A MODEL OF THE DEMAND FOR ENERGY AND ENERGY CONSUMING APPLIANCES IN THE U.K. Theory and Preliminary Results

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ECONOMICS
DEPARTMENT

SURREY ENERGY ECONOMICS
DISCUSSION PAPER NUMBER 11

NOVEMBER 1982

A MODEL OF THE DEMAND FOR ENERGY AND ENERGY CONSUMING APPLIANCES IN THE U.K. - THEORY AND PRELIMINARY RESULTS

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The purpose of this paper is to develope an econometric model of the demand for energy in the U.K. residential sector which takes into account the links between the energy consumed and the appliances utilised in its consumption.

This analysis builds upon and extends two approaches which have been developed recently - one emphasizing the residential dwelling as an essential factor in the production of desired heating levels (see Scott refs 1, 2 and 3) and the other stressing the priority of appliance ownership decisions to the actual consumption of fuel which appears in recent (unpublished) work by Tomlinson. These two approaches are discussed briefly in the next section and then used in the specification of a more comprehensive demand model in the third section. The fourth section describes the estimation of this model over a large cross section time series sample drawn from the Family Expenditure Survey.

A. THE HOUSEHOLD PRODUCTION FUNCTION APPROACH TO RESIDENTIAL ENERGY DEMAND

Various experimental efforts including the Bucknall's Close experiment in the late 1940's and the Better Insulated House project (1972 - 1980) in the U.K. and the Twin Rivers project in the U.S.A. have been made to determine the effects of dwelling characteristics including insulation levels on heat demand. These experiments have involved field trials and classical sampling methods whereby energy consumption is recorded for separate groups of dwellings with distinct design features in order to test for significant differences between types. Unfortunately, very little emphasis is placed in these studies on economic factors, such as fuel prices and household incomes in explaining variations in energy demands so that the results are of little value either in forecasting future energy demands or in estimating the benefits of government subsidy policies towards conservation. Scott (ref. 1 and 2) after subjecting these studies to a highly critical review puts forward a demand model which distinguishes three elements in the consumer's fuel consumption process.

The consumer's house provides him with a production function in which fixed factors (house characteristics (Hm) and heating system) may be combined with a variable factor (fuel inputs (F) in order to obtain desired heat levels (S) with given external temperatures (T).

The production function is assumed to exhibit initially increasing and then diminishing marginal productivity for fuel inputs as the consumer first heats the living area and then progressively raises the heat level in other areas of his house. This assumption, whilst intuitively appealing since it provides one explanation of why relatively poor people spend little of any subsidy they may receive on extra fuel purchases, is not subjected to any empirical testing in Scott's work and plays no role in his estimation procedure. The consumer is assumed to understand and be able to control his heating system so that the production function may be interpreted as supply of heat function as follows:-

$$S = f_s \ (F, T, Hm)$$

A conventional demand function is assumed in order to explain the consumers demand for heat in the second element in Scott's model. Heat demand is viewed as a function of the price of heat (P_1), other prices (P_o), income (Y), wealth (W) and social characteristics (S_i) and is written as:

$$D = f_d \ (P_1, P_o, Y, W, S_i)$$

Unfortunately, desired heat levels are difficult both to define and to observe. Even if it were practical to measure room temperatures throughout all areas of the house, it is not possible to assign unequivocal weights expressing the role of each heat level in the consumers utility function. The final element of the analysis consists in solving out for (observable) fuel consumption (F) by equating supply and demand so that $F = f_e (P_1, P_o, Y, W, S_i, T, Hm)$ and, lastly, replacing P_e by a function of the (measurable) price of fuel input P_f. Scott's model has been estimated over two distinct samples. In the first of these - 110 houses near Edinburgh - data on fuel consumption was available on a quarterly basis for the period 1968 - 1977, yielding over 3,000 usable observations, and application of O.L.S. showed significant and correctly signed effects of house characteristics (number of bedrooms) insulation levels, weather variables (temperature and frost days), and price on fuel consumption. Unfortunately, data on such economic variables as income or weather was lacking.

This could have two effects on the empirical results. In the first place, to the extent that preference for larger houses may increase with income level, the interpretation of the effect of variation in number of rooms as a production effect is incorrect. It implies that the larger house somehow requires greater fuel input in order to attain desired heating levels whereas actual fuel use will vary with the occupant's pattern of occupancy of the house - a demand effect dependent on family composition and economic activity. Thus it would be invalid to use these results for example in connection with forecasts of smaller size housing requirements in the future to predict reduced heating requirements. The second source of bias arises from the composition of the sample which, as noted by the author, consisted entirely of young professional families with no more than two children. The energy consumption behaviour of this group is unlikely to be of much assistance in explaining that of the country as a whole and particularly of poorer groups, including pensioners and single parent families. Allowance is made for income in more recent work (Scott and Capper ref 3), but not for household composition or fuel prices so that the empirical results are not of general applicability.

Two further problems arise with the Scott and Capper-Scott approaches. Whilst the model purports to explain the consumption of fuel for heating purposes, only data on total fuel consumption is available to measure the dependent variable. Since non-heat usage of fuels is a significant part of total fuel consumption, and is likely to vary with income levels, a familiar econometric problem of errors in variables occurs leading to biased estimates of some of the coefficients. Thus any estimate of the income elasticity must be interpreted as a composite energy elasticity. As such it has limited relevance to the assessment of government conservation policy, the emphasis of which has been upon reducing the demand for fuel for heating purposes.

The other limitation of the model is that it does not take into account changes in the technology of fuel consumption through the use of appliances. Both studies considered electrical demand only and related to dwellings with homogeneous fuel equipment. However, the most significant way by which domestic fuel consumption has changed in the past decade is through the replacement of single room heating by central heating systems. On the one hand such systems permit the owner much greater control over dwelling heat levels so that the marginal rate of substitution between fuel input and external temperature is greater.

On the other hand, the technical complexity of such systems tends to impose a rigidity of response of fuel input to external weather conditions as owners may be unsure about how optimally to adjust their heating systems to take account of fuel price changes.

B. THE OWNERSHIP OF ENERGY CONSUMING APPLIANCES

Early studies of the demand for energy (Fisher and Kaysen ref 4) emphasised the link between fuel consumption and appliance ownership. Their results were however, marred by lack of published information on stock or ownership levels thus hindering the direct estimation of joint energy/appliance demand functions. In spite of such problems, it has been argued that structural changes in the U.K. demand for energy can only satisfactorily be explained by including appliance stock levels as an explanatory variable (Peirson P.21, ref 5). It is likely following Pyatt (6) that over time appliances change from being luxuries to being necessities as ownership spreads and that this would be reflected in altered income and price elasticities. These points have been incorporated in Tomlinson's recent extensive analysis of the demand for fourteen electricity and gas appliances and their associated fuel demands using cross section time series data. Tomlinson's model consists basically of a set of equations explaining appliance ownership levels (Y) average consumption of fuel per appliance per consumer (AC), number of domestic fuel consumers (Nt) and finally, total fuel consumption (E_t) as the product $N_t\ (\Sigma_j\ Y_{jt}\ AC_{jt})$ where

$$Y_{jt} = a_{oj}Y_{jt-1}(a_j-Y_{jt-1})\ (b_{oj}+c_{oj}I_t+d_{oj}P_{kt}+e_{oj}C_t+f_{oj}C'_t)$$

$$AC_t = a_1+b_1P_t+c_1DM_t+d_1I_t \quad \text{(for space and water heating)}$$

$$N_t = a_2+b_2Pop_t+c_2NHH_t$$

and j = appliance type j, I_t = real permanent income, P_k = real durable price index, C_t = real credit outstanding, C'_t = real new credit extended on durables, Dm = degree months Pop = population, P_t = relative price of durables of other discretionary goods and NHH = number of persons per household.

In the ownership equation, changing elasticities are allowed for by prior estimation of a_{oj} as a logistic function of time, factoring out of $a_{oj}\ Y_{jt-1}\ (a_j - Y_{jt})$ and estimation of the rest of the equation by O.L.S. This type of specification ensures that ownership elasticities with respect to prices, incomes and credit vary with penetration levels rising from low values, through high values and returning eventually to low value as the market saturates reflecting the familiar 'S' shape of the logistic function. It does not however, provide any economic explanation of this process but does imply irreversibility which, in view of recent declines in the ownership levels of certain forms of electric central heating is undesirable in a forecasting model.

The equations explaining average consumption and numbers of consumers are useful first approximations to a more complicated relationship between household composition, dwelling characteristics and appliance utilisation. This relationship will be developed in the next section in the context of an overall economic model of the demand for fuel and fuel using appliances.

C. MODEL OF RESIDENTIAL ENERGY DEMAND

(i) The Level of Aggregation

There are good apriori grounds for believing that different types of households are likely to differ markedly in their fuel consumption patterns. Thus pensioner households whose members are likely to be more sedentary in their habits are likely to give high priority to adequate heating provision than are other households at comparable income levels. Demand elasticities are also likely to vary systematically for households with young children and also with higher occupancy rates (e.g., through members being unemployed). We assume a common utility function for each household type j which may differ in the weight placed on different goods in the function.

(ii) Model of the Utilisation and Choice of Central Heating

The model developed here has the following component parts -

an analysis of utilisation and thermal comfort, a utility function displaying trade offs between central heating and non central heating ownership and operation which enables conditional energy consumption and then ownership to be determined. Since energy inputs are required to overcome differences between desired indoor and actual outdoor temperatures, the actual utilisation of energy by a central heating system can be represented for given household type, as a function of the number of rooms at a particular temperature times the temperature difference adjusted for solar gains, where control is achieved by means of a thermostat.

$$H(\tau) = \int_{-\infty}^{\tau} (\tau-t)\ f(t)\ dt - C_1 = \tau F(\tau) - \int_{-\infty}^{\tau} t f(t)\ dt - C_1$$

where

$H(\tau)$ = utilisation (heating degree hours) for thermostat setting τ degree

$f(t)$ = probability density of t $[F(\tau) = CDF]$

C_1 = gains from solar, etc., structure of dwelling etc.

Obviously, C_1 will vary with the thermal resistance of the materials of which the dwelling is made, as well as occupancy patterns and adventitious gains from solar energy and other appliances. This function will be used in the calculation of heating costs. At the same time the thermal comfort (Z) supplied by a system will vary directly with the temperature to which the indoor atmosphere is raised (τ), thus Z (τ) is equal to the control temperature times the probability of experiencing indoor temperature of τ or less.

$Z(\tau) = \tau \int_{-\infty}^{\tau} f(t)\ dt - C$, where C is an allowance for a possible upper limit to comfort.

Available evidence suggests that far from there being a fixed internal temperature at which all families attain an equilibrium level of comfort, such as is assumed in many physical models of energy demand, observed indoor temperatures have increased steadily over time with improving living standards (ref: 7). This suggests the adoption of a diminishing marginal utility functional form to model the link between indoor temperature and utility. Households decisions as to central heating ownership are assumed to be based on a trade-off between the utility of other goods and central heating and other fuel uses. Other goods are represented in the household utility function as the difference between income and expenditure on central heating consisting of capital and running costs. Specifically $U = \upsilon\,(Y - pF - r,\ Z\,(\tau),\ F - \frac{\eta\lambda}{EER}\,H(\tau))$ where p is running cost of CH, r is capital cost, η = occupancy factor, EER = efficiency of appliance. $\lambda = \mu BTU$ = capacity of appliance. Before we define p and r it is useful to derive the optimal combination of other goods and central heating for any household. This can be done, following Hausman (1979 ref 8) by differentiating υ with respect to τ, the thermostat setting which may be assumed to be a continuous variable within a wide range of values

$$\partial\upsilon/\partial\tau = \upsilon_2\ \partial Z(\tau)/\partial\tau + \upsilon_3\left(\frac{-\eta\lambda}{EER}\ \frac{\partial H(\tau)}{\partial\ \tau}\right)$$

$$= 0$$

i.e. $\upsilon^2/\upsilon^3 = \eta\lambda/EER$

Where υ^2 and υ^3 are derivatives of υ with respect to arguments 2 and 3 in the utility function.

$$\text{now}\quad \partial\upsilon/\partial F = \upsilon_1\ (-p) + \upsilon_3$$

$$= 0$$

$$\text{i.e.}\ \upsilon_3 = p\upsilon_1$$

$$\upsilon_2/\upsilon_1 = p\eta\lambda/EER$$

The first order conditions give us $\upsilon_2/\upsilon_1 = p\,\frac{\eta\lambda}{EER}$ which is the familiar condition that for optimal thermostatic setting the marginal rate of substitution between central heating and other goods is equal to the marginal cost of heating corrected for efficiency. This marginal condition can be used, together with a specific functional form for $H(\tau)$ and $Z(\tau)$ to derive appliance utilisation and ownership functions. Relative to other goods (and other fuel uses) it is plausible to assume that the marginal utility of comfort declines more rapidly at higher levels. Thus we choose to enter comfort as a logarithmicvariable but other goods and fuel uses linearly in the assumed utility function.

$$U = \upsilon(Y - pF - r, \alpha \log(Z(\tau)), F - \frac{\eta\lambda}{EER} H(\tau)$$

We use the marginal conditions to derive fuel use as follows

$$\upsilon_2 = \alpha/Z(\tau) = p\eta\lambda/EER$$

or $Z(\tau) = \alpha \; (1/\frac{p\eta\lambda}{EER})$

Now $H(\tau) = Z(\tau) + HDD$

The demand for fuel for heating F_h is therefore

$$F_h = H(\tau) \frac{BTU}{EER} \mu$$

$$= \frac{BTU}{EER} \left[\mu \frac{\alpha}{p\eta} \frac{EER}{BTU} + \delta \; HDD \right]$$

$$= \mu\alpha/p\eta + \delta \frac{BTU}{EER} HDD$$

But F_h is not known, only $F = F_h + f$

Therefore $F = \delta_1 \; (1/p) + \delta_2 \; (BTU/EER) \; HDD + \delta_3$ (pensions, income) where f is a function of income, numbers in family etc. Since BTU capacity is largely determined by the physical house characteristics, we may replace it by a function of the number of rooms and arrive at a final form for F of:

$$F = \delta_0 + \delta_1 \; (1/p) + \delta_2 \; (\text{Rooms}) \; (\text{HDD}) + \delta_3 \; (\text{income, persons}) \; (\text{given efficiency}) \qquad (1)$$

This equation can be estimated by O.L.S. over a sample of households to explain energy utilisation including optimal comfort conditions from which short run energy demand elasticities may be calculated.

The ownership of central heating appliances is explained in terms of a choice model whereby owners are assumed to own ch_i when $u_i > u_j$ (all $j/_i$). Although there is a small number of households who own combinations of ch systems, these can be ignored and the choices can be treated as mutually exclusive. The theory of choice between mutually exclusive alternatives was developed largely to explain choice of transport mode (ref 9), but has recently been applied to choice of consumer durables by Hausman. To explain the choice between owning and not owning central heating, we let the utility derived from alternative i, $u_i = v_i + \varepsilon_i$ where v_i is representative utility and ε_i is a random component reflecting the idiosyncrasies of individuals (Hensher and Johnson, Page 29) and $v_i = \Sigma\beta_i x_i$ a function of individual and commodity attitudes. The choice criteria can be expressed as:

choose i if $v_i + \varepsilon_i > vj + \varepsilon j$ or $(v_i - v_j), > (\varepsilon_j - \varepsilon_i)$

So the probability that i is chosen equals the probability that the difference of the random utilities is less than the difference between the representative utility levels of i and j. Assuming the distribution of $(\varepsilon_i - \varepsilon_j)$ is random across the population, we need a statistical distribution to permit estimation of $u_i - u_j$.

To clarify, $P_i = p\,[(\varepsilon_j - \varepsilon_i) < (v_i - v_j)]$ the probability of i being chosen.

There are various contenders to describe the distribution of the $(\varepsilon_j - \varepsilon_i)$s including probit (simple or multinominal) and logit. We choose the logit distribution for three reasons:

1. It closely approximates the normal distribution
2. It is much easier to evaluate
3. Empirical investigation reveals little difference between logit results and those obtained by applying more sophisticated methods.

$$P_{iq} = 1\,/(1 + e^{-(\varepsilon i - \varepsilon j)}) \quad = \quad 1/(1 + e^{-\Sigma\beta_i x_i})$$

This function has to be estimated by maximum likelihood methods since P_{iq} is unobservable and the probabilities must sum to unity. The method of maximum likelihood chooses values for β such that the likelihood of the actual choices arising from this type of probability function is maximised. We use the logit transformation of P_i to $\log P_i/1-P_i = \Sigma\beta_i x_i$, largely because of availability of suitable software.

The utility of central heating system i is given after substituting for optimal comfort $Z(\tau)$ and incorporates the determinants of non-heat demand for energy (income, persons) as

$$U_q = \Sigma\beta_1 x_i = \beta_0 + \beta_1 Y + \beta_2(pF) + \beta_3 r + \beta_4\ (1/p\ \text{Rooms}) + \beta_5\ (\text{persons}) \qquad (2)$$

It should be noted that the fourth term implicitly contains the assumption of constant efficiency. For forecasting purposes one needs explicity to model the development of efficiency and the trade-off between cost (capital cost) and efficiency (running cost).

D. EMPIRICAL ANALYSIS

A major limitation of previous empirical work in this area has been its restriction to specific types of energy consumers, often highly unrepresentative of the population as a whole. Apart from the energy industries own marketing surveys, there are two official surveys which provide national coverage and collect data on appliance ownership - the General Household Survey and the Family Expenditure Survey.

The main reasons for preferring the Family Expenditure Survey are firstly, that it provides a longer historical record (CH ownership since 1968) and secondly that unlike the General Household Survey, it obtains information on expenditure on fuels, both in value and in physical unit terms, and finally, that extracts from survey tapes are available one year after the publication of the Family Expenditure Survey Report.

Data tapes on subsamples of approximately 1,000 households for each year from 1968 to 1979 were sought from the SSRC Survey Archive at Essex University. So far, tapes have been made available for the year 1968 to 1975 and for 1978, and these have been subjected to preliminary analysis on the University of Surrey's Prime computer. In this paper, some results from the analysis of the 1978 tapes are given and this will be followed in due course by a complete analysis of the period 1968-1979.

The strength of the Family Expenditure Survey lies in its extremely detailed data on consumers income, fuel spending patterns, household composition, housing ownership and size of property. Data on central heating ownership of gas, electric, oil and solid fuel systems (part and complete) is recorded (since 1970), together with ownership details of the major electrical appliances, TV, CTV, refrigerators, washing machines. Although the survey relates to periods of fourteen days per household, information on gas and electricity expenditure is obtained from the most recent quarterly bills enabling seasonal relationships to be established. Problems arise in the interpretation of recorded expenditure on solid fuels and oil, since only actual expenditure within the fortnight is recorded. Briefly, the data understates the number of oil and solid fuel transactions made in the year and complicates the statistical analysis by failing to distinguish between non-buyers and those whose purchases were made outside the survey period. To some extent bias may be avoided by including only recorded purchases of these fuels in the estimation of the appropriate utilisation equation.

(i) <u>Fuel Expenditure and Utilisation</u>

Equation (1) was estimated by O.L.S. for total fuel expenditure (FLPEXP) and for gas (GEXP), electricity (ELEXP) and other (TOILSFEXP) fuel expenditure separately. Preliminary analysis showed that the linear model was superior to an alternative log linear formulation and also established that dividing the sample into distinct household categories did not improve the estimates. This latter result suggests that, for example, retired households energy consumption behaviour is explained adequately by income and family size variations and does not require special factors outside the model. Size of family emerged as one of the most important explanatory factors and this was refined by including separate variables for children in various age categories (CHILD L2, CHILD 25, CHILD 578) and a single variable for adults (ADULT). Finally, significant seasonal variation not attributable to degree day variation was found and allowed for by the inclusion of quarterly dummies (QDUM 2 to QDUM 4).

The impact of central heating on demand is tested by including dummy constant and slope effects for RHDD and price (CH, RHDD and $CHINP_i$ where i is fuel i). Systematic variations due to differences in conditions of tenure and in region are analysed by a standard F test procedure and were generally found not to be significant at either 0.01 or 0.05 levels (see Table 1). The goodness of fit varies considerably depending upon the fuel dependent variable, the best fit being obtained for gas (GEXP) (R^2 = 0.64), then electricity (R^2 = 0.36) followed by relatively poor results for FLPEXP (0.24) and other fuels (0.15). It should be noted however, that high R^2 values are not encountered in cross section analysis and that the results here compare favourably with similar studies (ref 8). The income variable (GROSSINC) has a significant but small impact in the FLPEXP and ELEXP equations but not in the GEXP or TOILSFEXP equations, reflecting the link between electricity consumption and ownership of non-basic durable goods. Ownership of central heating (CH_i) is highly significant for both gas and electricity consumption and has a significant impact on the slopes of the Rooms x Degree Days variable (RHDD). This result tends to support the hypothesis that CH owners adjust their fuel consumption much more readily to weather changes and in proportion to the size of their dwellings than do non central heating owners.

In fact, the constant in the RHDD effect is non significant on its own and only becomes significantly positive in combination with ownership of central heating. In contrast, the price variables performed less well with correctly signed (positive) but non significant co-efficients. This is perhaps not surprising in view of the limited amount of variation in prices which could be incorporated in the estimates. Regional prices for each fuel given in the Energy Digest of the Department of Energy were converted to useful thermal equivalent prices and allocated to each household on the basis of regional location. Improved results may be expected from the complete pooled time series cross section analysis which is currently being prepared. The effect of family size was much clearer and indicated

TABLE 1 : FUEL EXPENDITURE EQUATIONS 1978 $(£x10^{-3})$

	FLPEXP	GEXP	ELEXP	TOILSFEXP
CONSTANT	30229.6	-4370.7	-5331.8	58028.1
GROSSINC(E-02)	0.325 (9.9)	0.028 (0.4)	0.364 (25.4)	0.265 (1.5)
CH_i	142.5 (0.5)	532.8 (27.6)	5957.9 (9.2)	-
CH_{ni}	-	-148.4 (4.5)	-357.96 (15.7)	-
RHDD(E-02)	-0.405 (0.5)	-0.0885 (0.1)	-0.851 (5.6)	1.555 (2.0)
CH_iRHDD(e-01)	0.195 (10.1)	0.264 (73.0)	0.331 (23.1)	0.039 (0.1)
INP_i		3996.4 (0.1)	94043.1 (1.1)	-2521381 (1.5) SF -38883 (0.1) OIL
$CHINP_i$		-	-490663.1 (7.2)	
$CHILDL_2$	795.5 (13.0)	11.9 (0.0)	583.6 (14.2)	782.8 (2.6)
CHILD 25	317.1 (3.8)	73.2 (1.1)	277.8 (6.0)	285.8 (0.8)
CHILD 518	350.6 (27.5)	99.5 (11.2)	298.9 (41.7)	-233.9 (3.6)
ADULT	552.7 (28.7)	149.4 (10.9)	386.9 (29.8)	100.3 (0.2)
GSUP	-195.6 (2.5)	1245.7 (354.7)	-585.9 (39.5)	-1126.4 (25.6)
EUSUP	-191.1 (2.5)	-15.7 (0.1)	-171.5 (4.1)	-
INPGAS/EL	-	-23486.5 (0.2) (el)	28362.7 (1.5)	-
INP_{sf}	-	1886.3 (0.0)	-130374.6 (8.8)	-
QDUM 2	91.1 (0.3)	196.96 (6.2)	244.3 (3.95)	-433.9 (1.7)
QDUM 3	-514.6 (9.8)	-62.3 (0.7)	-214.4 (3.4)	-180.6 (0.3)
QDUM 4	-138.3 (0.5)	-182.4 (4.1)	-359.8 (6.6)	803.3 (4.6)
N_i	-	-222.5 (13.5)	-297.2 (5.8)	-
MAWOM	25.3 (0.0)	95.7 (2.5)	-5.3 (0.0)	-160.7 (0.4)
REGIONS (10)	F = 0.77	F = 0.18	F = 2.08	F = 1.40
TENURE (4)	F = 5.08	F = 0.03	F = 0.99	F = 2.07
DF	22/1037	20/1039	21/1038	23/311
R^2	0.24	0.64	0.36	0.15
F	14.6	91.7	27.7	3.4

substantial differences in energy consumption between different age groups with children less than two years old and adults being associated with approximately twice the electricity and other (non gas) fuel expenditures than other individuals. Finally, a rather unsuccessful attempt was made to allow for differential occupancy of dwellings by including the binary variable MAWOM - 'married woman not working'. Although the presence of a MAWOM led to a significant but small increase in gas expenditure, for other fuels the effect was not significant. Unfortunately, data on actual occupancy behaviour is not available and indirect measures require strong assumptions about behaviour which do not appear to be justified.

(ii) The Ownership of Central Heating

The basic assumption behind the model of central heating ownership (equation 2) is that consumers will tend to own central heating when the utility of the optimal heat level with central heating exceeds that obtainable without central heating. This utility is however not observable and can only be estimated indirectly by using actual choices as indicators of preference. A logit model with log (Pch/1-Pch) as the dependent variable (Y) was estimated by maximum likelihood methods using the program WALDUN made available by the London School of Hygiene and Tropical Medicine. Briefly, y was given the value 1 when a household was observed to possess central heating and zero otherwise and the co-efficients estimated so as to maximise the log likelihood L (B) by the method of interactive weighted least squares. These are co-efficients most likely to generate the observed set of ownership situations.

Preliminary analysis showed that numbers of persons in the household did not contribute significantly to the log odds of central headting ownership and the variable was dropped from subsequent estimates. This result is perhaps not surprising in view of the strong positive association between family size and income levels. It was necessary also to exclude the capital costs of central heating (r) since information obtained from building industry sources including Laxtons Building Price

Book, indicated an approximate equality between the total installation costs (boiler costs plus labour) for all systems.

Initially the model was estimated for total central heating ownership with $y = \log\left(\frac{P_{ch}}{1-P_{ch}}\right) = \beta_o + \beta_1 Y + \beta_2 \frac{1}{P.RMS} + \beta_3 F$ using the entire subsample (1073 observations). Significant and correctly signed co-efficients were obtained for income (GROSSINC) and optimum utilisation (INPiRMS) - See Table 2, Column 1 - and a chi-squared test of the likelihood ratio indicated that tenure differences exert a significant influence on the log odds of central heating ownership. In particular, the log odds of householders who live in private unfurnished dwellings owning central heating, were reduced by 0.86 (i.e., a 73% reduction in probability of ownership) whereas those for owner occupancies were increased by 0.57 (a 64% increase in probability of ownership) from mean values.

The results imply an income elasticity of central heating ownership of 0.25 at mean income and central heating levels since $\eta y = y\beta(1-P_{ch})$ in the logistic model. It should of course be noted that this elasticity declines as the probability of central heating ownership increases.

The remaining columns of the table present results obtained from a fuel by fuel central heating choice model. The population is divided into four subsamples each containing only those who own one type of central heating and those who own none. Then for each subsample log

$$\left({}^{P_{chi}}/_{1-P_{chi}}\right) = \log\left(\frac{P_{chi}}{P_{noch}}\right)$$ is estimated by maximum

likelihood.

The probability of non ownership can be derived from the sum of the P_{chi}/P_{noch}'s. As in the case of fuel expenditure, the gas central heating choice model performs better than those for the

TABLE 2 : LOG ODDS OF CENTRAL HEATING OWNERSHIP

	C.H.	CH GAS	CH ELECT.	CH S.F.	CH OIL
CONSTANT	2.94 (1.35)	2.01 (.72)	7.09 (2.06)	-9.11 (-1.94)	4.67 (0.79)
GROSSINC (E-05)	0.55 (4.38)	0.67 (4.19)	-0.12 (0.60)	0.56 (2.39)	0.59 (2.58
INP$_i$RMS	0.51 (1.84)	0.74 (1.92)	1.07 (2.52)	-1.07 (-1.73)	1.19 (1.51)
GEXP (E-02)	-	0.11 (10.08)	-	-	-
ELEXP (E-02)	-	-	0.04 (6.34)	-	-
FLPEXP (E-04)	1.59 (4.51)	-	-	-0.16 (-0.24)	3.25 (3.88)
GSUP	-	0.23 (0.66)	-0.99 (-4.42)	-1.59 (-5.77)	-1.83 (-4.67)
REGION	-	significant	significant	significant*	significant
TENURE	significant*	significant*	significant*	significant	significant*
X^2 (due to I.V)	92.3	352.8	112.0	85.7	111.4
DF	9	8	8	14	8
N	1073	815	639	575	556

other fuels with a X^2 likelihood ratio due to the model of 352.8 well above the critical value (0.01 level). The income co-efficient is similar for gas, oil and solid fuel central heating but is negative and not significant for electric systems. This may be due to the influence of local authorities on the acquisition of electric central heating in public sector housing irrespective of tenants income levels and preferences. The high value of the constant term in the CHEL equation measures the increased odds of electrical central heating ownership in local authority property as may be seen from the following analysis of tenure effects in rented property.

Log odds due to Tenure	Local Authority	Private Unfurnished	Private Furnished	Rent Free
→	7.09	6.21	5.70	6.46

Except for solid fuel, the influence of specific fuel expenditure (pf) is positive, suggesting that the utility of non heat uses of fuel is being measured by this variable rather than that of non fuel expenditure. This may result from the smallness of pf in relation to total expenditure and its dominance by the latter. Finally, the existence of a gas supply is seen to have a positive impact on the odds of gas central heating ownership but a negative affect on all other types.

CONCLUSIONS

Analysis of a sample of 1073 households from the Family Expenditure Survey, 1978, tends to support the two stage hypothesis of fuel use put forward in this paper. On the one hand fuel use (expenditure) is seen to depend crucially upon the possession of central heating and upon the households and dwelling characteristics of the consumer. On the other hand, ownership emerges as a function of household income and decision maker type as determined by dwelling ownership with local authority ownership tending to bias the choice of central heating systems towards electricity. Because of the representative nature of the data the model may be used to evaluate a wide range of future scenarios without requiring the rather naive engineering and political assumptions of many existing models.

ACKNOWLEDGEMENT I am indebted to the Social Science Research Council for financing this work through a Senior Research Fellowship.

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APPENDIX - VARIABLE DEFINITIONS

GROSSINC	Household gross income (£ E-03 per week)
RHDD	No rooms x Heating degree days per Quarter
CHiRHDD	Central heating (1 or 0) x RHDD
INPi	Inverse price for fuel i
CHINPi	Central heating x INPi
CHILDL	No of children in household less than two years old
CHILD25	" " " " " between two and five
CHILD518	" " " " " between five and eighteen
ADULT	No of adults in household
GSUP	1 if any gasexpenditure, 0 otherwise
EUSUP	1 if any units supplied, 0 otherwise
INPGAS/EL	INPi for i=gas, el
Ni	Expenditure on some other fuel (1 if positive)
MAWOM	1 if married woman not working
REGIONS	Standard Regions
TENURE	TRPU private rented unfurnished, TRPF private rented furnished, TOM private owner occupied, TRFREE rent free.
INPiRMS	Log of inverse of price x rooms
FLPEXP	Total fuel light and power expenditure
GEXP	Gas expenditure less rebates
ELEXP	Electricity expenditure less rebates
TOILSFEXP	FLPEXP - GEXP - ELEXP