The Household Demand for Energy and Energy using Appliances in the U.K.

David Hawdon

Surrey Energy Economics Centre
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Introduction

In this paper I develop a model of the demand for energy in the domestic sector of the U.K. economy. This model takes into account explicitly the complementary relationship which exists between central heating appliances and the fuels used in these appliances in order to produce heating and other characteristics desired by householders. The choice of appliance and of fuel consumption level is viewed as the outcome of a joint optimisation process in which households are assumed to make a prior calculation of optimum fuel use over the set of appliances available and to choose the appliance which exhibits minimum cost. Finally the household determines the actual fuel use not only in the light of this prior decision but also with reference to current levels of price, temperature, and other variables. Following a brief introduction to domestic sector energy demand, the model is formally developed and econometric estimates presented. The model is used firstly to explain the changes which have occurred in energy demand over the period 1970 to 1982 and then to estimate long and short run income and price elasticities.

The domestic sector is the single largest energy market in the U.K. having surpassed the 'other industry' market in 1981. Not only has energy consumption in this sector increased (from 14639 to 15569 million therms between 1970 and 1982 - see Table 1) but its share in total final energy consumption has grown from 25.3% to 28.7% over the same period. This is perhaps surprising in view of the substantial increases in the real costs of energy over the period. It also contrasts with the course taken by energy demand in certain other "developed" countries. In the OECD area as a whole (see Figure 1) residential energy demand fell by just over 5% in the period. However, both in the USA and in Germany in particular, the decline has been much more substantial (13% and 28% respectively). Britain, although by no means comparable to Japan where consumption increased by almost 60%, occupies a position similar to countries like France whose demand is slightly higher at the end of the period. The UK is, however, like Japan in that its residential demand is actually greater in 1982 than in 1973. The implication of this casual inspection of data is that some one or group of factors distinguishes the history of energy

TABLE 1

Energy Demand in the U.K. Domestic Sector 1970-1982

(million therms)

	Solid Fuels	Gas	Elect.	Oil	Total
1970	7137	3542	2929	1335	14643
1971	6136	3930	2754	1321	14141
1972	5397	4509	2966	1523	14395
1973	5318	4815	3116	1668	14917
1974	5059	5384	3161	1482	15086
1975	4343	5891	3045	1434	14713
1976	4009	6194	2905	1435	14543
1977	3073	6590	2932	1450	15045
1978	3736	7261	2929	1443	15359
1979	3800	8225	3061	1405	16501
1980	3313	8439	2939	1125	15816
1981	3090	8764	2882	1014	15750
1982	3078	8719	2825	947	15569

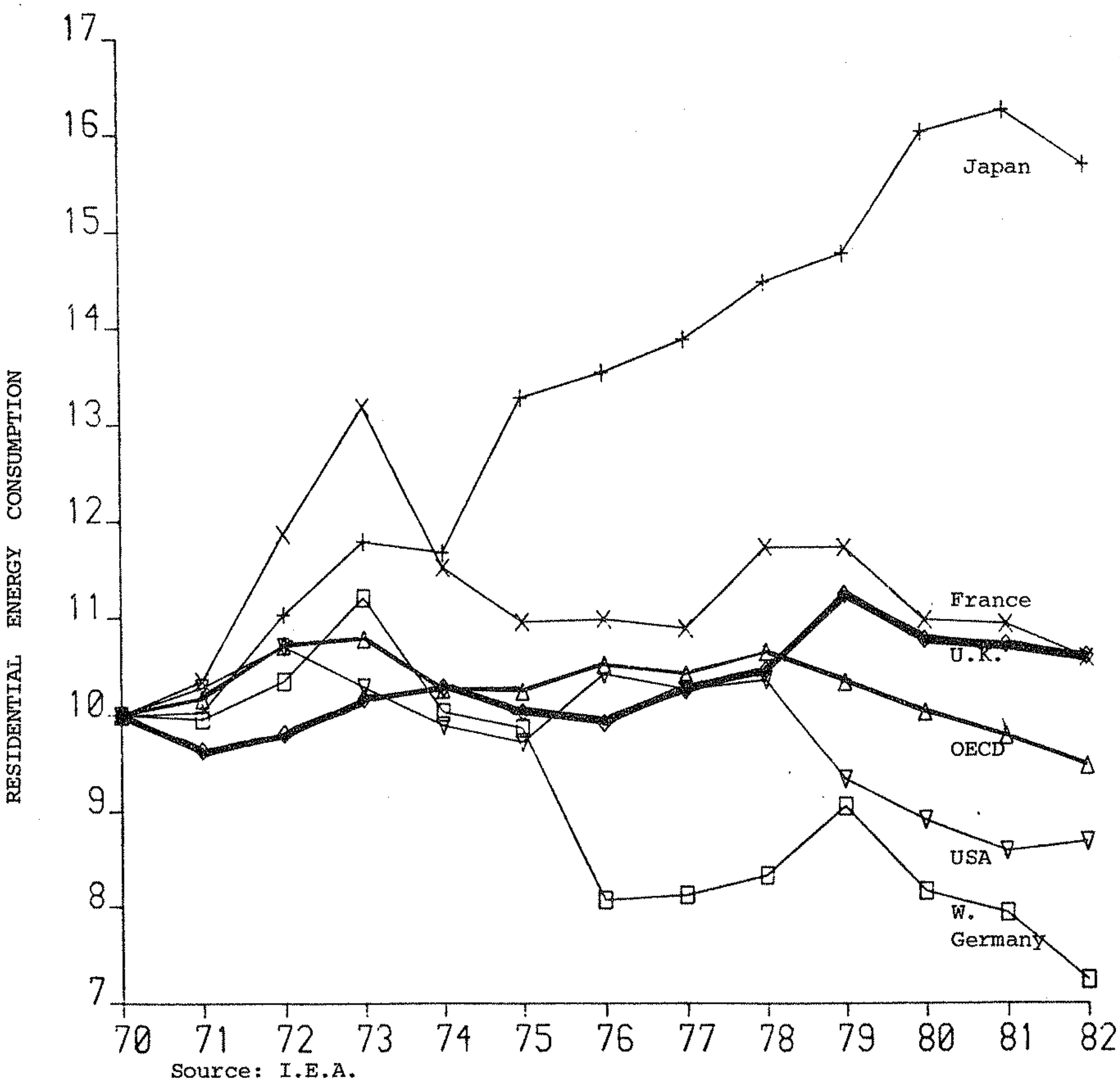
Source: Digest of U.K. Energy Statistics various issues

FIGURE 1

RESIDENTIAL ENERGY CONSUMPTION IN

OECD, USA, JAPAN, FRANCE, WEST GERMANY, UK

(1970 = 100)



Source: I.E.A.

1970 to 1982

demand in the UK. We shall argue that this factor consists in the unique stock of energy consuming durable goods and of central heating in particular acquired in the UK during this period.

Central heating, ie the provision of heat throughout all or part of the dwelling from a single controllable source either via radiators (so called wet systems) or air ducts (warm air systems) or electric storage heaters separately metered, was available in less than 30% of UK households in 1970. Although the available data is based on sample surveys leading to some differences between estimates, by 1982 it seems that the situation was almost reversed to the extent that just under 40% were without any form of central heating (see Table 2). This remarkable change in heating equipment is likely to have had the following effects on energy demand:

1. a substitution of more for less efficient heating systems leading to a reduction in energy input to achieve existing heating standards.

2. a reduction in the marginal cost of heat supplied to previously unheated parts of the dwelling leading to an increased demand for energy input.

3. a reduction in the costs of controlling the system leading to greater responsiveness of energy input to climatic changes.

4. an increase in the complexity of the technology of home heating leading to increased use of energy inputs by consumers with inadequate information or technical knowledge eg. the elderly.

TABLE 2

HOUSEHOLDS WITH FULL OR PARTIAL CENTRAL HEATING

According to

	General Households Survey (GHS)	Family Expenditure Survey (FES)
1970	-	29.6
1971	34	32.2
1972	37	37.4
1973	39	38.5
1974	43	43.0
1975	47	46.7
1976	48	47.1
1977	51	50.8
1978	52	53.8
1979	55	55.0
1980	57	59.1
1981	59	60.5
1982	60	62.8
1983	64	63.9

Note: (1) GHS survey is based on a sample of approximately 12,000 households in Great Britain, commenced in 1971 (see General Household Survey: Introductory Report. HMSO 1973)

(2) FES survey is based on a sample of approximately 7,000 households covering the whole of the UK (ie including Northern Ireland). Although continuous surveys have operated since 1957, data on central heating is only available (continuously) from 1968. In 1964 a household equipment distribution indicated a 7% central heating "possession" level.

The Model of Residential Energy Demand00

Our model of residential energy demand has been fully discussed elsewhere (Hawdon 1982) so that only a brief discussion is necessary. Apart from any other characteristics, households are assumed to derive utility from the "thermal comfort" (Z (T)) supplied by a heating system set at temperature T.

$$Z(T) = T\int_{-\infty}^{T} f(t)dt - c_1$$

where $\int_{-\infty}^{T} f(t)$ is the cumulative probability of experiencing temperatures below T in any given period and C represents an upper comfort limit. In other words whenever the given temperature is less than T degrees the household is supplied with the comfort of T degrees by its central heating system. We impose no upper limit on Z(T) for two reasons. In the first place a wide gap exists between average indoor temperatures and the so called psychologically neutral temperature of 34^{o} C and secondly people are able to choose varying amounts of clothing, work and heat input to achieve any desired environmental temperature. There is also some evidence to suggest that actual indoor temperatures have tended to increase through time (see McIntyre 1980).

A household production function for thermal comfort is specified as $Z(T) = k_1 H(T)$ where H(T) is the utilisation of the households central heating system in terms of days of use and kl is the capacity of the system. Utilisation (H(T)) is

$$H(T) = \int_{-\infty}^{T} (T-t)f(t)dt - c_2$$

where (T-t) measures the temperature difference to be overcome by the system and C_2stands for temperature gains through building fabric, solar effects and so on.

The household then is assumed to compare the benefits of extra thermal comfort Z(T) with the sacrifices of other items in its budget schedule (y - pH(T))) where y is household income and p is the price of energy. To model this process we adopt the following utility function

$$u = u((y-p(kH(T) + F_{nh}), a\log Z(T))$$

where Z(T) appears in logarithmic form to allow for likely diminishing marginal utilities of heat at high levels of temperature. The optimum level of Z(T) can be obtained by differentiating this function with respect to T, the thermostat setting. Since

$$\delta H(T)/ \delta T = \delta Z(T)/\delta T,$$

optimal $Z(T) = a/pk$

The optimal value of T can also be obtained by solving

$\int_{-\infty}^{T} Tf(t)dt = a/pk$ but only if f(t) is known.

We begin to define the demand for energy by first noting the link between H(T) and degree days in the period. It can be shown that

$$H(T) = Z(T) + HDD - \left(\int_{\infty}^{t_0} t_0 f(t)dt + \int_{t_0}^{T} tf(t)dt\right)$$

where HDD = degree days per period measured from base t_o. Since degree days in the UK are measured from 15.5^oC, $t_o = 15.5$. The first term in brackets clearly varies only with temperatures below t_o and is closely linked with HDD so that HDD can be used as an instrument for the two variables combined effect. The second term varies not only with temperature but also with T, the chosen thermostat setting, which is not only a function of price, as we have seen, but also depends on the level of y. Thus the second term is a combined temperature price and income interaction effect which will be approximated by HDD.p.y.

Next, the demand for fuel for heating F_h is stated as

$$F_h = kH(T)$$

$$= k(a/pk + HDD + HDD.p.y)$$

$$= a/p + k.HDD + k.HDD.p.y$$

Now the choice of appliance capacity is largely based on the physical characteristics of the dwelling and in particular its size in terms of number of rooms. Thus k in the second and third terms may be replaced by d.(Rooms). Finally, data on F_h is rarely available only combined data on energy consumption for all purposes. The non heat part of energy demand we assume to depend on income levels, household size, etc. Our demand equation is therefore

$$F = F_h + F_{nh}$$

$$= d_o + d_1(1/p) + d_2RHDD + d_3R.HDD.p.y$$

$$+ d_4y + d_n \qquad (1)$$

This equation effectively represents the short run demand for energy conditional upon the attainment of optimal thermal comfort levels.

The ownership of central heating appliances is explained in terms of a choice model whereby owners are assumed to own ch_i when they consider that the utility derived from possession (u_i) exceeds that from non possession (u_j), i.e. $u_i > u_j$. Although there is a small number of households who own combinations of ch systems, these are ignored in the subsequent analysis and the choices are treated as mutually exclusive. The theory of choice between mutually exclusive alternatives was developed largely to explain choice of transport mode.

The advantage of using the logistic distribution in qualitative response models have been well described in Amemiya (1981). Firstly it is easier to estimate than the normal probability distribution. This is still true despite the increased availability of software for estimating probit functions. Secondly it can be shown that close approximations to normal distribution results can be obtained by suitable transformation of the logistic function. Specifically, the transformed logistic

$L(w)=\exp(1.6w)/(1+\exp(1.6w))$ is very close to normal.

Thus coefficients derived from logistic estimates ($\hat{b}_L$) can be converted approximately into their equivalent normal estimates ($\hat{b}_{\phi}$) according to

$$1.6\ \hat{b}_{\phi} = \hat{b}_L$$

In addition the logistic distribution is symmetric and has constant variance ($\pi^2/3$)

For estimation purposes we transform the logistic probability function $P_i=1/(1+\exp(-(e_i-e_j))$

$=1/(1+\exp(-\sum b_i x_i)$ into its logit form,

$$\log(P_i/1-P_i)=-\sum b_i x_i$$

It is appropriate to estimate this function by maximum likelihood methods since P_i is unobservable and the probabilities must sum to unity.

The estimation of the central heating choice model presents a number of problems. In general terms we have assumed that

$$U_{ch} = f(y,p,z,\ldots\ldots)$$

and it is necessary to specify the exact form of the function for estimation. We have chosen a basically linear relationship on the grounds of simplicity. However in order to preserve the implied shape of the indifference map between y-pH(T) and Z(T), we enter

Z(T) in additive logarithmic form. Here of course Z(T) is the optimum heating level implied by prices and size variables so that we substitute a/p for Z(T) in U. Since prices now appear in the function through Z, possible problems of collinearity can be avoided only by excluding p from the equation to be estimated. Finally the term y in U ch should read y -pH(T). However the influence of p is already represented in Z and H(T) can also be expected to vary with Z. Thus it is safer from the econometric point of view to drop the term pH(T). We are left with the following equation to be estimated

u=a+b.y+clnINPRMS+TENURE+REGIONALS

where INPRMS = ln(l/p.r) and TENURE and REGIONALS are dummy variables for the various tenure and regional types. Although we believe that the above specification is probably the best which can be achieved a priori, we have estimated two alternative specifications,viz:

u = a+b.y+c.p.F+dlnINPRMS+TENURE+REGIONALS and

u = a+b(y-pF)+clnINPRMS+TENURE+REGIONALS

Since these are not nested within any general model it is not possible strictly to reject their results in favour of the chosen model. However neither alternative leads to an improved fit to the data and both give cause for rejection on economic criteria in terms of signs of coefficients.

Data Sources and Variables

The fuel expenditure and central heating ownership equations were estimated using data derived from the annual Family Expenditure Surveys (FES) series. Apart from special surveys carried out within the fuel industries themselves, the FES represents the only source of information, at a household level, both of the economic variables (income, and fuel expenditures) and of the social and physical data (household size, rooms, etc.) needed to estimate both models. This makes it superior as a source of data both to the General Household Survey and the House Condition Survey neither of which give details of fuel expenditure. Nevertheless the problems associated with using the FES are well known. Data is collected by responding households over fortnightly periods, rather than for the year as a whole and the definition and coverage of certain variables have altered over time. Thus for example data on physical units of electricity and gas was collected up to 1979 but subsequently dropped on grounds of economy. We were thereby prevented from undertaking any detailed analysis of energy pricing differences between different income strata of the population. Again it is known that the response rate varies somewhat across the sample, being lowest for both ends of the income range for understandable reasons. Despite these difficulties it was felt that the FES represented the most reliable source of data available and that the above mentioned problems would not detract too greatly from the quality of the analysis.

The spreading of the samples over the year was in some ways an advantage since it enabled us to link variation within the year to changes in degree days and other seasonal factors. The date of each households quarterly gas or electricity bill was available and enabled us to associate the correct heating degree days quarterly value with billed consumption and expenditure. To carry this out, each household was assigned to its nearest regional degree day reporting centre and the relevant quarterly degree day sum was incorporated in the data file. The same operation was carried out for energy prices. These were taken from the regional Energy Price tables of the Energy Digest, converted to pence per therm of useful energy matched geographically and then added to the data record for each household. All income data was converted into real values on a 1978 basis using the Consumers Expenditure Deflator published in the annual Blue Book. The fuel expenditure series - GEXP, ELEXP AND TOILSFEXP were deflated by an index of useful therm prices of the relevant fuels, and for the overall series (FLPEXP) by a 1978 expenditure weighted combined fuel price index. Both gas expenditure (GEXP) and electricity expenditure (ELEXP) cover payments recorded on quarterly accounts and other bills, slotmeters (net of any rebates) and consumption in second homes. Detailed definitions of other variables are given in Appendix 1 .

Random samples of approximately 1,000 households per year were provided by the ESRC Data Archive at the University of Essex for each year of the the period 1970 - 1982 totalling in all 14,000 observations. A suite of computer programmes was created which reads each year's FES data tape and produces output tapes on a consistent format. These output files are used in the maximum likelihood estimation of central heating ownership where relatively severe economy in variables and observations was necessary. For the expenditure analysis it was possible to read directly from the FES tapes under SPSS. The system is set up so that subsamples of data relating to specific subgroups eg. different tenure types, household size types , etc. may be selected for specific analysis, and this is a possible point of departure for future work. Another program loads the individual year's data sets together with a time variable into a complete file (DATAALL) for the whole period suitable for mixed cross section time series analysis.

The problem of irregular purchases of coal and oil has also to be dealt with. Certain consumers of these products will not make purchases during the sample period, and their recorded zero consumption will affect the analysis. We tackled this problem by selecting only those households who actually recorded purchases of these fuels for the coal and oil analysis. This ensures that both expenditure and ownership functions are estimated over consumers of these fuels in accordance with theory, although it leaves us with a problem of establishing and predicting total numbers of oil and solid fuel consumers in any forecasting exercise which may be based on the estimates.

The Conditional Demand for Fuel

Equation (1) expresses the household's expenditure on fuel as conditional upon the presence or absence of central heating. One implication of this approach is that we do not need to be concerned about market shares constraints and can choose whether or not to adopt total fuel expenditure (FLPEXP) or expenditure on individual fuels (gas GEXP, electricity ELEXP and others TOILSFEXP purely on the grounds of econometric performance. Another implication is that we must combine the expenditure results with those obtained from the central heating ownership model in order to get complete estimates of expenditure elasticities. Since all expenditures are measured in constant (1978) prices however the expenditure model can be comsidered as yielding quantity rather than revenue estimates and the elasticities can be interpreted as demand elasticities. We will discuss these combined results in the final section of the paper.

Although the model of equation 1 varies slightly from that used in Hawdon (1982), it was decided to take advantage of the insights gained from that study in order to rule out certain possibilities from the outset. These insights were firstly that a linear version of the model was likely to produce superior results to a logarithmic one, secondly that division of the samples into subgroups based upon household composition would do little to improve the estimates and finally that variables should be included to allow for seasonal variation in demand over and above what might be attributable to temperature variations. The 1982 work had also demonstrated the importance of family size in explaining demand and we separately identified the effects of numbers of children in various age categories (CHILDL5 , CHILD 25, CHILD 518) and the number of adults (ADULT).

The model differs from the earlier version in including an interaction term (INTERAC) designed to measure the combined effects of income, central heating, temperatures and price on demand. This is in addition to the variable CHRHDD which tests whether fuel users respond differently to temperature changes according to whether or not they possess central heating, and upon the size of their dwelling in terms of numbers of rooms.

The actual equation estimated for each year separately was

$$\begin{aligned} FLPEXP = {} & b_0 + b_1 GROSSINC + b_2 RHDD + (b_3 + b_4 RHDD) CH \\ & + b_5 INTERAC + b_6 ADULT + b_7 CHILDL + b_8 CHILD25 \\ & + b_9 CHILD518 + (QDUM2 - QDUM4) + (TENURE\ DUMMIES) + \\ & (REGIONAL\ DUMMIES) \end{aligned}$$

O.L.S. was considered to be an appropriate estimation method in view of the large sample sizes involved (around 1,000 for each year). Although some variation in estimates is inevitable in view of the independence between samples, some regularities do emerge from the analysis (see Table 3). In the first place the significance of size and compositon of household for determining energy demand stands out above that of any other variable. This applies in all years and indicates that of the households´ members, adults and children (5-18) would appear to have a basic demand for energy independent of income level. Secondly, gross income whilst not explaining a major part of demand is positive and significant in 10 out of the 13 years. The direct income elasticity however is never more than 0.1 (.08) in 1982. The effects of the interaction term INTERAC are not at all clear from the estimates since in no year does it contribute significantly at either .05 or .01 level to the explanation of FLPEXP. RHDD appears as a significant positive influence in 9 years and is associated with the highest elasticity value (0.36 in 1982). The variable CHRHDD, measuring the slope of the CH effect, is more significant suggesting that as with the 1982 analysis, there is a substantial difference in the fuel consumption response to size/temperature changes between households with and those without central heating. It is interesting to note that it is the joint effect of size, temperature and central heating that is important rather than central heating itself, whose coefficient is significant in only 2 years. This provides additional confirmation of the hypothesis noted in the 1982 paper that CH owners adjust their fuel consumption more readily to weather changes in proportion to the size of their dwellings than do non CH owners.

The impact of price movements is unclear from the year by year analysis, although in the majority of cases the coefficient is correctly signed (negative) but insignificant. We can use a standard F test of difference in R^2 to determine the effect of regional and tenure variations. It is clear from Table 4 that the regional factors do not account for a substantial proportion of the unexplained variance in FLPEXP. Tenure differences were significant but only in the earlier years. Both factors can therefore be ignored in further discussion of the model, although they will reappear in our analysis of central heating choice. Finally the behaviour of the constant term is of interest. The constant is very much greater (3 to 8 times) in 1974, 1975 and 1978 than in the remander of the period suggesting that the cross section price variables need to be augmented by a time series analysis to explain the full impact of price changes.

TABLE 3

Estimated Coefficents of FLPEXP Equation 1970-1982
(£E-03 1978 prices)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
GROSSINC	0.04 (0.0)	0.39 (4.1)	0.53 (6.3)	0.10 (0.3)	0.38 (2.7)	0.26 (3.7)	0.42 (5.8)	0.33 (3.2)	0.46 (6.5)	0.72 (14.7)	0.34 (5.7)	0.28 (1.4)	0.35 (2.1)
RHDD	0.03 (0.09)	0.33 (15.3)	0.31 (9.8)	0.12 (1.7)	0.27 (6.0)	0.21 (7.4)	0.23 (7.5)	0.27 (11.4)	0.99 (1.21)	0.44 (25.9)	0.08 (1.4)	0.75 (21.3)	0.51 (15.4)
CH	0.14 (0.22)	-.65 (6.5)	-.19 (0.5)	0.04 (0.?)	-.04 (0.0)	-.26 (1.4)	-.20 (0.9)	-.08 (0.1)	-.08 (0.1)	-.14 (0.4)	-.21 (1.2)	-.66 (2.9)	-.02 (0.0)
CHRHDD	0.01 (0.07)	0.27 (14.0)	0.17 (4.5)	0.05 (0.5)	0.16 (2.5)	0.14 (4.5)	0.24 (13.8)	0.21 (12.0)	0.25 (13.2)	0.18 (8.2)	0.00 (9.3)	0.34 (8.6)	0.17 (3.3)
INTERAC	1.74 (1.35)	-.45 (0.1)	-2.50 (3.2)	0.76 (0.4)	-2.42 (1.7)	-.19 (0.3)	-1.19 (4.5)	-.22 (0.2)	-.43 (1.0)	-.78 (3.7)	-.32 (1.5)	-.23 (.5)	-.23 (0.7)
ADULT	3.63 (14.24)	2.51 (7.8)	4.17 (21.4)	6.54 (40.1)	7.42 (32.8)	6.01 (38.7)	4.62 (21.1)	4.18 (16.3)	5.35 (28.0)	2.14 (4.1)	4.42 (22.2)	6.34 (14.8)	5.16 (12.5)
CHILDL2	2.60 (1.55)	2.77 (2.0)	2.96 (2.2)	1.92 (0.8)	8.26 (10.1)	3.33 (3.2)	2.77 (1.7)	5.23 (6.1)	7.41 (1.4)	7.95 (16.0)	2.36 (1.1)	-.19 (0.0)	-.11 (0.0)
CHILD25	6.89 (18.83)	4.74 (10.4)	2.07 (2.1)	3.48 (5.1)	3.00 (2.3)	2.29 (2.4)	2.16 (1.9)	2.08 (1.8)	2.89 (3.2)	0.47 (0.1)	4.26 (7.7)	10.3 (16.2)	0.73 (0.1)
CHILD578	1.99 (8.93)	2.31 (14.3)	1.76 (8.4)	3.39 (34.4)	3.56 (24.7)	2.11 (13.4)	1.98 (11.5)	2.81 (27.4)	3.49 (28.0)	2.59 (17.9)	4.08 (52.9)	4.06 (15.1)	2.89 (9.0)
GSUP	0.47 (10.9)	0.44 (12.1)	0.40 (10.3)	0.50 (15.3)	0.90 (33.2)	0.45 (14.7)	0.13 (1.2)	0.00 (0.0)	-.20 (2.5)	-.39 (8.6)	-.20 (2.7)	-1.37 (42.6)	-1.15 (35.9)

TABLE 3 (CONTINUED)

Estimated coefficients of FLPEXP Equation 1970-1982

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
EUSUP	-.11	-.43	-.40	-.33	-.53	-.42	-.39	-.19	-.20	-.05	-.34	-.57	-.50
	(0.7)	(13.0)	(11.7)	(7.2)	(13.8)	(14.6)	(11.9)	(3.0)	(2.9)	(0.2)	(4.8)	(5.1)	(4.5)
INPEL	-.60	-.34	-.62	-.10	-.11	-.67	-.66	1.22	.80	.48	-1.9	-6.1	-3.3
	(6.79)	(0.9)	(3.7)	(0.3)	(0.5)	(0.3)	(0.4)	(2.4)	(0.5)	(0.0)	(1.3)	(2.9)	(1.9)
INPGAS	-.02	.25	-.04	.09	-.15	-.16	-.21	-.88	-.64	-.43	.39	2.00	-1.5
	(0.05)	(3.7)	(0.1)	(0.4)	(1.1)	(0.8)	(1.3)	(16.8)	(3.9)	(1.6)	(0.2)	(2.2)	(4.8)
INPOIL	.01	.85	.26	.14	-3.5	-1.5	-2.1	-.77	-9.7	-.15	-	-	-
	(1.09)	(6.9)	(0.1)	(0.0)	(0.7)	(2.1)	(0.7)	(0.1)	(0.9)	(0.4)			
INPSF	-.32	-.25	-.56	-.20	.30	.16	.08	.23	-1.4	-.90	-1.0	-2.4	-2.0
	-	(1.3)	(4.7)	(1.0)	(1.0)	(0.2)	(0.0)	(0.2)	(0.8)	(2.5)	(1.1)	(8.0)	(5.7)
QDUM2	-.42	-.32	-.23	-.25	.22	.03	-.12	.23	-.15	-1.1	.08	-.55	-.38
		(2.9)	(1.4)	(1.8)	(1.2)	(0.0)	(0.5)	(2.2)	(0.5)	(25.9)	(0.3)	(24.2)	(2.6)
QDUM3	-.83	-.10	-.38	-.37	.80	.14	-.32	.07	-.40	-.11	-.04	.43	.53
		(0.3)	(4.0)	(3.4)	(0.1)	(0.6)	(2.5)	(0.2)	(5.4)	(0.4)	(0.1)	(1.2)	(2.3)
QDUM4	-.61	.85	.27	-.14	.44	.72	.25	.62	.18	.69	-.08	2.4	1.5
		(10.0)	(1.2)	(0.2)	(1.6)	(8.5)	(0.9)	(5.7)	(0.5)	(8.5)	(0.2)	(26.2)	(11.2)
CONSTANT	0.73	-0.32	0.54	0.23	.44	4.39	0.78	0.37	2.70	.47	.48	.69	1.23
DF	928	1088	1039	1035	909	1097	1102	1099	1042	1030	1065	1217	1188
R^2	0.15	0.18	0.16	0.18	0.20	0.19	0.17	0.37	0.24	0.20	0.19	0.21	0.15

TABLE 4

Tests of Regional and Tenure Effects on FLPEXP and Individual Fuels

(n)	Year	Base R^2_K	Base+ Regional R^2_{Q1}	Base+ Tenure R^2_{Q2}	Regional F	Tenure F
(945)	1970	0.150_{18}	0.163_{25}	0.166_{21}	2.04	5.91*
(1106)	1971	0.176_{18}	0.198_{25}	0.191_{22}	4.23*	5.02*
(1057)	1972	0.162_{18}	0.171_{25}	0.175_{22}	1.60	4.08
(1053)	1973	0.184_{18}	0.198_{25}	0.190_{22}	2.56	1.91
(927)	1974	0.203_{18}	0.213_{25}	0.215_{22}	1.64	3.46*
(1115)	1975	0.191_{18}	0.198_{25}	0.204_{22}	1.36	4.46*
(1120)	1976	0.173_{19}	0.178_{25}	0.182_{22}	1.11	4.03*
(1123)	1977	0.236_{19}	0.244_{25}	0.240_{22}	1.94	1.93
(1060)	1978	0.238_{19}	0.242_{25}	248_{22}	0.91	4.60*
(1048)	1979	0.215_{19}	0.217_{25}	0.218_{22}	0.37	0.98
(1083)	1980	0.193_{18}	0.198_{25}	0.196_{21}	0.94	1.32
(1234)	1981	0.205_{18}	0.211_{25}	0.2_{21}	1.31	0.51
(1205)	1982	0.154_{18}	0.168_{25}	0.154_{21}	2.84*	0

K = 18 except in 1976-1979 (19), Q_1 = 25,
Q_2 = 22 except in 1970, 1980-1983 (21).

(n)		1982 Base R^2_K	Base+ Regional R^2_{Q1}	Base+ Tenure R^2_{Q2}		
(454)	GEXP	0.565_{18}	0.575_{26}	0.568_{22}	3.47*	2.05
	ELEXP	0.364_{21}	0.368_{28}	0.365_{24}	1.06	0.62
	TOIL	0.212_{16}	0.235_{33}	0.209_{19}	1.85	0.55
	FLPEXP	0.154_{18}	0.168_{25}	0.154_{21}	2.84*	0

* Significant at the 1% level where

$$F_{n-Q,Q-K} = \left[\frac{R^2_Q - R^2_K}{1-R^2_Q}\right] \left[\frac{n-Q}{Q-K}\right]$$

The Fuel by Fuel Model

The overall fuel expenditure model may be criticised on two main grounds. The first of these is aggregation - the degree to which significant differences in the markets for the individual fuels are obscured by combining fuels. This may occur because we have used the wrong weights in adding fuels together or because the contribution of a variable, important for a single fuel is obscured in the reduced variance of the overall total. The second cause for unease lies in the treatment of oil and solid fuels. Whereas for electricity and gas the responding household is asked details of their latest quarterly account, thus ensuring an expenditure observation for every user of these fuels, for solids and oil only the actual expenditure incurred in the fortnight of the survey is recorded. To the extent that some purchases are not recorded, the overall fuel expenditure figure is biased downwards. We therefore decided to estimate modified versions of equations for each fuel over each year of the sample period.

At the individual fuel level account must be taken of the fact that expenditure on one fuel is likely to be reduced to the extent that the household uses other fuel burning appliances. Thus a household's gas expenditure is likely to be affected not only by income and price but by the existence of an alternative source of heating within the dwelling. We allow for this by including a binary variable CHN (fuel i) which takes a value 1 where the household possesses central heating not of the type whose expenditure forms the dependent variable. This would be expected to have a negatively signed coefficient in the empirical estimates. In addition, not all households may be able to obtain supplies of their preferred fuel since they may be outside the distribution area for that fuel. It was impossible to match households with distribution areas, but dummy variables GSUP and EUSUP were included to measure the effect of non zero levels of expenditure on gas or electricity on the householder's expenditure on the individual fuels.

In comparision with the overall FLPEXP equation the individual fuel results on the whole did quite well in terms of goodness of fit (see Table 5 for 1982 results). We would expect relatively low R^2 from cross section analysis but those for GEXP ranged between .55 and .67, those for ELEXP between .33 and .57 while the R^2 of the FLPEXP estimates stayed only between .16 and .24. The results for TOILSPEXP on the other hand were somewhat worse than those for FLPEXP (R^2s from 0.08 to 0.25)

TABLE 5

Fuel by Fuel Expenditure Equation Estimates 1982
(£E-03 1978 prices)

	GEXP		ELEXP		TOILSFEXP	
	Coeff.	F	Coeff.	F	Coeff.	F
CONSTANT	1720	-	2018	-	16503	-
GROSSINC (E-03)	.638	0.7	1.623	2.3	0.235	-
RHDD (E-02)	.709	2.7	0.947	2.8	0.245	1.5
CH_i	143.2	1.6	-5592	3.7	-8.465	-
CHN_i	-328.0	16.2	-286.9	11.5	-	-
CHRHDD (E-01)	0.25	77.0	0.411	28.61	-	-
INTERAC (E-06)	-0.833	-	1.298	-	-	-
ADULT	159.0	12.2	3262	24.7	24.4	-
CHILDL2	137.2	1.9	112.4	0.7	-502.2	0.6
CHILD25	-26.5	0.1	184.6	3.6	-389.7	0.6
CHILD518	138.7	20.1	302.2	48.8	34.7	0.0
GSUP	1103	192.7	-550.05	34.6	-3190	71.0
ENSUP	-273.3	12.2	-731.12	47.8		
INPEL (E-05)	-2.567	4.1	3.044	2.9	-9.957	1.4
INPGAS (E-03)	-5.973	0.0	5.972	1.5	-2.081	1.1
INPSF (E-04)	-2.152	0.2	-2.181	13.9	-3.412	1.5
QDUM2	35.9	0.2	68.54	-	-259.9	0.3
QDUM3	176.7	2.3	-5.37	-	181.3	0.1
QDUM4	135.8	0.8	109.05	0.2	1567.5	2.8
DF	1187		1184		439	
R^2	0.57		0.36		0.19	
$\bar{R}^2$	0.56		0.35		0.16	
F	85.8		32.3		6.8	

which may be attributable partly to the much smaller samples involved. Of the explanatory variables, GROSSINC was more frequently significant in the ELEXP equation (11 out of 13 times) than in either of the other two. This may reflect the fact that electricity consumption is associated with a much greater diversity of appliances, whose ownership is highly income elastic. The mere possession of central heating by contrast is more important for GEXP than for either of the other fuels although its significance declines with time. Interestingly the coefficient of central heating in the TOILSFEX equation is negative suggesting that households actually save fuel when they convert from open fires to the more efficient boiler systems. The combined CH_IRHDD variable is, as in the FLPEXP equation, significantly positive in almost all years for both GEXP and ELEXP indicating the same pattern of usage irrespective of CH system type. Our hypothesis regarding the impact of another type of central heating on the consumption of a particular fuel is confirmed by the nearly universal occurrence of significant negatively signed coefficients for CHN_i. Size of household measured in terms of adults and children separately emerges as an important explanatory factor especially in the case of ELEXP (13 cases) and less so in the case of TOILSFEXP (only 7 for adults and 5 for children). Finally the binary variable GSUP plays an important role in explaining GEXP (positively) and TOILSFEXP (negatively) in all years. It has a much less clear impact on ELEXP, however, although even here, where gas is available (GSUP = 1), ELEXP will tend to be lower on average, as expected.

Estimates for the Full Period 1970 - 1982

The individual year results, whilst agreeing in their assignment of significance and signs to the explanatory variables, reveal considerable variation in parameter estimates. There is no evidence that this variation is systematic but rather would appear to be due to sample differences. If this is so we can minimise variation by pooling all the observations within one model and we can also then use the model to explain the changes which have occurred on the conditional demand for fuels over the period. Pooling the samples creates a data set of 13,996 observations for estimates of the FLPEXP GEXP and ELEXP equations and of 9,610 observations for TOILSFEX. To take into account the effect of taste changes and technological progress we added a set of binary variables TIM1 to TIM13, one for each year. The results for FLPEXP together with 1982 elasticities are to be found in Table 6. The TIM effects are somewhat ambiguous, however, and it is difficult to find clear

TABLE 6

FLPEXP Equation Estimates for Full Period 1970-1982
(£E-03 1978 prices)

Variable	Coefficient	F value	1982 Elasticity
Constant	1066.6	-	-
Grossinc	0.284	87.2	0.071
RHDD	0.132	45.9	0.095
CH	-106.96	2.9	-0.016
CHRHD6	0.133	55.1	0.062
ADULT	439.40	270.4	0.196
CHILDL2	387.44	46.3	0.007
CHILD25	330.14	58.3	0.010
CHILD518	305.37	329.6	0.041
INPFLP	787.37	81.2	0.282
QDUM2	-81.2	270.4	0.196
QDUM3	-264.7	2.7	0.005
QDUM4	125.3	25.1	0.015

$\bar{R}^2 = 0.16$ F = 199.8   DF = 13,982

Time Coefficients

(TIM2 = 1971, etc.) ($R^2 = 0.183$)

TIM2	-30.0	TIM6	-47.3*	TIM10	-386.9*
TIM3	100.0	TIM7	-683.0*	TIM11	698.9*
TIM4	222.9*	TIM8	-486.2*	TIM12	-705.6*
TIM5	1194.4*	TIM9	-301.2*	TIM13	-839.3*

* Significant at 1% level.

evidence either for significant changes in tastes or for a conservation effect over and above that caused by rising energy prices. The main independent variables are much better defined than in any of the yearly samples. In particular all the household size variables (CHILDL2 to ADULT) are now significant and indicate a ranking of ADULT > CHILDL2 > CHILD 25 > CHILD 518 in terms of energy consumption. The real price variables INPFLP is significant (F = 81.2) and correctly signed and yields an elasticity of 0.28 for 1982 price and expenditure levels. This low price elasticity is consistent with our hypothesis of the interrelated demand for fuel and central heating In fact again it is the combined CH, Rooms and Heating Degree Days variable value rather than CH itself which is of greater significance in explaining fuel expenditure.

The pooled samples analysis enables us to evaluate own and cross price elasticities for each fuel (see Table 7). The equations impose no symmetry on the results since they are designed to indicate price and other effects in the presence on account of certain appliance stock. Own price elasticities are well defined for gas and electricity (0.356 and 0.809 respectively) but not for TOILSFEXP (0.061). The relatively higher elasticity of electricity with respect to price reflects the far greater number of uses to which electricity is put and therefore the greater ease of adjusting marginal use in response to price changes. Some interesting asymmetries are revealed by the cross price elasticities. The negative cross price elasticity of GEXP with respect to electricity prices (-0.067) indicates that gas substituted for electricity in marginal uses during the period as the relative price of electricity rose. However, given the stocks of central heating appliances, there does not seem to have been any significant impact of gas prices on ELEXP. Rather, only solid fuel emerges as a substitute for electricity in the ELEXP equation (cross elasticity of (-0.327). In the case of TOILSFEXP, gas substitutes for oil or coal or both (-0.068) but this is not reflected in the GEXP equation possibly because of the insignificance of oil and coal expenditure in the domestic sector.

TABLE 7

OWN AND CROSS PRICE ELASTICITIES - FULL PERIOD ANALYSIS
1982 VALUES

	GEXP	ELEXP	TOILSFEXP
PG	0.356*	0.630	-0.068[8]
PEL	-0.067*	0.890*	-0.077
POTL	-0.075	0.055	0.039
PSP	0.019	-0.327*	0.061

* Significant at F 0.01 level

Explaining the Major Changes in Fuel Consumption

By inserting the actual changes in the exogenous variables in the model estimates it is possible to obtain some idea of the impact of the various factors on fuel expenditure over the period. This is quite clearly rather different from the previous elasticity analysis which merely reported the potential impact of the variables. We began by examining the period 1970 to 1973 to find an explanation of the changes in real expenditures in all fuels (Dy), by noting that

$$Dy=+\{b_i Dx_i + b_{i+1} Dx_{i+1} + \ldots\} - \{b_j Dx_j Dx_{j+1} + \ldots\}$$

i = variables whose effect on y is positive
j = variables whose effect is negative

It may be seen from Table 8 that most (56%) of the predicted growth in FLPEXP in this period was due to the fall in real energy prices, with the combined effects of dwelling size , central heating and climate contributing 23%. The growth in incomes was responsible for only 13% of the change in FLPEXP and the rather colder weather of 1973 a further 8%. On the debit side the reduction in household size, particularly in the average number of adults from 2.1 to 1.9 was the major factor - only slightly conterbalanced by an increase in the average numbers of children in the 5 to 18 age group. This pattern is repeated for all the individual fuels except ELEXP where increases in the real price of electricity in these years were largely responsible for moderating the rise in consumption. The combined CHGRHDD central heating effect was as important for gas as the price effect, each contributing 33% to the gross increase in GEXP. Also important for gas was the extension of the numbers actually receiving a gas supply (12%) and the competitive gains from higher electricity prices (5%). For electricity, the model did not do at all well, predicting a net reduction in ELEXP when it in fact rose slightly between 1970 and 1973. The positive central heating, income and cross price effects are all outweighted by a large negative own price effect. The fall in the consumption of the other fuels (oil and solids) is attributed mainly to the reduction in household size (40%), income changes (34%), and the extension of gas supply (20%).

TABLE 8

Analysis of Changes in Fuel Expenditures, 1970-1973 and 1973-1982
(£E-03 1978 prices)

	1970-1973				1973-1982			
	D FLPEXP	D GEXP	D ELEXP	D TOIL	D FLPEXP	D GEXP	D ELEXP	D TOIL
Actual Change	+224.1	+327.8	+59.4	-162.8	-40.3	+262.2	-2.4	+300.0*
Due to:								
D RHDD	+10.5	+1.5	+3.9	+7.1	+30.1	+4.4	+11.2	+20.4
D GROSSINC	+28.5	+11.3	+34.7	-29.7	+23.8	+9.5	+29.0	-24.8
D $CH_{F,i}$,	-11.3	+29.3	+0.2	-5.0	-27.4	+87.7		+30.9
D CH_{ni}	-	-5.7	-27.2	-	-	-2.8	-99.2	-
D $CHRHDD_i$	+47.4	+73.2	+35.1	-	+118.0	+198.6	-29.8	-
D GSUP	+1.6	+26.0	-17.0	-17.4	+3.3	+55.6	-36.4	-37.2
D ADULT	-63.9	-12.0	-29.7	-35.0	-0.1	-0	-0.1	-0.2
D CHILDL2	-6.7	-1.1	-5.9	-35.0	-1.3	-0.2	-1.2	-0.1
D CHILD25	-5.1	-4.7	-3.5	-.5	-5.8	-1.6	-4.1	-0.1
D CHILD518	+3.9	+1.1	+2.7	-4.2	-6.4	-1.8	-4.2	-0.1
D INPFLP	+116.9	-	-	-	-330.7	-	-	-
D INPGAS	-	+73.0	+23.3	-	-	-84.1	-21.2	+164.0
D INPEL	-	+6.0	-129.1	+8.8	-	+29.0	-626.9	+43.0
D INPOIL	-	-	-	-	-	-	-	-
D INPSF	-	-	-24.5	+3.3	-	-	+207.9	-27.9

* This is the increase in oil and solid fuel expenditure per <u>consumer</u>. In fact, per household consumption fell by 463.1 between 1973 and 1982 due to a sharp fall in the number of mainly smaller consumers and leads to the fall in overall FLPEXP.

In the 1973-1982 period, only gas consumption is greater at the end of the period than at the beginning. Most of the reduction in overall FLPEXP is seen to be due to increased real fuel prices which more than outweigh the positive effects of central heating and income growth, and temperature variations over the period. In the case of GEXP by contrast, the positive effect of CH growth is more than sufficient to over come the negative impact of gas price increases. The model fares badly in predicting substantially lower ELEXP in 1982 due to large negative own price effects, reinforced by the impact of declining electric central heating ownership. The growth in average TOILSPEXP by households where other fuels are consumed is explained mainly by some substition away from electricity and gas. At the same time the negative income and gas availability effects continue to operate but not sufficiently strongly to override the substitution effects. It should be noted that the model does not provide any explanation of the secular decline in number of households consuming any oil or solid fuel.

Results for Central Heating Ownership

The basis of our choice model is that households will tend to own central heating when the utility available to them from their optimal heat level, determined by fuel prices and appliance capacity, is greater with central heating than without. We are unable however to observe household utility and hence all estimates must be carried out using the choices actually made as the dependent variable. The traditional approach would have been to use grouped data such as those presented in tabular form in the published FES results. This has two principal disadvantages. On the one hand the results are dependent on the principle of grouping adopted. Any classification of ownership by income levels may hide significant changes in relationships. With each income class the data take the form of averages which tends to reduce the variation available for statistical estimation. The second disadvantage is that the number of independent variables is reduced since it is not practical to publish the entire set of possible two way tables between all variables.

Use of individual household data overcomes both of the above problems but raises some daunting problems of its own. In the first place we are obliged to go farther than we may wish on theoretical grounds. We are required to hypothesis that individuals (or rather households) actually do behave according to the utility maximisation hypothesis over the full population set. Secondly it is not so easy to justify the use of standard statistical distributions of errors when dealing with data samples than when dealing with averages and this complicates our inferences regarding the stability of any estimated results. Nevertheless the benefit to be set against the above costs is that by use of the appropriate estimating technique - in this case maximum likelihood - one is able to test the validity of a maintained hypothesis over a much greater range of data values than is usually available. The maximum likelihood method finds parameter estimates which make it most likely that the pattern of choices in the sample would have occurred. In addition they are consistent, asymptotically efficient and normally distributed so that t and X^2 tests can be applied (Pindyck and Rubinfelt p311).

Our study of the FES data for 1978 indicates that central heating ownership depended positively on income and on INPRMS and that tenure and regional characteristics were significant contributory factors in the case of some if not all fuels. It could be argued that these results merely reflected the state of the market at a particular moment in time and give no indication of their stability and hence usefulness in forecasting. The availability of a much larger data set provided us with the opportunity to test this possibility. Having approximately 1,000 observations for each year from 1970 to 1982 enabled us to carry out a series of cross section estimates followed by a mixed time series, cross section analysis of a reduced set over the whole period

The model for central heating as a whole was estimated in logit form

$$z = \log(P_{ch}/1-p_{ch}) = a+b.y+c\log(1/P.RMS)+R+T$$

with z = 1 when central heating ownership was observed, and 0 otherwise and results for the separate cross sections are given in Table 9 . A number of features of the results are noteworthy. In the first place, income emerges as the single most important explanation variable as each of the years in terms of statistical significance. It has a positive effect throughout and the coefficients exhibit a substantial degree of stability. The interesting feature here is that there seems to be no overall trend in income effect over the period, although on average somewhat higher coefficients were found in the earlier years up to 1975. This would seem to justify the use of income as an explanatory variable. The alternative - a simple logistic time trend which is often incorporated in saturation models - would not have yielded the pattern of coefficients shown in Table 9 , but one where the implied income effect first increased until 50% saturation was achieved and then fell away steadily.

A second feature of these cross section results is the emergence of the compound variable INPFRMS as a significant contribution to the explanation of central heating ownership only consistently after 1977. In only two previous years - 1971 and 1974 - wasthe coefficient on INPFRMS significant and considerably higher than in the other years in this period. The same effect is observed with various specifications of the model and does not seem to be due to errors of measurement. There are two alternative explanations. One is that the model is defective in that it does not explain why consumers should behave differently in two time periods. The other is that consumers behaviour was stable but that there was insufficient variation in the data to generate a statistically significant coefficient on INFPRMS. The second explanation seems to be the more likely for two reasons. Firstly the significant coefficients on INPFRMS achieved during the first period are similar in value to the 1978-1982 coefficients. This indicates that the same preferences for central heating existed in both periods but that variation in the data differed between years. The second reason is the fairly obvious one that energy prices in Britain did not change a great deal until the latter half of the period. In periods of low and steady energy prices conventions about levels of appliance utilisation tend to become established . It is only when prices change noticeably that households might be expected to revise their assessments of the optimum rate of utilisation and hence of the attractiveness of central heating ownership. Using the result that in a logistic model $e_y=y.b_y(1-Pch)$ we can see that the income elasticity of ownership , declined from .64 in 1970 to .29 in 1982 (see Table 10) although there has been substantial variability throughout the period. We would expect a decline in elasticities as the penetration of central heating increased and it is possible to isolate the exact contribution of this factor. Using 1970 estimated coefficients and income levels, the change in penetration alone was sufficient to explain 91.6% of the fall in the elasticity. This more than outweighed the effects of rising real incomes in the period but was reinforced by the reduced value of the coefficient estimates for 1982. Table 10 also shows the rate of growth of central heating ownership with respect to income for each year. If income had been the most important factor explaining central heating choices, we would have expected the rate of ownership to have peaked when Pch = 0.5 since

TABLE 9

Maximum Likelihood Estimates of Logit Central Heating Choice Model

	Coefficients of GROSSINC	Coefficients of log INPFRMS	X^2
1970	9.77 (6.4)	2.05 (0.6)	941
1971	9.01 (6.7)	7.39 (2.5)	1191
1972	7.55 (5.8)	2.73 (1.0)	1254
1973	9.10 (7.0)	-1.12 (-0.4)	1194
1974	10.27 (7.6)	7.71 (2.6)	1080
1975	9.27 (7.6)	2.88 (1.1)	1347
1976	5.21 (4.8)	4.16 (1.7)	1430
1977	6.01 (5.2)	3.48 (1.4)	1437
1978	6.68 (5.6)	5.76 (2.1)	1338
1979	8.72 (6.8)	1.20 (4.1)	1298
1980	7.87 (6.5)	5.67 (2.1)	1303
1981	9.13 (7.6)	6.85 (2.4)	1377
1982	7.38 (5.9)	6.12 (2.2)	1360

T ratios in brackets

Full results for 1982 are:

$$\ln\left({}^{Pch}/_{1-Pch}\right) = \underset{(2.0)}{4.83} + \underset{(5.9)}{7.39\text{x}10^{-6}}\ \text{GROSSINC} + \underset{(2.2)}{0.61}\ \text{lnINPFRMS}$$

+ [-0.06 (0.2)] Regions (2-11)
  [-0.21 (0.6)]
  [0.10 (0.2)]
  [-0.21 (0.7)]
  [0.50 (1.8)]
  [0.32 (0.9)]
  [-0.13 (0.4)]
  [0.17 (0.5)]
  [0.17 (0.6)]
  [-0.26 (0.8)]

+ [-8.89 (5.1)] Tenure (2-5)
  [-0.78 (1.8)]
  [0.60 (3.9)]
  [0.39 (0.8)]

TABLE 10

ELASTICITIES OF CENTRAL HEATING OWNERSHIP

	Income Elasticity	Rate of CH with INC Index	Price/Size Elasticity
1970	0.636	196	-.148*
1	0.553	194	-.507
2	0.448	175	-.174
3	0.561	215	.069*
4	0.609	248	-.457
5	0.503	231	-.151
6	0.276	130	-.222
7	0.287	150	-.169*
8	0.327	166	-.272*
9	0.412	216	-.056*
1980	0.333	188	-.226*
81	0.411	219	-.275*
82	0.286	170	-.218

Notes:

(1) Income elasticity
$e_y = y.b_y(1-Pch)$

(2) Rate of CH with respect to income
$dp/dy = b_p Pch(1-Pch)$

(3) Price elasticity
$e_p = -b_p(1-Pch)$

$$dP_{ch}/dy=b.P_{ch}(1-P_{ch})$$

However, maximum values of dPch/dy were attained in 1974 when Pch = 0.41. By the time central heating ownership had reached 50% (around 1978), the rate of penetration had fallen to 60% of its 1974 value and this loss of acquisition is part of the total welfare effect of the 1973/74 energy crisis.

In the model it is the combined effect of energy prices and appliance capacity approximated by size of dwelling which represents the cost of choosing central heating. Since there is considerable variation in size of dwelling across the samples a significant impact of this cost variable might have been expected in all years. However this is not so for six of the periods. The significant price impact in 1974 is not repeated however until 1978. Thereafter price effects cannot be ignored in the estimated equations. At the same time, the relative importance of operating (ie fuel) costs to capital costs changed substantially. In the case of a three bedroomed semi- detached house, quoted in D.O.E. (1981) it is possible to show that the ratio of annual fuel costs to first year finance payments on a 7 year loan increased from 32% in 1970 to 40% in 1981 for gas central heating, and similar results can be obtained for other types of dwelling and fuel systems. Taken together these two developments are consistent with a hypothesis that central heating choice behaviour altered around 1978 - that fuel price effects are not important until fuel costs exceed a critical proportion of total appliance holding costs. Such a conclusion would have implications for forecasting and would suggest that results based on pre 1978 data for appliance choice are of limited value for predicting future ownership levels.

It is interesting to compare the two periods 1970-1977 and 1978-1982 in terms of the major factors responsible for changes in central heating ownership. Using coefficients from the 1970 estimates we can calculate the proportions of the increase in log odds of central heating heating ownership between 1970 and 1977 which was due to changes in the main independent variables.

On this basis only 2.8% of the increase was due to alterations in the distribution of population as measured by the regional dummy variables, as much as 30.1% was due to increased levels of gross income of households whilst by far the greatest contribution to change was made by changes in tenure conditions. The shift of ownership away from private rented unfurnished and rent free accommodation to private owner occupied housing (involving around 6% of all households) accounted for 68.6% of the change in the log odds of central heating ownership. Clearly this is not merely another way of describing the income effect, but reflects a marked change in taste on the part of households, associated with fewer restrictions on the installation of major structural appliances like central heating.

In the period 1978-1982 by contrast, the change in the log odds of cental heating ownership was much smaller (0.02 compared with 0.26 in the earlier and slightly longer period). (For this analysis we used coefficients derived from the 1978 estimates). Ignoring prices the relative contribution of population movements, was greater in this period (10%) while those of income changes and tenure variation were somewhat smaller (29% and 65%) to compensate. This is likely to overstate the effect of price changes since we are dealing with what is essentially a long run response. It does indicate however that sustained high levels of energy prices had not been sufficient to halt the growth in central heating ownership up to 1982.

The Choice of Central Heating System

The most striking feature of the growth of central heating ownership in the UK has been the market domination of gas systems - boilers and warm air units - over competitive systems. Following an aggressive marketing programme in the late Sixties, by 1970 gas central heating had attained a slightly higher penetration of households than electricity (8.8% compared to 8.3%), but oil's share was only slightly less (7.6%) (see Table 11). By 1982 however more than $^{2}/_{3}$rds of all central heating systems were gas, and, even more significantly, almost all the net growth in central heating penetration had been in terms of gas central heating (33.5% out of a total increase of

TABLE 11

Ownership of Central Heating by Fuel Within Samples % of Households

	Electricity	Gas	Oil	Solid
1970	8.3	8.8	7.6	3.3
1971	9.2	10.8	8.1	3.3
1972	11.4	14.0	7.2	3.7
1973	11.2	16.9	5.8	4.7
1974	13.3	18.8	5.2	3.3
1975	10.8	24.5	6.8	5.6
1976	14.0	20.6	6.3	6.0
1977	12.5	26.8	6.9	5.2
1978	12.4	28.8	6.7	4.9
1978	10.6	33.2	5.0	5.0
1980	12.6	37.8	6.0	4.0
1981	9.6	40.4	6.3	3.6
1982	9.2	42.3	8.9	4.0

Source: F.E.S. Data Tapes, Main samples

36.4%). The rapid growth of one system over the period raises questions about the stability of parameters in the overall central heating model - in particular those of the household income and price variables. If for example overall growth in central heating was due mainly to the (non price) marketing exertions of the gas industry then the estimated coefficents of the model could not be relied upon for predictive purposes, owing to the possibility of effective (non price) marketing counter measures being taken by the other fuel suppliers. Again, growth in central heating might be concentrated in some specific submarket (tenure type or regions) and, once complete, the relationships estimated with the model would change.

In the spirit of the overall central heating model, an individual fuel central heating choice model was developed for subsamples of the population of households consisting of owners of particular types of central heating plus non owners of central heating. Then for central heating i, the probabilities of ownership were estimated from the log odds expression

$$\log (Pchi/1-Pch) = \log (Pchi/Pnoch) \text{ by maximum}$$

likelihood using household gross income, a cost variable consisting of the log of the inverse of fuel i price times number of rooms, together with regional and tenure dummies and finally a variable GSUP measuring the extent of the gas supply area. This latter variable was included in order to allow for an inevitable restriction in choice where the gas infrastructure did not exist in certain areas. One advantage of constructing the model in this way was that, if impressive results had been obtained, an alternative estimate of overall central heating choice could have been made from

$$Pch=(\sum Pchi/Pnoch)/(1+(\sum Pchi/Pnoch))$$

since $Pch = \sum Pcni = 1-Pnoch$. In the event this alternative was not attractive.
The models were estimated, again by maximum likelihood, for each of the 13 years 1970 to 1982 and results are presented in Table 12 . In the case of gas, solid fuels and oil, the contribution of income and price taken together was highly singificant according to likelihood ratio tests. This was especially so in the case of gas where values of -2 ln l ranged between 99.7 and 255 for k = 3, (including GSUP) well above the critical chi-squared value of 12.84 at the .005 level. Although there is clearly some variation in parameter values for different samples (ie. years), the average

TABLE 12

Maximum Likelihood Estimates of Logit Central Heating Choice Models

	Gas			Electric			Solid			Oil		
	G E-6	I_q E-4	X^2	G E-6	I_E E-1	X^2	G E-6	I_S E-1	X^2	G E-6	I_O E-5	X^2
1970	9.62	6.26	373	6.75	-2.96	443	17.12	-0.34	142	9.53	1.41	378
	(4.2)	(1.1)		(3.1)	(0.6)		(4.9)	(0)		(4.1)	(0.2)	
1971	11.57	12.99	494	6.60	7.95	557	10.26	-2.14	205	6.87	1.12	484
	(5.3)	(2.6)		(3.4)	(1.8)		(4.0)	(0)		(3.2)	(0.2)	
1972	10.17	2.14	577	5.72	6.77	639	8.56	-5.49	231	3.45	1.15	403
	(5.3)	(0.5)		(2.9)	(1.6)		(3.0)	(2.7)		(1.4)	(0.2)	
1973	11.45	0.74	581	4.76	-4.85	605	12.06	1.01	233	5.30	-2.1	360
	(6.1)	(0.2)		(2.6)	(1.1)		(4.5)	(0.1)		(2.2)	(0.3)	
1974	12.99	1.21	519	7.27	10.4	579	12.68	1.69	178	13.74	4.89	272
	(6.4)	(2.6)		(3.9)	(2.8)		(4.2)	(0.2)		(4.8)	(0.7)	
1975	9.61	2.91	762	7.63	12.62	571	8.80	-5.10	261	9.31	-7.92	384
	(6.1)	(0.8)		(4.1)	(3.1)		(3.2)	(0.8)		(3.7)	(1.3)	
1976	6.40	4.0	761	3.25	5.61	709	7.95	7.36	294	3.07	4.42	377
	(4.4)	(1.2)		(2.2)	(1.5)		(3.8)	(1.3)		(1.4)	(0.7)	
1977	6.95	1.19	822	3.91	9.15	662	6.67	-0.50	275	5.34	2.82	394
	(4.51)	0.3)		(2.4)	(2.4)		(2.8)	(0)		(2.6)	(0.5)	
1978	8.09	3.59	853	3.00	10.77	602	9.14	1.08	220	5.66	-6.84	334
	(5.4)	(1.0)		(1.7)	(2.6)		(3.5)	(1.4)		(2.4)	(0.9)	
1979	10.39	9.15	852	5.58	19.15	525	8.18	8.91	227	7.70	-3.49	244
	(6.5)	(2.6)		(2.7)	(4.2)		(2.7)	(1.1)		(2.7)	(0.4)	
1980	9.52	2.02	866	2.00	14.35	579	8.87	-0.71	178	8.11	3.22	271
	(6.3)	(0.6)		(1.1)	(3.6)		(2.9)	(0.1)		(3.2)	(0.5)	
1981	9.34	2.92	949	5.55	1.65	516	9.96	-1.10	157	8.53	3.27	332
	(6.5)	(0.8)		(3.1)	(3.5)		(2.7)	(1.2)		(3.6)	(0.1)	
1982	8.64	6.04	922	5.80	1.51	481	5.80	7.15	196	5.50	3.51	418
	(5.7)	(1.8)		(3.0)	(3.3)		(1.8)	(10)		(2.6)	(0.1)	

G = GROSSINC, I_q = INPGRMS, I_E = INPERMS, I_S = INPSRMS
I_O = INPORMS

income coefficient was identical for gas and solid fuel central heating (.0000096) and somewhat lower for that of oil (.0000068) suggesting that these three types of central heating compete strongly within similar markets. The coefficient on income in the electricity central heating equation is just over half the size of the gas or solid fuel coefficients indicating a lack of widespread acceptability and a concentration in lower income households. This is confirmed by an examination of the tenure coefficients where it may be seen that the log odds of gas central heating being in an owner occupied house are in most years well over double those of electricity (four times as great in 1982 - see Table 13). In the case of electricity the results are not so clear cut since log likelihood ratio tests are significant in only 10 out of the 13 years. Nevertheless the coefficients of income and price are individually significantly different from zero in the majority of years.

The importance of tenure conditions as a decisive independent influence on central heating ownership is demonstrated by the log likelihood ratio tests for gas and solid fuels. In the case of gas, a significantly greater preference for central heating is exhibited by owner occupiers, than by local authority households whilst private tenants both in furnished and unfurnished accommodation display lower log odds of ownership than average. By contrast, solid fuel central heating although again preferred mainly by home owners, is in general least preferred by local authority tenants. Results for the other central heating owners are not so clear cut, but demonstrate the importance of home ownership upon decision making in this area.

Regional differences are less important sources of variation in central heating ownership than income, price or tenure. Only in certain years (1977-1980 for gas and 1974-76 for electricity) do the log likelihood ratios for additonal regional dummy variables exceed the critical X^2 ratio. This suggests that the main economic variables account for most of the regional differences in ownership but this conclusion ought not to be pressed too far in view of some of the high likelihood ratio values for certain years.

In general the coefficents for the individual fuel central heating models exhibit much more variability than those of the total central heating model. Again the price coefficients although largely of the expected sign were very often insignificant in the individual fuel case. Thus it would be inappropriate to derive price elasticities of ownership from these results. It would seem sensible to rely more on the overall equation

TABLE 13

Estimated Tenure Coefficients 1982

	Gas	Electric	Solid	Oil
TRPU	-2.65	-0.53	-4.94	-1.93
	(3.7)	-(1.1)	(1.6)	(2.5)
TRPF	-0.53	-1.35	0.76	4.98
	(1.0)	(1.6)	(0.9)	(4.4)
TOM	0.75	0.17	1.26	0.02
	(4.0)	(0.7)	(2.8)	(0)
TRFREE	0.82	0.32	0.61	-0.26
	(1.3)	(0.41)	(0.5)	(0.3)

results than on those for individual fuels in any forecasting exercises; although the major differences in parameters between the two major fuels gas and electricity would make any such effort to be of dubious value.

Conclusions

The availability of data on individual household fuel consumption and appliance ownership over the period 1970 to 1982 enabled us to estimate interrelated demand functions for energy and capital in the domestic sector of the UK economy. The size of the samples allowed us to control for many socioeconomic factors such as household size, dwelling characteristics and regional effects. In the first place we found that the hypothesis of simple complementarity between fuel expenditure and appliance ownership has to be rejected in favour of a more complex, although still complementary joint relationship with appliance ownership, dwelling size and temperature. Both the short run income and price elasticities of energy demand are found to be quite low, although in the separate fuel equations electricity demand emerges as more responsive. Most of the changes in fuel expenditure over the period are, according to the model attributable to real fuel price movements, with appliance ownership and income changes playing relatively minor but still significant roles. Turning to the explanation of appliance ownership, the analysis ascribes an important role to income with an ownership income elasticity varying between 0.6 and 0.3 over the period. The most important source of variation in appliance ownership lies, however, in conditions of tenure. This effect is seen particularly clearly in the case of gas central heating where growth in the stock of appliances is closely associated with the spread of home ownership.

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APPENDIX 1

Variable Definitions

ADULT	No of adults in household.
CHILDL2	No of children in household less than two years old.
CHILD25	" " " " " between two and five .
CHILD518	" " " " " between five and eighteen.
CHiRHDD	Central Heating (1 or 0) x RHDD.
CHINPi	Central Heating x INPi.
D	Difference in a variable's value over a specified number of years.
ELEXP	Electricity expenditure less rebates.
EUSUP	1 if any units supplied, 0 otherwise.
FLPEXP	Total fuel, light and power expenditure.
GEXP	Gas expenditure less rebates.
GROSSINC	Household gross income (£ E-03 per week). G
GSUP	1 if any gas expenditure, 0 otherwise.
I_q	INPGRMS.
I_E	INPERMS.
I_S	INPSRMS.
I_O	INPORMS.
INPi	Inverse price for fuel i.
INPiRMS	Inverse of price x rooms.
INTERAC	Grossinc*CH*HDD*P.
PGAS	Retail price of gas in certain large towns.
PEL	Retail price of electricity " " " ".
POIL	Retail price of oil.
PSF	Retail price of solid fuels in certain large towns.

QDUM2-QDUM4 Binary variables indicating date (quarter) of fuel bill.

REGIONS Standard Regions.

RHDD No rooms x Heating degree days per Quarter.

TENURE TRPU private rented unfurnished, TRPF private rented furnished, TOM private owner occupied, TRFREE rent free.

TIM2,TIM12 Binary variables representing year of sample such that TIM2=1 in 1971 and 0 otherwise, etc.

TOILSFEXP FLPEXP - GEXP - ELEXP