	49.8
1962	18121	0.5164	13 843	50.4
1963	19500	0.5177	14 959	51.1
1964	21247	0.5101	16 039	52.4
1965	23143	0.5076	17 062	54.5
1966	24554	0.5254	17 857	56.5
1967	26657	0.5467	19 339	58.4
1968	28885	0.5550	20 216	59.6
1969	31505	0.5565	21 528	61.5
1970	34890	0.5545	22 630	64.1
1971	38040	0.5772	23 747	67.7
1972	41648	0.6108	24 038	72.1
1973	46578	0.6484	25 049	78.9
1974	52558	0.6822	26 949	88.1
1975	57869	0.7950	27 370	100.0
1976	63355	1.0360	27 742	111.3
1977	67125	1.5353	27 743	123.6
1978	72780	1.7887	28 366	136.2
1979	80582	1.8980	29 432	154.1
1980	87539	2.0242	31 767	175.3
1981	93844	2.2811	32 044	201.9
1982	96135	2.8038	30 877	231.6
1983	98251	3.3606	30 441	260.2

SOURCES: Electricity Sold and Average Price of Electricity from the Annual Report of ESCOM 1983. Gross Domestic Product from various issues of the International Financial Statistics, IMF, and the Consumer Price Index from various issues of the South African Statistics, Statistics Office, Pretoria

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