ENERGY DEMAND MODELS IN THE U.S.A. AND U.K.

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1. DEMAND MODELLING SINCE 1973

1. The period since 1973/74 has witnessed a remarkable development of econometric modelling work relating to almost every aspect of energy availability and requirements. Whilst a number of useful surveys of global energy supply models have recently become available (see e.g., (1) (2)) there exists very few assessments of the attempts that have been made to explain and predict the demand for energy (3), (4). This is rather surprising in view of the vital importance for national resource allocation and investment programmes of anticipating accurately the responsiveness of energy consumers to energy prices and other policy instruments.

In this paper we seek to remedy this deficiency by providing a review and critical analysis of recent econometric energy demand models. We confine our attention to U.S. and U.K. studies, not because we believe that contributions from elsewhere are unimportant, but because (a) it is in the U.S. that the econometric approach is taken most seriously and (b) for obvious reasons we are more familiar with work in these two countries.

2. CRITERIA FOR COMPARISON OF MODELS

An apparent requirement of econometric models is that they should be well specified according to some relevant economic theory. Unfortunately, the conventional theory of demand imposes conditions (such as additivity, homogeneity, symmetry and negativity) which much applied research has shown simply do not hold at least at the usual levels of aggregation required by data availability. Thus while we shall comment on the theoretical foundations of the models we shall not regard lack of conformity to demand theory as sufficient ground for rejection. More important from a practical point of view, are the behavioural assumptions, the treatment of market dynamics and stock adjustment processes, the impact of supply considerations and finally, the forecasting performance of the models. Whilst a thorough going investigation of forecasting performance would be of considerable value to policy makers two factors make this impossible at present.

In the first place, only a tiny minority of the models are used to produce demand forecasts - the majority being content with tests of hypotheses over the sample period. Secondly, because of the time lags involved in energy investment, the forecasts which have been made usually relate to intervals of at least five years so that at most only two observations exist against which to assess performance. Nevertheless, at the conclusion of the discussion we present a brief informal analysis of forecasting achievements of one U.S. and one U.K. model.

3.1 INDUSTRIAL SECTOR MODELS

In the U.S. and U.K. as in other industralised economies the single largest energy consuming sector, in volume if not in value terms, is the industrial sector. The demand for energy by this sector has however proved extremely difficult to model and estimate for a number of reasons. In the first place the degree of non-homogeneiety between industrial energy consumers is larger than in any other sector. This applies not only to the number of significantly different industrial processes requiring energy inputs but also to the disparity in objectives between private and state controlled businesses. Secondly, the availability of energy on special unpublished contract terms to large industrial consumers complicates the task of measuring the price responsiveness of energy demand. Finally, the lack of data on stocks of fuel using appliances in industry hinders the separation of long term from short term demand effects.

Models of energy demand in the industrial sector tend to fall into one or other of three main groups - two of which, the translog and input output models, are firmly based in economic theory while the third, a miscellaneous collection of empirical models, have a purely ad hoc basis. The translog model has become increasingly popular and we shall now describe briefly its derivation and then look at some of the many applications which have been made.

3.1.1 Translog Demand Models

One of the problems of earlier analyses was that specific forms of production functions (e.g., Cobb Douglas or C.E.S.) had to be assumed in order to derive the demand for fuel inputs (5).

Apart from the general criticism that production functions are unobservable and therefore are of little relevance to input decisions, it was impossible to test the validity of the required assumptions from demand equation estimates. Christensen, Jorgenson and others since then have instead used the modern theory of the duality between unobservable production functions and observable cost functions to derive less restrictive energy demand functions. Firms are assumed to maximise output (y) subject to a factor cost constraint ($C=\Sigma P_i.X_i$). The dual of this is the minimisation of costs (C) subject to a production function ($y = f(X_i)$). Now traditional factor demand equations of the form $X = g(P_i,y)$ can of course be derived from this cost minimizing procedure, but these clearly depend on the production function y.

However, substituting the X_s*so derived back into the cost function gives $C(P_i, P_2,y) = \Sigma P_i . X_i^*$ which can be differentiated to yield $\partial C / \partial P_i = X_i^*$, the result known as Shephards lemma. Factor demands may thus be obtained as the derivatives of cost functions explaining costs in terms of factor prices and output levels.

In order to obtain estimable relationships it is necessary to approximate the arbitary cost function $C = C(P_1, P_2\ y)$ by a 'flexible' functional form, i.e., one which does not unduly restrict the range of elasticities in advance. Although there are a number of possible candidates, researchers in the Jorgenson tradition have opted for the second order transcendental logarithmic form which approximates C as $\log C = a_0 + a_1 \log y + \frac{1}{2}g \log y^2 + \Sigma a \log P_i + \frac{1}{2} \Sigma b \log P_i \log P_j + \Sigma g \log y \log P_i$.

The demand functions take the form of expenditure share functions S_i and are found from

$$\partial \log C/\partial \log P_i = \frac{\partial C}{\partial P_i} \frac{P_i}{C_i} = \frac{X_i P_i}{\Sigma X_i P_i} = a + g \log y + \Sigma b \log P_i = S_i$$

by assuming that the economy's overall production function is weakly separable between capital, labour, energy and materials inputs - ie., that marginal rates of substitution between any individual fuels are independent of levels of the other major inputs, it is possible to estimate the demands for aggregate inputs (SK, SL, SE, SM) as functions of capital, labour, energy and materials prices only and in a separate stage the demands for each fuel SE_1, SE_2 etc.) input as dependent solely on the set of fuel prices.

3.1.1.1 Applications of the Translog Model

Whilst there have been numerous studies of energy demand which have adopted the translog cost function approach, the results are at best only moderately encouraging. Estimated elasticities seem to be highly sensitive to the country and data period chosen, the restrictions imposed on the co-efficients and to the type of data used, whether cross section or time series. This lack of robustness as well as reducing the value of the model for forecasting purposes, casts doubts on the underlying specification.

Unlike many subsequent models of industrial energy demand, the Hudson Jorgenson model (2) integrates energy demand into a complete macro model of the U.S. economy. This consists of nine intermediate sectors of which five are energy producing industries, linked through input output co-efficients to four categories of final demands. The input output co-efficients are simply found by combining overall factor shares (e.g., SE) individual factor components (e.g., specific fuel) shares (e.g., SE_1) and prices in the following way.

$AE_1I = (SE, SE_1) \ P_1/PE_1$, giving the input of fuel I required per unit output of industry I. Crucial to the overall model are the demand (share) equation and these are estimated in three stages - first the shares of individual fuels in each sector in order to yield weights for constructing (secondly) the overall price of energy which is finally used as an explanatory variable in the factor share equation.

Although the models are translog in form, the authors impose restrictions on the co-efficients to ensure firstly separability between energy, capital, labour and materials, secondly that the shares in relevant equations add up to one, and finally symmetry of responsiveness of factor demands to changes in factor prices, i.e., $\partial SE/\partial PK = \partial SK/\partial PE$. The models have constant returns to scale and prices of outputs are homogeneous of degree 1 in input prices. Using annual data for the 1947 - 1971 period for the U.S.A., the authors find a fairly inelastic own price elasticity for energy as a whole in the manufacturing sector of -0.5, complementarity between energy and materials (-0.46) but gross substitutability between energy and labour (+0.57).

Although these results were supported by Berndt and Wood (7) using virtually the same model and data but a different estimating technique, they have been challenged in more recent work. Griffin and Gregory (8) argues that estimation of the static model using time series data would capture only short term responses. In the short run, with relatively fixed capital equipment, substitution of labour for energy is likely to lead to under utilisation of capital and apparent energy capital complementarity. In the long run, however, capital energy substitution is likely through the installation of more energy efficient plant. The authors instead use pooled cross section time series data on nine industralised countries for four time periods separated by five year intervals (1955, 1960, 1965 and 1969). This raises many problems concerning comparability of data between countries, and differences in the composition of the manufacturing industries. Griffin and Gregory test specifically for intercountry differencies and find that these significantly affect constants in the equations but not elasticities. They also test for the symmetry, positivity, and concavity assumptions underlying the translog specification and find that these are upheld.

In regard to relationships between energy and other factors they find that own price elasticitites of energy demand are significantly higher (-0.79 for the U.S.A.) than Hudson Jorgenson elasticities, that capital and energy are substitues ($\eta_{KE} = 0.15$) and similarly, labour and energy ($\eta_{LE} = 0.64$). It should be noted that Griffin and Gregory ignore materials in their demand function treating them as separable from the other inputs in production. Again, the lack of statistical significance of the estimated KE elasticity makes it impossible to draw strong conclusions about substitutability or complementarity. Finally, no attempt is made to model the path towards the long run and the value of the results for forecasting purposes is reduced accordingly.

The Griffin Gregory thesis is supported by Pindyck in his recent study of the structure of world energy demand using translog models (9). Again, this is a pooled cross section time series study but covering ten industralised countries, and using annual data for the period 1959 - 1974. Positive and statistically significant KE price elasticities of between 0.02 (U.S.A.) and 0.06 (Japan) are estimated implying substitutability between capital and energy in the long run.

At the same time Pindyck's model, unlike previous studies, includes an output term in the factor share equations, and his estimates of the energy output elasticity indicate that even in the absence of price changes there is substitution away from energy as output increases (estimated elasticities are all less than 1). Although Pindyck's results are quite respectable on statistical grounds, they are nevertheless flawed by failure to take into account the long lags which delay complete adjustment in the industrial market.

A number of alternative approaches to the problem of estimating dynamic adjustment in industrial energy markets have been advocated, but very little empirical work has been published to date. Berndt, Fuss and Waverman (10) point out that disequilibrium in one fuel market is likely to produce adjustment effects in all fuel markets so that interrelated processes must be estimated. Applying a simple Koyck transformation $S_t - S_{t-1} = B(S_t^* - S_{t-1})$ to 1948 - 1971 U.S. data where S_t^* is a vector of long run shares and B is the co-efficient adjustment matrix they find own price energy elasticities of about 0.7, much nearer to Pindyck's long run estimates but are not able to identify the lag structure. They propose, but do not estimate, a model incorporating positive increasing marginal costs of adjustment where the adjustment co-efficients vary inversely with marginal adjustment costs and the rate of interest (r). On the basis of a quadratic approximation to adjustment costs the optimal adjustment process for fixed capital is:

$$K_t - K_{t-1} = \left[-\tfrac{1}{2}\left(r - \left(r^2 - \frac{4\beta kk}{q_k d_{kk}}\right)^{\frac{1}{2}}\right)\right]\left[-\frac{1}{\beta_{kk}}\left(\alpha_k + \beta_{EK} P_E + \beta_{LK} P_L + \beta_{MK} P_M - V_K - r q_k d_k\right) - k_{t-1}\right]$$

where qk = net asset prices, d is the rate of increase of marginal adjustment costs, vk is the cost of using capital series and the βii are price co-efficients from the demand functions. This rather formidable expression should be estimated simultaneously with the demand equations. It should be noted however, that such an adjustment process is inconsistent with a translog model of energy demand and indeed, the authors have to switch to a quadratic approximation to obtain the above adjustment function.

Remaining in the translog tradition, Peterson (11), proposes an alternative adjustment process based on serial correlation in the error process rather than on optimal behavious assumptions. Incorporating first order autocorrelation $u_i(t)=\sum r_{ij}u_j(t-1)+e_i(t)$ (where i, j are the factors including energy) into the translog share demand equation with time trend y yields:

$$S_t = [I - R\Lambda](\;+ \ln P + \ln q + t) + RS_{t-1}$$

where Λ is the first order lag operator and R is the auto-correlation co-efficient matrix. The model is estimated by maximum likelihood methods for eight industry groups in the U.K. and five in the Netherlands over the period 1954 - 1978, but only for individual fuels (solid fuel, oil, gas and electricity). Peterson's results suggest that the serial correlation model fits better than one based on simple Koyck assumptions and considerably better than the static model. In general the computed elasticities are of the right sign and imply long run values at least as large as those found by Pindyck. Again, the greater degree of dis-aggregation revealed insignificant differences between short and long run elasticities for a sizeable minority of industries. It will not be possible however to judge between the alternative dynamic models until more empirical work is available, particularly on the Berndt, Fuss Newmann model.

It is possible though to identify at least four remaining problems with the translog approach. In the first place, there is the difficulty of specifying a theoretically satisfactory dynamic form of value shares equation since these are affected by (automous) price as well as quantity changes.

Secondly, there is the problem of aggregation. We have already discussed the differences in results across industry groups in the Peterson model. These differences appear in other disaggregated studies and Halvorsen (12) for example in a cross section analysis of 19, 2-digit U.S. industries found own price energy elasticities varying between -0.124 and -1.096 for electricity, between -1.151 and -4.3 for fuel oil, -0.425 to 2.184 for gas and -0.686 to 2.531 for coal, and further-more had to reject cost function regularity assumptions for nine of the industries.

Apart from uncertainty about the theoretical underpinnings of the model, these results complicate its use in forecasting since explicit assumptions need to be made about the composition of manufacturing industry in order to identify the approximate overall elasticities. Thirdly, there is the problem that results seem to be sensitive to the number of factors of production which are incorporated. Thus it has been argued (7) that KE substitutability in a three factor (KLE) case is consistent with complementarity in a four factor situation, including materials under certain circumstances. Anderson (13) however has found for the U.S.A. that the price elasticity between energy and materials is close to zero which would reduce the practical weight of this theoretical argument. Finally, and more importantly, results obtained from applications of the translog model are sensitive to the definitions of the variables. Field and Grebenstein (14) show that when capital is measured as value added (Jorgenson etal) EK substitutability is indicated whereas when it is measured by service price (Berndt etal) complementarity is found. The value added approach however includes working as well as physical capital whereas the service price approach only includes physical capital. Energy expenditure may therefore substitute readily with working capital (yielding overall KE substitutability) but not with physical capital except in the long run. Care must also be exercised in the interpretation of dynamic adjustment processes since each component of capital is likely to respond differently to exogenous changes in prices or output.

3.1.2 Other Models : Input Output Models

Apart from the relatively sophisticated input output analysis of Jorgenson's model, more conventional 1-0 models have been used to explain the industrial demand for energy. The strength of the input outputapproach is that it recognises the interdependence among intermediate sections of the economy in meeting final demands. Thus it assessesnot only the direct effect on fuel demand of a change in output of the consuming industry, but the complete chain of direct and indirect feed-back effects throughout the economy. The 1-0 model can also incorporate a high degree of disaggregation and make direct use of survey data about input output requirements of industrial processes.

Recently Al-ALi (15) developed the following model of industrial energy demand (X_{ej}) for Scotland : $X_{ej} = Re.Fj$ where e = energy source e,j = industry j, Re is the e^{th} energy row in the Leontiev inverse, $R = (1-A)^{-1}$ and Fj is final demand for products of industry j. This type of model is clearly of considerable use in situations where official time series data is either absent or not readily available as may be the case in regional and developing economies. Its value is however, limited to the short run as it is built on the assumption of zero own and cross price elasticities for energy products and constant returns to scale.

3.1.2.2 The Birmingham Energy Model

The Birmingham Energy Model is a fully integrated supply/demand model of the U.K. energy sector which uses mathematical programming methods to predict energy availability and utilisation in the long term. It is interesting as an example of a model with a demand component specified not on behavioural grounds but on grounds of consistency with the model builders objective function. The objective of the energy sector (see Carey (16)) is taken to be that of maximizing consumer benefits - the area under the demand curve in the case of a single commodity but here the line integral of the system of demand functions. In order to make use of this criteria it is necessary to impose symmetry on cross price effects between equations $\partial Y_i/\partial P_i = \partial Y_i/\partial P_j$. The specification adopted is the linear demand system $y = A_p+b$ where A is symmetric negative definite matrix of constants and b is a constant vector covering all other influences. Attempts to estimate this type of demand equation, however, proved unsuccessful in the sense that estimated A was either non symmetric (unrestricted estimates) or very different from observed values (constraint estimates). Nevertheless, the linear system with modified co-efficients is used for forecasting in view of its conforming with the 'benefit' function. Own price elasticities are negative but quite low at -.05 for coal, -.07 for oil and -.07 for gas, whilst gas is viewed as a substitute for oil and coal. Electricity is not included in the demand system but treated exogenously. It is clear that the programming framework provides a flexible means for assessing the impact of new technology and energy sources on the U.K. energy sector. This advantage does seem to be achieved however at considerable cost in terms of the reliability of demand estimates.

3.1.2.3 The U.K. Department of Energy Model (45)

Public ownership of three out of the four main energy industries (coal, electricity and gas) together with substantial involvement in North Sea Oil, makes it hardly surprising that the U.K. D.O.E. should develop its own forecasting methodology for the energy sector. The process is briefly to forecast total useful heat demands by sector, to make explicit allowance for energy conservation, to use market share models to allocate demands to particular fuels and finally, to reconcile these demands with availabilities using programming methods. In the industrial market a distinction is made between Iron and Steel for which forecasts are made in other Departments, and other Industries for which a simple aggregate linear model has been developed.

$$U_{OI} = 2413.27 + 75.55\ MP$$

where U_{OI} = useful energy consumed by other industries and MP = a manufacturing production index. This model was estimated over the period 1960 - 1973. Total energy demand is then divided between premium (process heating and power) and non-premium (bulk steam raising) uses . In the premium market, electricity is assumed not to compete with other fuels and its demand is determined from a straight forward linear relationship with industrial production. Oil demand per unit of output is modelled as an output co-efficient with declining time trend, any remaining premium demand is met by natural gas. Only in the non-premium market is gas demand considered responsive to price and its share, in physical units, is found from

$$S_t = (1 - \phi)\ S_{t-1} + \phi\ \frac{a_g\ P_g^{\ -\theta}}{\Sigma_j\ a_j\ P_j^{-\theta}} \qquad \text{where } \phi \text{ is an adjustment term.}$$

Other fuels are assumed to follow time trends with the exception of coal which is the balancing item in this subsector. This is a prime example of a series of ad hoc models whose specifications are justified largely on practical grounds (lack of data, ease of forecasting etc.,) rather than theoretical grounds of consistency and conformity with theory.

A particular problem for long term forecasting is the lack of a price variable in the overall energy demand equation especially in view of the evidence on own price elasticities provided by the translog models.

Finally, it is not clear how the dynamic structure of the individual fuel (gas) model is reconciled with the essentially static total energy and electricity models.

3.2 RESIDENTIAL AND COMMERCIAL SECTOR MODELS

Econometric models of residential and commercial energy use originate principally from the United States. Understandably they deal predominantly with U.S. markets although a few have undertaken pooled estimations across a number of countries. Studies emanating from British authors have been relatively few and far between. However, there are now signs of increased activity, not least inspired through the contentious nature of some of the existing works.

In common with industrial and transport markets, such economic theory as has been applied to residential and commercial model specifications has largely been the work of American authors. The 'translog' indirect utility function has again been the favourite medium through which to introduce explicit theory, but the proportion of models having these rigorous foundations is low. Moreover, their results cast doubt upon the usefulness of the technique and in particular its applicability to residential and commercial sectors.

Relatively few studies of the commercial sector have been undertaken. On both sides of the Atlantic the sector embraces customers who are anything but homogeneous in their basic characteristics of energy use. Analysis is therefore very difficult and is aggravated in the United States by the inclusion of large residential appartment blocks under commercial tariff classification. Studies of the commercial sector therefore usually appear in conjunction with residential analyses. This situation is likely to change. Rising consumer expenditure on services, both in Britain and the U.S., is promoting energy demand within this sector at a time when demands from other sectors are falling. In relative terms the importance of the sector is increasing. Further studies are therefore likely.

Classifying studies according to their country of origin would produce two sections an order of magnitude different in size. Similarly disaggregation by fuel or fuels considered would produce an unbalanced coverage of material. The majority of studies produced for residential and commercial markets relate solely to electricity demand. A few have been produced for gas, of which the work by Balestra (17) is fundamental, but no notable works have been produced specifically for either coal or liquid fuels. This is not an over-sight. Both have historically accounted for only a small proportion of total fuel supply in the residential and commercial sectors and over recent years this proportion has been declining. Throughout this review, studies have been grouped according to similarity of approach. Although this is felt to be the most rational approach, the whole area is somewhat unfortunately characterised by a wide diversity of methods largely resulting from the preference for ad hoc specifications drawn from the theory of consumer demand.

Simplicity is not a fault of these models. Authors have implicitly recognised the justification for modelling only to the level at which consumer perception of price tariff structures and investment returns upon competing durables can be realistically defended. After all, consumer expenditure on energy has historically accounted for a relatively low proportion of total household expenditure. Moreover, with the exception of gasoline, a substantial fraction of these purchases are paid for up to three months inarrears, introducing significant limitations to information perception. If future research follows the consensus of past approaches we will remain firmly encapsulated between the standard works of Balestra (17) and Jorgenson (18). None of the alternative approaches introduced have yet gained universal acceptance.

One general criticism of models of the residential and commercial sectors, their unwavering confidence in econometrics, must be mentioned now. Authors invariably succumb to the temptation of introducting ex post economic explanations for unsuspected estimation results invariably produced either by specification errors or through spurious statistical associations between variables.

3.2.1 Translog Indirect Utility Functions

The fundamental work by Jorgenson (18) and the subsequent developments by Pindyck (19) represent the most elegant mathematical attempts at simulating residential energy consumption. Both are based upon the translog function introduced by Christensen, Jorgenson and Lau (20) in 1975. Derivation of the basic translog form has been dealt with earlier in the industrial review.* Jorgenson's work on the residential sector analyses the main avenues of expenditure in the United States, Pindyck applies translog functions to consumers in nine countries, including the United States and Britain.

Each study assumes consumer expenditure between durables (K) energy services (E) and other non-energy durables (N) is separable. Utility is first maximised in the Pindyck study within the energy category by choice between fuels. Both studies allow consumer preferences to vary with time through the dubious inclusion of trend as an independent variable. Predictably, this causes problems although both Jorgenson and Pindyck put forward casual explanations for their respective negative income share elasticity and positive electricity cross-price elasticities. Each reject the hypothesis of significant changes in consumer preferences.

Both models are based upon share equations of the form below. Utility from each commodity is represented by

Pi/M, the price of i divided by total per capital expenditure. Time is denoted by t and per capita energy consumption by E.

$$\frac{P_E . E}{M} = \frac{\alpha_E + \beta_{EK}\ln\frac{P_k}{M} + \beta_{EE}\ln\frac{P_E}{M} + \beta_{EN}\ln\frac{P_N}{M} + \beta_{Et} . t}{\alpha_M + \beta_{MK}\ln\frac{P_k}{M} + \beta_{ME}\ln\frac{P_E}{M} + \beta_{MN}\ln\frac{P_N}{M} + \beta_{Mt} . t}$$

where $\alpha_M = \alpha_K + \alpha_E + \alpha_N$ and $\beta_{MJ} = \sum_P \beta_{JP}$. J,P = K,E,N.

Budget constraints are applied across equations to restrain the sum of commodity expenditures to the recorded total. Both models are estimated using Zellner efficient techniques.

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* see pages 2 and 3 above

In common with the majority of other residential and commercial studies, no forecasts are made. Elasticities however are produced. Those from Jorgenson relate only to energy's share in total consumer expenditure whilst those from the Pindyck study additionally deal with fuel choice.

Own Price and Cross Price Elasticities from Translog Models

Author	Own Price(E)	Cross Price	
Jorgenson (18)	-0.31 ~ -0.45	-0.03	E on K, N
		0	N, K on E
Pindyck (19)	-1.05 ~ -1.15	~ 0.1	E on A, D*
		0.3 ~ 0.8	E on F
		-0.2 ~ -0.5	E on T, R
		0.03 ~ 0.1	A, D, F on E
		-0.03 ~ -0.4	T, R on E

*A = clothing, D = durables, F = food, T = transport, R = other

Partial Fuel Price Elasticities (Pindyck (19)) - U. K.

	Coal	Liquid	Gas	Electricity
Coal	-0.99	-0.10	0.71	-0.61
Liquid fuels	-0.36	-1.29	2.29	-1.64
Gas	0.43	0.41	-1.39	-0.46
Electricity	-0.27	-	-0.33	-0.19

Elegance of approach in these models has not been achieved without serious cost. Other studies, with simpler specifications, have correctly embodied the dynamic nature of energy demands whereas both Jorgenson and Pindyck restrain their analysis within a static framework. Instantaneous adjustment of ex ante to ex post demands is assumed throughout and durables are treated as if no different to consumer goods. The fundamental relationships between energy demand and a stock of durables is nowhere explicitly recognised. Waverman (3), in identifying similar objections to the translog form, declares that the simulation is just not good enough.

3.2.2 Static 'ad hoc' models

Residential and commerial demands for energy are each derived demands. Energy is not consumed for its intrinsic qualities but rather for its provision of one or more of three basic services; heat, light and power. Consumption of these services is therefore fundamentally related to the stock of capital goods able to transform fuel input into a desired service. Energy demand, in common with other home consumed commodities and services which require some degree of processing before consumption, can be divided into distinct short run and long run components. Within a short time interval consumers' stocks of appliances may remain relatively stable, therefore placing an upper constraint on their ability to consume services derived from energy use. Studies conducted within such short time intervals can legitmately focus upon consumers' utilisation of their existing appliance stock. Extending the interval eventually invalidates this assumption and studies conducted over longer time intervals must explicitly account for variations in consumers' appliance stocks. Ignorning the variability will lead to an over-statement of all parameter estimates during a period of growing consumer wealth.

Somewhat surprisingly a number of studies have ignored this fundamental dimension of the problem. Authors have instead been concerned with final specification details within the utilisation component of demand. Arguments over the relative merits of average and marginal prices abound and some models, notable those of Halvorsen (22), Wilson (23), Nelson (24), Bloch (25) and others, mysteriously claim to produce long run elasticities from specifications which are at best questionable. Taylor (4), in his review of residential studies instigated much of the price debate. Denouncing the use of both average and marginal prices by themselves, he maintained that specifications should include a full mathematical description of the position and shape of the tariff structures.

This view has been recognised as unrealistic by the majority of authors. Only Kerry Smith (26) has attempted the direct inclusion in a demand equation of prices for each block of consumption.

His electricity demand equation for residential consumers in the U.S. took the form below:

$$\underline{Y} = \underline{Z}b + \underline{P}c + \underline{u}$$

where $\underline{Y}$ is a vector of electricity consumption
$\underline{Z}$ is a matrix of socioeconomic variables
$\underline{P}$ is a price matrix relating to individual consumption blocks

Predictably, Kerry Smith concluded that the alternative specification replacing the full price structure, $\underline{P}c$, with an average price approximation, $f(\underline{P})$, provided a reasonable approximation to the demand structure. He consequently inferred that it may not be necessary to construct estimates of relevant marginal and infra-marginal expenditures as suggested by Taylor. Econometric repudiation of this assertion is preceeded in other works by economic rejection. Credit payments of up to three months in arrears dilute consumers' awareness of price. In studies where the problem has been acknowledged, the argument is usually reduced to the choice of a relevant measure to reflect consumers' perception of price. Some authors, such as *Wilson* (23), have assumed only a minimum degree of information perception and have explored the use of 'typical bill' variables in place of both average and marginal prices. Although the typical bill variable performed well econometrically, first order economic criteria question its inclusion in a single equation model where income also appears as an independent variable.

Halvorsen's (22) U.S. study of residential electricity consumption uses marginal price in the specification but average price in the estimation, after showing the equivalence of average and marginal elasticities when the demand equation is expressed in log-linear form. Identification is achieved through an explicit price equation which expresses marginal price in terms of sales per consumer and utility's supply cost. Other authors have not explicitly accounted for the partial endogeneity of price but like *Wilson* (23), have noted the identification problem that this simplification introduces.

In his cross-sectional analysis of U.S. residential gas demand Bloch, on the other hand, makes the assumption that each household is a price taker and the demand function is therefore identified. Only when fuels are sold at a single rate will this assertion hold. However, the study does attempt use of a lagged variable to explicitly introduce information delays and also the use of a trend to capture the overstatement in the price co-efficient which Bloch believed to be present through a growing consumer price awareness over time.

Despite these experiments, the principal model characteristics remain firmly lodged within a static framework. Halvorsen's price equation, on the other hand, permits movement of consumers through the tariff structure in accordance with their consumption levels, whilst the position of the tariff structure is determined by exgonous factors. Block's treatment, as illustrated in the equation below, is therefore over simplified.

$$N_m = b_o + b_1Q+b_2L+b_3K+b_4F+b_5R+b_7T+v$$

where N_m = nominal marginal price of electricity
Q = average sales per consumer
L = cost of labour
R, F, I, K = physical supply variables
T = time

This view is reinforced implicitly in Nelson's U.S. space heating demand study which pursued Halvorsen's treatment of price in the demand equation but did not explicitly model price. Nelson, like Wilson recognises the subsequent identification problem which may result. The studies by Hirst (27) and Chern (28) of energy use in the U.S. commercial sector and the combined residential and commercial sectors respectively both use average prices without any reference to either the marginal versus average price debate or the endogeneity of price in the demand equations. The study by Hirst uses a simple linear specification to analyse density of energy use and nominal energy use in a cross-section of institutional buildings. Chern first describes aggregate fuel demand over a combined residential and commercial sample and then disaggregates fuels using linear share equations.

Only Halvorsen's study attempts to introduce any dynamic behaviour into demand estimation. A series of arbitrary pascal lags, inverted V structures and moving average regressions are estimated for one cross-section of his pooled sample to pay lipservice to what is an intrinsic characteristic of both the short and long term components of energy demand. No firm conclusions are drawn from these limited experiments.

In common with the Jorgenson and Pindyck translog approach, the ad hoc specifications of Nelson, Wilson, Bloch, Chern and Hirst put forward models which are both static and do not explicitly account for consumers' stocks of durables. Both Waverman (3) and Taylor (4) acknowledge that this is clearly incorrect. The only useful function of all of these studies has been to highlight the debate over prices. Consumers are invariably faced with some prices latitude because of declining block tariff structures. Some respect for the at least partially endogenous nature of price is therefore essential. Overall however the debate can only be resolved through an honest appeal to consumers' perception of price information.

A less notable feature of this group of studies is their ability to derive an inordinate range of elasticities from specifications which share the same basic form.

$$Y = a_0 + a_1X_1+a_2X_2+a_3+a_4X_4+e$$

or, $$Y = AX_1^{c1}\ X_2^{c2}\ X_3^{c3}\ X_4^{c4}\ e^u$$

Chern (28).	Combined Residential and Commerical Elasticities			
	Electricity	Nat. Gas	Pet. Prods	Income
Electricity	-1.40	0.01	0.17	0.91
Natural Gas	0.84	-1.51	0.44	0.73
Petroleum Prods.	0.34	0.77	-1.40	-0.36

Hirst (27).	Commercial Sector Price Elasticities	
	Fossil Fuels	Electricity
Fossil Fuel use	-0.28	0.11
Electricity use	-	-1.05
Total energy	-0.18	-0.32

Other Residential Studies. (Long Run Elasticities)			
	Electricity own price	Electricity cross price	Income
Halvorsen(22)	-1.00∿-1.21	0.04∿0.08	0.47∿0.54
Nelson (24)	-0.19∿-0.28	0.504∿0.509	-0.158∿0.267
Bloch (25)	0.583∿-0.666	not considered	-
	-0.249∿-0.260*	not considered	-
Kerry Smith (26)	-0.76∿-0.84	0.97∿1.10	-

* with trend to account for increased consumer awareness.

Surprisingly, the Domestic sector model of the U.K. Department of Energy (45) falls into this category of static models. It does at least seek to take rudimentary account of appliance stock through the introduction of central heating ownership levels but beyond this it is worthless.* Energy consumption is related only to total household expenditure. No disaggregation across fuels is undertaken, central heating ownership is regarded as exogenous, other physical variables do not appear and no reference is made to economic determinats of demand. In essence it is incorrect to call it an economic model. After dropping one variable because of multicollinearity, its estimated form is as below:

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* We understand that the D.O.E. are currently revising their models of energy demand so that these comments relate to the pre 1981 situation.

$$U_{HH} = 192.88 + 152.77 \frac{CH}{HH} + 104.62CEX_{HH}$$

$$(3.47) \quad (3.26) \quad (2.72) \quad \text{(t-statistics)}$$

$R^2 = 0.925$ D.W. = 1.91

where U_{HH} = average useful energy consumption per household

CH/HH = proportion of household with central heating

CEX_{HH} = total household expenditure

All of the studies so far dealt with in this review have specification shortcomings in at least one or two basic areas; a dynamic framework and explicit recognition of the derived nature of residental and commercial energy demand. Before passing to a selection of models which have developed more realistic simulations in their specifications it is worth considering briefly a series of electricity by 'time of day' demand models. Although unremarkable in themselves, they provide useful insight to modelling at the finest levels of disaggregation and offer guidance to future research on both prices and worthwhile aggregation levels.

Before proceeding however, a convenient point emerges to make brief reference to the domestic section of the Birmingham energy model (16), which has already been discussed at some length in the review of industrial markets. Estimation of a linear demand system having a symmetric negative definite matrix of price effects was attempted for U.K. residential gas, electricity and oil demands. Coal demand is treated exogenously. Repeated attempts failed to produce meaningful results and the authors resorted to introducing synthetic co-efficients to obtain a satisfactory forecasting model. The work cannot be interpreted as an attempt at identifying market parameters and comparisons are invalidated through its method of production.

3.2.3 'Time of Day' Electricity Demand Studies

A particular group of American models have taken the investigation of price effects to its empirical extreme. Between 1975 and 1976 the U.S. Federal Energy Administration, in a bid to stabilise residential load curves and reduce peak generation costs, allocated funds for field experiments of residential time-of-day electricity price tariffs.

Data collected from these trials have been analysed independantly in a number of studies. Those by Atkinson (29), Lawrence and Braithwait (31), Taylor)32) and Granger et al (30) are representative.

Each study attempted to estimate both a series of own price elasticities for electricity consumption within particular tariff bands, and also the cross price elasticities between different price bands depicting potential for load movement between peak and off-peak times. Recurring throughout the studies is again a non uniformity of approach and a wide diversity of results. Final conclusions are in some cases contradictory between studies.

In two of the time-of-day studies, attempts were made to develop the model structure from a rigourous economic base. Atkinson draws heavily upon the indirect transcendental logarithmic function developed by Jorgenson and Lau (21). Lawrence and Braithwait develop their demand equations from the linear expenditure system first estimated by Stone (33) in 1954. The remaining two studies employ utility maximization through ad hoc specifications. Reference in each case is made to elementary consumer demand theory.

There are just a few common features shared by all four studies. Separability is assumed in each piece of work, that is electricity consumed at different times through the day is regarded as different commodities. Consumers are therefore faced with a range of differently priced services from which to maximize their utility. Taylor (32) realistically argues that within a short time intervals consumer appliance use is essentially random. All four of the studies concluded that the time-of-day pricing had induced only weak load movements. The necessary assumption of separability may therefore be too strong for the present modes of analysis. Taking an honest lead Atkinson and Taylor both argue that consequent to the short sample period the substitution results are predictable. Full adjustment of 'time-of-day' tariff structures will only be achieved after a considerable gestation period during which consumers rearrange their patterns of appliance use, many of which are interlinked with lifestyle patterns.

The second common thread through each work is the exogenous treatment of appliance stocks. Although the derived nature of electricity demand is explicitly recognised, close temporal spacing of observations within sample periods of months rather than years, leads legitimately to the assumption of fixed durable stocks. However, to constrain households' ability to absorb services provided by electricity, a measure of appliance load is included in each model. Significantly the two studies with elaborate economic specifications did not find appliance stocks to be important. This may be partially attributed to their emphasis of the price mechanism and in the case of Atkinson the questionable inclusion of both appliance stocks and lagged consumption in the specification.

Schematically, the estimated functions from Atkinson's study, the most complex, and Granger et al, the simplest are listed below together with sets of broadly comparable own price and cross price elasticities. In common with so many other studies of the residential sector, no forecasts are attempted by any of the models.

$$w_i = \frac{\alpha_i + \Sigma\beta ij \ln P_j^* + \Sigma\gamma_{bi} \ln Z_K}{\Sigma\alpha_i + \Sigma\Sigma\beta_{ij} \ln P_j^* + \Sigma\Sigma\gamma_{ki} \ln Z_k}$$

where i = peak, mid peak and off peak, Atkinson's (29) equation gives the share, (Wi), of total expenditure on electricity occuring during period i. P_i^* is the price of electricity in period i relative to total expenditure on electricity, Z represents other non-price indexing prices. The equations are estimated using Zellner efficient techniques.

$$Yi = X_i \ B_i + E_i$$

Granger et al (30) equation is of more familiar form. Hourly consumption of household i, (yi) is related to a set of economic and physical determinants, Xi and a stochastic term. Equations were estimated by ordina ry least squares.

Estimated Elasticities			
Study		Own Price	Cross Price
Atkinson (29)	Off-Peak	∿ -0.2	-0.3 ∿ -0.4
	Normal	∿ -0.7	-0.1 ∿ -0.2
	Peak	∿ -0.6	-0.1 ∿ -0.3
Granger et al (30)		none produced	
Lawrence and Braithwait (31)	Off-Peak	-0.1 ∿ -0.3	< 0.1
	Normal	-0.2 ∿ -0.4	< 0.1
	Peak	-0.1 ∿ -0.3	< 0.1
Taylor (32)		none produced	

Weak conclusions on cross price elasticities from this pioneering group of studies considerably dilute the potential for further analysis at such dissaggregated levels. Failure may be partially attributed to treatment of the analysis within a largely economic framework. Physical constraints and sociological patterns of behaviour largely govern the way we live over short periods of time. If analysis at such a micro level is to be pursued in the future then a basic requirement will be to allow full physical and social adjustment to the new system before conducting economic analysis.

Salvation from the host of different demand specifications prelevant in conventional models has not been found through an appeal to individual behavious patterns. This seemingly intractible dilemma of specification is partially resolved in dynamic models although no single model as yet fully satisfies all the criteria which have emerged from this review.

3.2.4 Dynamic Models

Dynamic behaviour has been introduced into models of the residential and commercial sectors in a variety of ways and for two different purposes. Most commonly the static demand framework has been relaxed to incorporate consumers' expectations. Less frequently, the reason has been to directly lift the restrictive assumption of fixed appliance stocks.

No study has both explicitly modelled appliance stocks and also introduced expectations into demand patterns.

The debate over prices continues in dynamic models, but only the work by Ruffel (34) moves beyond a single equation model. For a conceptually complete study of residential and commercial sectors, all three of these problem areas will have to be drawn together in one model.

That such a study has not yet emerged is largely the result of inadequate data. Recorded ownership levels and patterns of consumer utilisation are only now beginning to emerge for electricity. In many cases complementary data for other fuels simply does not exist. Moreover, interpretation of this additional data is thwarted by transformation losses which affect both consumption and price data.

Specifications therefore pursue indirect methods of introducing dynamic behaviours. Empirically troublesome variables such as consumers' expectations are substituted out of reduced forms and the resulting demand equations resemble simple static forms with lagged consumption added to the end. The works by Uri (35) (36), Parhizgari and Davis (37), Murray et al (38) and Baughman and Joskow (39) are typical. A more general adjustment mechanism explored by Berndt and Watkins (40) gravitates to the same reduced form but from the starting position pioneered by Balestra and Nerlove (41).

Unfortunately, the inclusion of a lagged dependent variable in the model specification often induces severe collinearity between variables and leads both to suspect values for the adjustement coefficient and erroneous parameter estimates upon other regressors. The studies listed above, which share the flow adjustment approach, between them encompass adjustment periods ranging from 1 year (37) (40), to 13 years (39). As a consequence of the varying level of importance assumed by the lagged dependant variable, price and income elasticities predictably show considerable dispersion. This is heightened in the comparison of long run parameters which are each derived through amendments to the short run elasticities using the estimated adjustment coefficient. These comparisons are made in the table which follows.

Each of the above studies employs an adjustment mechanism similar to that below. The asterick denotes ex ante or desired demand.

$$Q_{it} - Q_{it-1} = K\,(Q^*_{it} - Q_{it-1})$$

Substitution of this relationship into the structural form yields an ex post demand equation which features lagged consumption as an independent variable.

$$Q^*_{it} = f(Y_{it},\ Z_{it},\ P_{it},\ e_t)$$

then, $$Q_{it} = b_0\,k + b_1\,KP_{it} + b_2KY_{it} + b_3\,KZ_{it} + (1-K)Q_{it-1} + Ke_t$$

Short and Long run elasticities (Various studies)

		Short Run		Long Run		
Study	R, C	Price	Income	Price	Income	K
Baughman (39)*	R, C	-0.13	0.10	-0.80	0.62	0.16
Uri (35) **	R	-0.21	0.04	-1.15	0.22	0.82
	C	-0.19	0.03	-1.28	0.16	0.85
Parhizgari (37)**	R	-0.15	0.71	∿-0.15	∿0.71	∿ 1
Berndt (40)+	R, C	-0.20	0.03	-0.69	0.13	0.90

* all fuels + gas ** electricity

The particular adjustment process illustrated is drawn from the Baughman and Joskow study which is unique in that it first considers aggregate residential energy demand and then dissagregates across fuels using a multinominal logit split. The remaining three studies are single equation models. Similar to Baughman and Joskow, Parhizgari and Davis also explore ex ante demand. Uri concentrates solely upon the role of expected prices whereas Berndt and Watkins, in their Canadian gas study, generalise and consider the transient component of each independent variable. In so doing however, they unrealistically apply the same adjustment coefficient to variables as dissimilar as housing stocks and income.

The residential model produced by Murray et al (38) which specifically sets out to remedy the specification shortcomings listed by Taylor (4), sits half way between the previous set of flow adjustment models and the simulation approach of Betencourt (44) and Ruffel (34). Sadly, from a most promising specification, the estimations produced only disappointing and inconclusive results. Data limitations forced the authors to retreat from their equality, describing electricity demand as the product of installed load and utilisation rates, back to a partial adjustment model of changing appliance stocks. The reduced form therefore shares more in common with the previous studies than the works of Betencourtand Ruffel which retain the equality based specification throughout. Nevertheless, the Murray study does recognise the intrinsic differences between residential and commercial energy demands and a distributed lag specification is put forward to capture the main threads of this latter demand.

$$\text{Log } Q_t = \sum_i c_i V_{it} + d_1 \text{ Log } Q_{t-1} + d_2 \text{ Log } Q_{t-12}$$

Both physical and economic variables are included within the summation over V. Consumption lagged by one month attempts to trace short run lags in response whilst the twelve month lag attempts to capture the dynamic adjustment of capital stocks.

As already mentioned, only Betencourt and Ruffel pursue simulation specification through to estimation and only Ruffel avoids the use of a proxy for appliance stocks. His basic demand equation sums over four main appliances the product of installed load and a utilisation rate assumed to depend upon a series of variables, X.

$$Y_t = \Sigma_a Z_{at} (\sum_j c_{jat} X_{jt} + e_{at})$$

The partial endogeneity of price appearing in the demand equation is recognised, and average price is described in a 2SLS estimation with reference to the prices of marginal blocks. Regretably however, appliance ownership levels are still regarded as exogenous and no appreciation of expectations is demonstrated.

Betencourt on the other hand, is forced to introduce the number of residential electricity consumers as what is a tenuous approximation for installed appliance load. His specification, which is basically similar to Ruffel's investigates alternative interrelationships between the price variable and other determinants of demand, but does not either deal with the problem of expectations nor more rigorously pursue the price argument. To conclude what is a truncated review of recent residential and commercial sector models, a comparison is made between this last, broadly similar, set of studies.

Short and Long Run Elasticities (Various Studies)

		Short Run		Long Run	
Study	R, C	Price	Income	Price	Income
Ruffel (34) *	R	−0.17[1]	0.45[2]	-	-
Betencourt(44)*	R	∿ −0.14[3]	-	-	-
Murray et al (38)*	R	−0.60	0.69	−1.01	0.69[4]
	C	−0.04 ∿− 0.08	0.02	−0.47 ∿ −0.71	0.70

* electricity demand

[1] reduced form estimation

[2] expenditure elasticity

[3] average for peak price elasticities, normal conditions

Throughout this review, models have been grouped according to their broad similarities of approach. Each group have their relative merits, and each group suffer from a number of shortcomings. That most model specifications have not been derived from economic theory is not an important deficiency. A selection of authors, notably Jorgenson, Pindyck, Atkinson and the team responsible for the Birmingham energy model, have all tried, but their results have not shown any advantages over simpler ad hoc specifications.

Moreover the basic requirement of a dynamic framework has yet to be incorporated into these specifications.

Other residential and commercial sector models fall naturally into distinct categories. Static models focus largely upon the utilisation component of demand and ignore the variability of consumers' appliance stocks. The reduced form of the flow adjustment models do likewise. Only Berndt and Watkins relax the assumption of fixed stocks. Their treatment of fixed and variable demand draws heavily upon previous work by Balestra (17) and others.

The principal concern of this group of studies is to identify the adjustment process which consumers work through when reacting to short run stimuli. Splitting reactions into permanent and transient components permits inferences to be made of long run behavious without the need for explicit long run analysis. Empirical results from the flow adjustment models are conflicting, but more importantly, their specifications are conceptually difficult.

It is questionable whether the variables which determine consumers' utilisation of their appliance stock will be the same as those which determine their acquisition of various white durables. Moreover the building of appliance stocks is an inherently non-linear process, as <u>Bossert</u> (42) and <u>Marris</u> (43) have independently noted. It is unrealistic therefore that long run behaviour should simply be expressed as a multiple of observed short run behaviour. <u>Ruffel</u> (34) has in any case suggested that the two may not be separable without imparting bias to estimated coefficients.

Until radically improved data bases are available it is difficult to see how this situation will alter. Only the final study in this review was able to partially overcome these difficulties and make some limited substitution for appliance stocks. Other studies have been forced to use proxy variables or have circumnavigated the problem altogether. Most however, make reference to the simulation approach, which suggests that it will feature more prominently in future work. Time, and improved data will tell.

During the course of this review, authors painstaking labours have indirectly and yet most effectively produced a list of specification requirements that an acceptable study of residential and commercial markets would incorporate.

Firstly, the markets must be separated to reflect their intrinsic differences and each must be analysed within a dynamic framework. Equally important is that a clear distinction must be made between short and long run demands. Consumers' utilisation of their appliance stock and their acquisition of durables are both worthy of analysis and specifications within both components could legitimately use flow adjustment approaches to introduce expectations.

Much of the literature surveyed is engrossed in debate over the correct treatment of prices. Whilst the position of a tariff structure may be exogenous to a particular model, consumers' position within that structure is clearly endogenous and requires a separate equation. Finally, and perhaps most difficult of all, the system must be recognised as non-linear.

3.3 TRANSPORT SECTOR MODELS

Transportation in both the U.S. and the U.K. constitutes the third major energy consuming sector. In contrast with other sectors the market tends to be dominated by one fuel - gasoline or petrol - used by private and commercial vehicles in road transport. This dominance of one fuel in one submarket helps to explain the proponderance of studies of the demand for motor gasoline in this sector. Another distinguishing feature is the strong link between fuel consumption and one appliance - the motor car. Due to the importance of the motor car industry in both economies much more detailed statistics are available about appliance stock levels, sales rates, size and quality than in other sectors. Models of energy demand tend to make use of this extra information and are able to explore the chain in consumer decision making in greater depth.

Again the model is not dynamic and makes no reference to the influence vehical stock on consumption. This might help to explain the fact that demand is consistently underpredicted over 1970 to 1972. The model has been applied to Canadian data (Dievees, Hyndman and Waverman - reference 48) and found to perform less well than dynamic models.

3.3.1.2 The Archibald and Gillingham Model (49)

Although not designed for forecasting purposes the Archibald and Gillingham study indicates how a simple model can be used together with detailed survey data to estimate short run elasticities of demand for gasoline. On the basis of household production theory according to which consumers 'combine gasoline, car services and other goods with their own time to produce transportation service', the demand function for gasoline is $g = G(p, \pi, Y: v, a_1, a_2, \ldots\ldots a_n)$ where p is the price of gasoline, π, a vector of other prices, Y permanent income, v a household characteristics vector and a_i a vector of characteristics of the i^{th} automobile.

Using a sample (from the U.S. Consumer Expenditure Survey) of 1853 households in 23 cities who did not change their automobile stock or demographic characteristics during 1972 - 1973, the authors estimated a translog version of their demand function to detect the impact of price changes unaffected by stock adjustments. They derived short run price elasticities of -.43 and income elasticities varying between .285 and .561 depending upon whether the household possessed one or more than one car. Significant household characteristics were location, sex, race, age and education, while the important automobile characteristics were numbers of cars per household and size of engine. This type of analysis is useful in assessing the impact of variables aggregated into the constant term because of lack of data. The work has two major drawbacks, however, from a forecasting point of view. In the first place nothing is said about the process of adjustment to price changes. This could have been investigated in a sub sample of households who actually changed their car stock in the period. Secondly, its dependence on official survey work carried out only infrequently implies that estimates are likely to be outdated quite rapidly.

3.3.2 U.S. Multi Equation Models

One basic defect of the single equation models discussed above is that they can only be used to assess the impact of one policy variable, i.e., the price of gasoline. The demand for gasoline can also however be affected by policy measures intended to improve car efficiencies and utilisation. These policies operate in the context of a slowly changing automobile stock so that the adjustment process needs to be modelled carefully. Such considerations have motivated the development of a large number of multi equation gasoline demand models but discussion of three recent examples - the models of Sweeney (5), Pindyck (51) and Dahl (52) - will be sufficient to indicate a broad similarity of approach.

3.3.2.1 The Sweeney Model (50)

This model is a development of the basic model used in the U.S. Federal Energy Administration's 1976 National Energy Outlook. It investigates in detail the consequences of the age structure of the automobile stock for the transmission of price and other policy effects to energy demand. The model consists of eight equations showing the links between stocks, efficiencies, utilisation and gas demand. The system of equations as estimated and used by the author in his paper is as follows:

1. $\mathrm{GAS} \equiv \mathrm{VM} / \overline{\mathrm{mpg}}$

2. $\overline{\mathrm{mpg}} \equiv \mathrm{ES}_t / (\mathrm{ES}_{t-1}\, \delta\gamma / \overline{\mathrm{mpg}}_{t-1} + \mathrm{NPCR}_t / \mathrm{mpg})$

3. $\mathrm{ES}_t \equiv \mathrm{ES}_{t-1} \delta\gamma + \mathrm{NPCR}_t$

4. $\mathrm{GCPM} \equiv \mathrm{PG} / \overline{\mathrm{mpg}}$

5. $\mathrm{PCR}_t = 0.935\ \mathrm{PCT}_{t-1} + \mathrm{NPCR}_t$

6. $\mathrm{mpg}_i = 3.344 + 0.721\ \mathrm{PG}_{-1} + 0.279\ \mathrm{Eff}_i$

7. $\mathrm{NPCR}_t = 20.994 - 4.11\ \mathrm{ES}_{t-1}/\mathrm{N} + 1.27\ \mathrm{VM}/\mathrm{N} + 3.31\ \mathrm{YD}/\mathrm{N} - 0.072\ \mathrm{Ru}$

8. $$VM/N = 1.372 - 0.225\ GCPM + 0.632\ YD/N + 0.005RU$$
$$-0.952\ HPEA + 0.306\ PCR_{-1}/N{-1}$$

Gasoline demand (GAS in equation 1) is the product of vehicle utilisation expressed in terms of fleet miles (VM) and average efficiency measured as gallons per mile ($1/\overline{mpg}$). The inverse of efficiency, $\frac{}{mpg}$ is a geometrically weighted average of the actual efficiency $\frac{1}{mpg}$ of the various vintages of cars in the total effective car stock (ES_t) in identity 2. This effective stock is calculated by adjusting previous period effective stock for reduced usage of older cars (γ) and scrapping rate (δ), assumed to be constant through time, and adding in the number of new passenger cars (NPCR) registered in t (identify 3). Of the two constituents of gas demand, only the average efficiency $1/\overline{mpg}$ is supposed to adjust over time. The first component of $1/\overline{mpg}$, namely mpg depends on technical efficiency (Eff_i) - given exogenously - and also on the lagged price of gasoline (PG) which indicates the extent to which substitution of more for less fuel efficient models takes place in response to increased gasoline price (equation 6). The second influence on efficiency, new car registrations (NPCR), is assumed to respond positively to the determinants of the desired stock of cars, disposable income YD, utilisation, VM, and unemployment R_u, and negatively to the previous stock level (ES'_{t-1}), and this is supported by estimates given in equation 7. Consumers principal short term response to price changes consists in altering their utilisation of the existing vehicle stock. Thus VM in equation 8 is estimated as a function of fuel cost per mile (GCPM) disposable income (YD/N), unemployment R_u), weekly hours of production workers (HPEA) - a measure of free time - and last period automobile stock (PCR).

Looking at the system as a whole the elasticity of gasoline demand with respect to price ranges from 1.22 in the short run to -.78 in the long run. Initially, a price change affects utilisation (vehicle miles) rather than efficiency. In the long run however, the major impact is felt through changes in fleet efficiency resulting from adjustment of the automobile stock. The income elasticity is relatively low (between 0.6 and 0.86) because of the rapid response of new car registration to income changes and the negative impact of such new registration on gasoline demand through the improvement of average efficiency.

Sweeney's model represents the various stages of the gasoline demand decision process with a high degree of sophistication and later studies have followed his general approach. One weakness in the model lies in its treatment of car stock depreciation as a constant rate (identify 3). The decision to scrap a vehicle and subsequently replace it is likely to be influenced by prevailing credit conditions, relative costs of old and new cars and deterioration due to degree of utilisation among other things. Since replacement demand is the most important means whereby improvements in average engine efficiency are achieved misspecification could lead to substantial errors in the estimation of long run elasticities. Another problem with the model is the inclusion of two different measures of capital stock (ES and PCR) without specifying the link between them. This could produce inconsistency in any long term forecast made with the model.

3.3.2.2 The Pindyck Model (51)

Like Sweeney, Pindyck views the demand for gasoline (Q) as the product of short and long run effects and defines it as the stock of automobiles (STK) times average car utilisation in kilometres per car per year, which he calls traffic volume per car (TVPC), divided by an efficiency variable EFF i.e., miles per gallon.

$$Q = STK.TVPC/EFF$$

Again, like Sweeney he views stocks as not being sensitive in the short run to gasoline price change although both additions to stocks (NR - new registration) and depreciation STK do respond to short run changes. Stocks adjust according to the accounting identity STK $STK_t = (1-r)STK_{t-1} + NR_t$ where r is the rate of depreciation of the stock. New registrations per head consist of depreciation$(r\frac{STK}{POP}{}_{t-1})$ plus a proportion w of the difference between desired stock (STK*) - a function of gasoline and car prices (PG and PC) and income (GDP) - and last period actual stock (STK_{t-1}), plus, less obviously, a proportion of last periods registrations $(\frac{NR_{t-1}}{POP_{t-1}})$.

The main innovation of Pindyck's model is his treatment of the depreciation rate as a function of economic variables - income and car prices. He argues that depreciation will increase as incomes rise since customers prefer and are now better able to purchase newer cars, but that price increases will have the reverse effect.

The remainder of the model is similar to that of Sweeney. Traffic volume (kilometres) per car (TVPC) is expected to respond positively to changes in income per head and negatively to the price of gasoline. Lagged TVPC is included in the equation to try to capture the delays in response. Finally fuel efficiency (1/EFF) is seen as changing rather slowly with gasoline prices. Two versions of this function are tested - one in which growth in efficiency is unrestricted and the other in which an upper limit to efficiency is imposed so as to prevent it rising beyond physically plausible values.

Estimates of equations are carried out using Pindyck's pooled cross section time series approach for 11 countries over the period 1950 - 1973 by Zellner efficient methods. The results are however rather mixed and indicate the need for further research. The stock term is either not significant or positive in the new registrations equation suggesting possible misspecification of the underlying adjustment process. Nevertheless, new registrations are found to respond most strongly to the price of cars (elasticities of -0.32 and 0.78 in the short and long run), then to the price of gasoline (0.26 and -0.64) and only slightly to GDP/POP (0.12 and 0.30). The depreciation rate equation performs worst in terms of goodness of fit ($R^2 = 0.519$) with the price of cars as the only significant explantory variable. Thus the implied elasticity of -0.71 may well be overstated. Better esimates could perhaps be obtained by including terms relating to technical obsolescence and credit availability and costs as extra explanatory variables. Traffic volume per car is found, contra the theory, to be unresponsive to the price of gasoline and to have a very low short run income elasticity (0.06) increasing to 0.66 in the long run. One problem here is that TVPC is based on traffic counts in each country and is subject to survey errors which could distort estimated coefficients even if the underlying theory is correct.

The final equation linking efficiency to the price of gasoline performs rather batter than the others. The price elasticity of gallons per mile (1/EFF) increases from 0.11 in the short run to between 1.43 and 2.63 in the long run (over 8.6 to 14.4 years depending on the version of the model).

Viewed as a whole, the Pindyck model performs quite well despite problems with the individual equations. The overall price elasticity of gasoline demand ranges from 0.11 (0.131) in the short term to -1.26 (-1.77) in the long term for the U.S. (U.K. figures in brackets). This long term (up to 25 years) is much longer than indicated by other studies due to the specific modelling of efficiency effects. Income elasticities again only approach 0.837 (0.898) in the long term and are quite inelastic in the short term (0.067 and 0.68).

3.3.2.3 The Dahl Model (52)

So far none of the models discussed has allowed for the effect of anti pollution legislation which was introduced in the U.S.A. in 1968. Dahl takes this into account by incorporating a dummy shift variable commencing in 1968 in her explanation of average mpg or efficiency. The effect of the policy is transmitted to gasoline demand via the identity QD = AMT/MPG where QD is gasoline demand and AMT is a measure of auto miles travelled per head. Using data over a long period 1936 - 1941 and 1947 - 1972, she estimates MPG as a function of gasoline price, incomes and D (the anti pollution dummy), and AMT as a function of gasoline price per mile (PGAS/MPG), income and automobile stock. Two stage least squares is employed because the stock of automobile and the price of gasoline are determined by accounting identities elsewhere in the model. The results are :

(1) $\mathrm{MPG} = 0.212\ \mathrm{PGAS} - 0.28\gamma - 0.013\ \mathrm{D} + \text{constant}$

and

(2) $\mathrm{AMT} = -0.101\ (\mathrm{PGAS}/\mathrm{MPG}) + 0.147\mathrm{Y} + 1.071\mathrm{SA} + \text{constant}$

where both equations are in double log form (except for D which is linear) and corrected for first order serial correlation. Equation (1) indicates that pollution control has had some significant negative impact on MPG, counteracting to some extent the positive price effect.

Equation (2) suggests that miles travelled responds slowly to gasoline prices and income level changes which supports the results of the previous studies. One problem with the model is that, instead of deriving QD as AMT/MPG, Dahl estimates QD as a separate function of gasoline price incomes and automobile stocks. The link between the definition of QD and the estimates of QD is not clarified and could be the source of misspecification error. Thus the author's overall estimated elasticity of demand for gasoline of -0.442, which although stated to represent a short run elasticity must because of the length of the time period covered contain long term effects, should be treated with some caution. Nevertheless, it lies within the range suggested by the previous studies.

3.3.3 U.K. Models

In the United Kingdom whilst there have been attempts to model the demand for gasoline within a framework of auto stock determinants and utilisation, a common approach has been simply to take automobile projections from transport forecasters, apply an energy consumption factor and thereby project fuel demand by this sector. The first approach will be illustrated by a consideration of the Tzannetis model (25) and the second by a brief examination of the U.K. Department of Energy's method (17).

3.3.3.1 The Tzannetis Model (47)

Tzannetis critises the use of the definitional relationship $Q = S*V/MPG$ to determine gasoline demand since data on S, V and MPC often come from very different sources and are based on sample survey data. The differences in sources raise questions about the consistency of the combined series, while the sample basis of the estimates introduces errors which render the exact definition of Q an impossibility. Instead, he proposes a looser link between the variables, replacing 1/mpg by EC, desired engine capacity. Consumers presumably choose the size of engine which yields desired average fuel consumption in an efficient engineering sense.

The model consists of four equations to explain stock of cars (SP), engine capacity (EC), utilisation (M) and finally gasoline consumption (Q). Using data for the U.K. over the period 1955 - 1973, the equations are estimated in deviation log form as:

1. $SP = 5.32\ P + 0.25 YPK - 0.32\ PC + 0.35\ SP_{t-1}$ (OLS)

2. $EC = -0.09\ PG + 0.91\ EC_{t-1}$ (OLS)

3. $M = 0.41\ YPK - 0.22\ PG$ (OLS)

4. $Q = -3.42 + 0.62\ M + 1.41\ EC + 0.77\ SP$ (2SLS)

where YPK is income per head. PG is price of gasoline and P is population. In general the equation fit is very good (R^2 above 0.97) except for the utilisation equation (M with $R^2 = 0.86$) and all the variables are significant and possess the expected signs. Equation 1 implies a fairly rapid rate of stock adjustment with 95% accomplished within three years. Equation 2 suggests a much longer adjustment process for engine capacities in accord with a priori expectation. The overall elasticity of gasoline demand with respect to the price of gasoline ranges between -0.27 in the short run and -1.68 in the long run. Income elasticities are more stable and lie between 0.44 (SR) and 0.55 (CR) largely due to the absence of a Y term in the engine capacity equation. Finally, an independent impact on gasoline demand is exercised by the price of cars, with elasticities of -0.24 (SR) and -0.37 (LR), mediated through the stock equation. This relatively straight forward approach succeeds in capturing most of the effects encountered in a more sophisticated approach. It does so however, at the expense of ignoring potential differences between new and replacement demand for automobiles. If this distinction had been made it is possible that significant credit effects might have been found in line with the author's original intention.

3.3.3.2 U.K. Department of Energy Model (17)

It is perhaps better to refer to the U.K. D.O.E. transport forecasting procedure rather than to an independent model. In fact forecasts of traffic are prepared by the Department of Transport and merely converted into fuel demands by the application of specific consumption factors (C).

This is the final stage of a procedure which begins with estimates of car ownership per head (Y) followed by mileage per car or vehicle kilometres (v). Then total fuel demand is given as (c.y.v.)* population. Car ownership per head is viewed as a logistic function of time, income and cost of motoring (including fuel costs) with a predetermined estimation level S taken to be 0.45 cars per head. The model is (see 2) :

$$y = S/(1 + ((S - Y_o)/Y_o) * (i/i_o)^{-bs} (P/P_o)^{-cs} e^{-as(t-t_o)})$$

so that income elasticity is b(s-y) and price elasticity is c(s-y), both declining as income rises. A wide varity of estimates of b and c are available and values of 5 for b and -3.1 for c are chosen somewhat arbitarily. The second step is to estimate vehicle miles, v which is taken to be a function of motorway development and the rate of growth of GDP per head. Assuming no further major motorway development the model is simplified to:

$$v = 14.3 \quad \text{(GDP per head)} / \text{(1972 GDP per head)}^{0.1}$$

where 0.1 is the rather low vehicle mile per car income elasticity. Finally, specific fuel consumption c is assumed to be a positive function of petrol price and conservation measures. The overall estimate of petrol price elasticity is -0.23 and that of income 1.0 at current ownership levels (2). It is difficult to reconcile elasticities which ultimately decline to zero with the evidence already discussed on short and long run elasticities. This curious implication of the model arises because prices and incomes are only allowed to influence the constant and not the saturation ownership level. It is implicitly assumed that after a certain degree of ownership is achieved the marginal utility of owning further car stock becomes zero. Evidence on two and more car ownership patterns however suggests that there is no fixed upper limit to consumers' desire for personal transportation services and that the logistic model is inappropriate.

3.4 ASSESSMENT OF FORECASTING PERFORMANCE

Only a small number of the energy demand models discussed in this paper have been used for forecasting purposes and even here the interest has been in the long run so that few comparisons of actual with forecast values can be made. Nevertheless, there are certain common problems with the existing forecasts and these emerge from quite straightforward examination of outturns. Of the models discussed in this paper only two - the Hudson Jorgenson and the U.K. D.O.E. models - present consistent forecasts for all sectors, although not for the same time periods. The HJ forecasts relate to 1980, 1985, 1990 and 2000 while those of the U.K. D.O.E. are for 1985 and 2000 only. Again, it should be noted that the HJ forecasts were made much earlier than those of the U.K. D.O.E. (1974 compared with 1978) so that one would not expect the same quality of forecasting performance for any particular year. Finally, in order to obtain U.K. forecasts for 1980 it is necessary to inerpolate between the 1970 and 1985 values given by the U.K. D.O.E. This was accomplished by giving weights of one third and two thirds to the 1970 and 1985 values respectively. The following table gives forecast and actual demands for 1980 for both models:

1980	U.S.A.			U.K.		
	HJ	Actual	Error %	UK DOE	Actual	Error%
	10^{15}Btus			10^{11}Btus		
Industrial	27.736	21.537	+28.8	25.367	19.591	+29.5
Household	22.118	18.181	+21.61	14.733	15.323	+3.8
Transport	22.000	18.556	+18.56	13.666	14.087	-3.0
Other	na	na	na	7.567	7.303	+3.6
Total	71.854	58.274	+23.4	61.333	56.304	+8.9

Sources : HJ (6), UK D.O.E. (53), Monthly Energy Review US D.O.E., Digest of Energy Statistics 1979 and Energy Trends, March, 1981 UK D.O.E.

There are two common features of the forecasts. In the first place both models tend to overpredict total energy requirements considerably despite slightly colder than average weather conditions in both countries in 1980.

For HJ this overprediction is due to some extent to failure to anticipate the large energy price changes which have occurred since 1974. Real energy prices in the U.S.A. rose by about 9% faster than was assumed in the HJ projection. However, against this, the U.S. economy grew more quickly than HJ anticipated - by 4.4% per year between 1975 and 1980 compared with 3.95% forecast - thus modifying the degree of overprediction. The size of error gives further support to the view that elasticities evaluated over pre-1973 time series data underestimates the impact of changes in exogenous variables. By contrast much of the error in the U.K. D.O.E. forecast seems to be attributable to overoptimism about economic growth. Economic growth was projected at 3% per year but only achieved an average of 1.2% per year in the period 1975 - 1980.

The second feature of both forecasts is that the most serious forecasting errors occur in relation to the industrial sector. Rather surprisingly the performance of the more recent U.K. D.O.E. forecast is slightly worse (29.5% over prediction) than that of the American model (28.8% error). The causes are however quite different. In the HJ model no restrictions were imposed on the demand for natural gas which was expected to grow rapidly. In the event, however, price regulation prevented the expansion of natural gas supplies and demands could not be met. The overpredictions of the U.K. D.O.E. on the other hand, seem to be due to undue optimum about the demand for coal (only 60% of the forecast level was achieved in 1980) as well as to lower than anticipated economic growth and particular problems in the steel industry. It is unlikely that much credence will be place in forecasts which proceed not on the basis of tested econometric relationships but on political considerations such as the need to placate powerful sectional interests (e.g., the miners).

The comparison of forecast with actual performance prompts three conclusions. In the first place models must include an adequate specification of the supply of energy if they are to be used for long term forecasting. Secondly, it is desirable that basic assumptions about growth, energy prices etc., should be realistic and bear some resemblance to actually achieved values if rational decisions about investments are to be made on the basis of the forecasts.

Finally, more attention needs to be given to improving the specification and estimation of industrial energy demand models in view of their poor forecasting performance relative to those of the domestic and transport sector models.

4. CONCLUSIONS

This review has shown that energy models of individual sectors exist at quite different levels of development. Throughout each sector progress has been constrained by the availability of data. Only in the transport sector where fuel consumption is linked to a reasonably homogeneous group of historically well documented appliances, (that is road vehicles), and concerned with just gasoline, have models been produced which satisfactorily embrace the principal characteristics of energy demand.

Elsewhere the picture has been less encouraging. In residential and commercial market models have not reached the maturity of the transport sector. Four fuels in place of just one and a split in end uses over space heating, cooking and motive power with numerous different appliances has effectively confined studies within static and quasi dynamic frameworks. Only recently have studies begun to emerge which resemble those of transport markets.

Studies of the commercial energy sector are predominantly combined with residential studies. Heterogeneity of energy end uses and poor statistical documentation have denied this sector all but cursory examination from just a few authors. The former difficulty, that of diversified uses, is largely responsible for the performance of industrial energy models, perhaps the poorest of all sectors.

Sustained attempts to develop models based on rigorous theory have shown continually disappointing results. In the translog approach, the theory itself is partly to blame for perpetuating the use of static models in a dynamic system. Serious problems of aggregation again stemming from heterogeneity of end uses, have also thwarted authors attempts most effectively.

In consequence, this review has not found it possible to identify concensus price and income elasticities for either the short or long run in any sector. Nevertheless, for broad comparison the following four tables set out the main characteristics of each of the studies reviewd and their representative elasticities.

Summary of Industry Sector Energy Demand Models										
Author	Elasticities							Comments		
	Price					Output				Static or
	Short Run				Long Run	Short Run	Long Run	Period	Country	Dynamic
	OWN	CAP/EN	LAB/EN	MAT/EN						
Hudson E.A. and Jorgenson D.W. (1974/1976)	-0.5	-0.18	0.57	-0.46	-	-	-	1947 - 1971	U.S.A.	Static Translog
Griffin J.M. and Gregory P.R. (1976).	-0.79	0.15	0.64	-	-	-	-	1955, 1960, 1965, 1969	9 Countries inc. U.S.A and U.K.	Static Translog
Pindyck R.S. (1979)	-0.75	0.02	0.03	-	-	0.64	-	1959 - 1974	9 Countries inc. U.S.A. and U.K.	Static Translog with Output Term.
Berndt E.R. Fuss M.A. and Waverman L. (1978)	-0.49 to -0.69				-0.47 -0.70	-	-	1947 - 1971	U.S.A.	Static and Dynamic models-Translog
Halvorsen R. (1977)	-0.92 (Electricity) -2.82 (Fuel Oil) -1.47 (N.Gas) -1.52 (Coal)				-	-	-	Cross section of 19:industries 1971	U.S.A	Static Translog
Anderson R. (1980)	-0.26 to -0.19	-0.08 -0.12	0.06 0.05	0.003 0.008	-	-	-	1947 - 1971	U.S.A.	Static Translog:uses net output
Field B.C. and Grebenstein C. (1980) * working capital elasticities	0.53 -1.65	0.16 -0.65	0.15 -0.9	0.01* 0.14*	-	-	-	1971,cross section 10 industries	U.S.A.	Static Translog working Capita

Summary of Industry Sector Energy Demand Models

Author	Elasticities							Comments		
	Price					Output				Static or
	Short Run				Long Run	Short Run	Long Run	Period	Country	Dynamic
	OWN	CAP/EN	LAB/EN	MAT/EN						
Al-Ali H.M. (1979)	0 - by assumption				-	1 - by assumption	-	1973	U.K. - Scotland	Input-Output
Carey M. (1978)	-0.05 (Coal) -0.07 (Oil) -0.07 (Gas)				-	-	-	not given	U.K.	Linear on Prices. Static
U.K. Department of Energy (1978)	not included					75.5Q/ (2413 + 75.5Q)		1960 - 1973	U.K.	Linear on Production Static

Summary of Residential and Commercial Sector Energy Demand Models

Author	Residential or Commercial	Elasticities				Comments		
								Static or
		Short Run	Long Run	Short Run	Long Run	Period	Country	Dynamic
Jorgenson (18)	Residential	-	-0.40	-	0.40	1947 - 1971	U.S.A.	Static
Pindyck (19)	Residential	-0.20	-1.10	-	1.02	1960 - 1974	U.K.., U.S.A. and others	Static
Halvorsen (22)	Residential	-	-1.10	-	0.50	1961 - 1969	U.S.A.	Static
Wilson (23)	Residential	-	-1.33	-	-0.46	not given	U.S.A.	Static
Nelson (24)	Residential Commercial	-	-0.28	-	0.27	1971	U.S.A.	Static
Bloch (25)	Residential	-0.22	-0.60	-	-	1971 - 1976	U.S.A.	Static
Kerry Smith (26)	Residential	-	-0.80	-	-	1957 - 1972	U.S.A.	Static
Hirst (27)	Commercial	-	-0.18	-	-	1977 - 1979	U.S.A.	Static
Chern (28)	Residential Commercial	-	-0.17	-	0.44	1971 - 1972	U.S.A.	Static
U.K. Department of Energy (45)	Residential	-	-	-	-	1950 - 1976	U.K.	Static
Birmingham (16)	Residential	-	-	-	-	not given	U.K.	Static

Summary of Residential and Commercial Sector Energy Demand Models

Author	Residential or Commercial	Elastisities				Comments		
								Static or Dynamic
		Short Run	Long Run	Short Run	Long Run	Period	Country	
Atkinson (29)	Residential	-0.70	-	-	-	1976	U.S.A.	Static
Granger et al (30)	Residential	-	-	-	-	1975 - 1967	U.S.A.	Static
Lawrence et al(31)	Residential	-0.30	-	-	-	1974 - 1976	U.S.A.	Static
Taylor (32)	Residential	-	-	-	-	1975	U.S.A.	Static
Baughman et al(39)	Residential Commercial	-0.13	-0.80	0.10	0.62	1965 - 1972	U.S.A.	Dynamic
Uri (35)	Residential Commercial	-0.21 -0.19	-1.15 -1.28	0.04 0.03	0.22 0.16	1972 - 1978	U.S.A.	Dynamic
Parhizgari et al(37)	Residential	-0.15	-0.15	0.71	0.71	1964 - 1974	U.S.A.	Dynamic
Berndt et al (40)	Residential Commercial	-0.20	-0.69	0.03	0.13	1959 - 1974	Canada	Dynamic
Murray et al (38)	Residential Commercial	-0.06 -0.06	-1.01 -0.59	0.69 0.02	0.69 0.70	1958 - 1973	U.S.A.	Dynamic
Ruffel (34)	Residential	-0.17	-	0.45	-	1955 - 1966	U.K.	Dynamic
Betencourt (44)	Residential Commercial	-0.14	-	0.22	-	1972 - 1976	U.S.A.	Dynamic

Summary of Transport Sector Energy Demand Models

Author	Elasticities				Comments		
	Price		Other				Static or
	Short Run	Long Run	Short Run	Long Run	Period	Country	Dynamic
Gasoline Demand							
Ramsey J. Rasche R. Allen B (1975)	-0.77 (Private -0.70 Commercial		1.34 (Private) 1.15 (Commercial)	Income Income	1947 - 1971	U.S.A.	Static Exponential
Archibald R. Gillingham R (1980)	-0.43		0.28 -0.56	Income	1972 - 1973 (Cross Section)	U.S.A. - 23 Metropolitan areas	Static Translog
Sweeney J (1978)	-0.22	-0.78	0.6 0.013	0.86 Income 0.017 Efficiency	Not defined	U.S.A.	Dynamic Multi- Equation
Pindyck R.S. (1979)	-0.11	-1.26	0.067 -0.32 NR/PC -0.71 R/PC	0.837 Income -0.78 NR/PC -0.71 R/PC	1950 - 1973	11 countries including U.S.A. & U.K.	Cross section Time Series Multi - Equation
Dahl C. (1980)	-0.44		0.23 AMT/PG	0.212 MPG/PG	1936 - 1941 and 1947 - 1972	U.S.A.	Static, 3 Equations
Tzannetis E (1979)	-0.27	-1.68	0.44 -0.24 PC	0.55 Income -0.37 PC	1955 - 1973	U.K.	Dynamic, 4 Equations
U.K. Department of Energy (1978)	-0.23	0	1.0	0	not defined	U.K.	Logis Dynamic

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