Micro evidence on household energy consumption

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1. SYNOPSIS

The purpose of the paper is to provide insight into the determinants of household demand for energy by analysing administrative register data using micro econometric methods.

2. ABSTRACT

In the paper is presented a micro econometric model of household electricity and natural gas demand for a cross section of 2,885 households observed in 1996. Estimates suggest that electricity consumption depends on the number of children, and depends linearly on income. The consumption of natural gas is found to vary with age, and to depend linearly on income, and on the technical characteristics of the dwelling. Particularly, it is found that the consumption of energy for space heating depends heavily on the building codes in force at the time of the construction of the house. Finally, a test of the dependence of gas consumption on the consumption of electricity and vice versa is carried out. The test indicates that demand for electricity is separable from demand for natural gas.

3. INTRODUCTION

Studying household energy demand is important because it constitutes a big part of total energy consumption, approximately 30% of the total final consumption of energy in the Danish economy. The household sector has been submitted to extensive policies designed to reduce energy consumption. As we are all part of the household sector, and because expenditures for energy usually make up an important share of the total household budget[1], it is important to understand what determines household energy consumption in order to understand how policies affect us.

The objective of this study is to estimate demand-relations for energy by households for heating purposes on the one side and for domestic appliances on the other side. These components constitute the uses of energy in most households not considering the use of energy for transport.

The household sector in Denmark is submitted to quite extensive regulation on the energy markets. For example, quite restrictive building regulations have been introduced in order to reduce consumption of energy for heating purposes. Building regulations put restrictions on the heat loss of the building shell. Building regulations important for the consumption of energy in single family houses were introduced in 1977, and tightened further in 1982, and 1985. The first building regulation nearly halved the allowed heat loss of the building. The next left the nominal heat loss unchanged, but changed the method of calculation of the heat loss. The latter restricted the heat loss allowance even further. Also other regulative actions have been taken. Huge resources have been allocated into developing collective heating systems by developing district heating, and natural gas distribution grids. The planning of these distribution grids has been made, so that houses located in areas with access to the natural gas grid do not have access to the district heating grid and vice versa. Following the development of these grids, installation of electric heating in new buildings has been banned since 1988, and from 1994 also in existing buildings in order to promote the use of natural gas and district heating. The purpose of this regulation is that electricity is not used as the main energy carrier for heating purposes in houses located in areas covered by the district heating or natural gas grid. In 1996, 17% of all single-family houses in Denmark used natural gas, and 35% used district heating as primary energy carrier. In 33% of all single-family houses the primary heating system is an oil based central heating system. For single-family houses using natural gas, district heating or oil, the practice is that only one primary heating system is present in the house. In this way about 85% of all single-family houses in Denmark are furnished with one primary central heating system using only one energy carrier, i.e. either natural gas, district heating or oil. For houses with these types of central heating systems the practice is further that hot tap water is supplied by the central heating system.

The focus of the paper is twofold. First, to get insight into the specification of the cross sectional relationships. It is of major importance that models are specified correctly, otherwise policy guidance may at best be imprecise. Secondly, to obtain knowledge on whether demand for natural gas is separable from demand for electricity and *vice versa*. The extensive planning and regulation of the heating supply would suggest that demand for natural gas for heating is not substituted by demand for electricity. This will be revealed by the separability test. The question of separability between energy carriers also has important implications for modelling household energy demand and for welfare evaluations.

The modelling approach in this paper follows a rather extensive number of more specialised energy demand studies, cf. a recent survey by Madlener (1996). These studies are usually single equation studies, based on energy survey data. This type of studies often includes an extended set of explanatory variables providing a richer description of the durable stock and other characteristics that are particularly important for the demand for energy. Examples are numerous, e.g. Branch (1993), Baker *et al.* (1989), Green (1987), Garbacz (1985), Klein (1988), and Poyer & Williams (1993). Common to this type of studies is that usually demand for energy is conditioned on goods that have a durable nature, namely the dwelling size, the insulation standard, the heating system and other characteristics of the house, and furthermore the stock of electric appliances, and the family composition. This can be interpreted as a short-run model, because it is reasonable to assume fixed technology only in the shorter run[2]. Demand for an energy carrier will also be modelled conditional on demand for other energy carriers. This approach allows a robust testing procedure for separability of demand for one particular energy carrier from demand for other energy carriers.

The main contribution of the paper, relative to previous papers within this line of literature, lies in offering new insights into the specification of single equation household energy demand relations. For example, the study suggests that the relationship between age and consumption of energy for heating purposes appears to be non-linear in some cases. Also, appropriate modelling of effects of building codes on energy consumption for heating purposes seems to be important. Finally, the dependence of demand for natural gas, used mainly for heating purposes, on demand for electricity, used mainly for domestic appliances, is addressed. This has not been done, so far, in the energy demand literature.

The plan of the paper is the following. In chapter 4 the sample is presented. In chapter 5 the econometric model, and the approach to testing for separability are addressed. In chapter 6 results are presented, and finally, in chapter 7 the paper is summarised and concluded.

4. DATA

The sample analysed here contains observations of 2,885 households in 1996, and includes information about individual households' consumption of energy, specifically natural gas and electricity. All the households use natural gas for space heating (central heating) and hot tap water. In some cases natural gas is also used for cooking instead of electricity, but this is not observed. As mentioned in the introduction, it is not expected that electricity is used for heating purposes, due to the institutional set up, but solely for domestic appliances. Also, as mentioned, when connected to the natural gas grid, the practice is that no other primary heating system is present in the house. It should be noted, though, that some houses may also have a wood-burning stove, but this information is not recorded in the data set.

The sample is constructed by merging public administrative registers[3] with registers of customers from the electricity utility company, NESA A/S, and the gas utility company, HNG I/S, and thus covers the grid of these companies, i.e. an area surrounding the northern part of Copenhagen. The administrative registers provide information about type, size, and vintage of the house, family composition, age, and information about household income, wealth and tax payments. The information about income, tax payments and wealth is used to construct a measure of total expenditure for the household[4]. The sample is delimited to include couples, both full-time employed[5], living in a single family house, and having at most two children. No old-age pensioners or students are included in the sample. This rather tight delimitation is taken in order to work with a rather homogenous sample that prevents matters from being far too complicated when pinning out the specification. For a further description of the data, see Leth-Petersen (2001).
The data set is constructed by considering the customers of only one energy supplier for each energy type in only one year. Therefore, no price variation is present to estimate price responses.

5. MODEL, TESTING AND ESTIMATION

The purpose of the paper is to investigate the cross-sectional patterns of demand for electricity and gas for households, and subsequently to test if the demand for natural gas is separable from the demand for electricity and vice versa. Finding the right specification is important when undertaking policy evaluations, since the results of these may be sensitive to the specification. Many studies assume linearity in income, age and the size of the house. This is by no means a trivial assumption. Therefore, the present analysis has been preceded by a non-parametric analysis, reported in Leth-Petersen (2001), suggesting that non-linearity may be present in one or more of these variables. Testing for separability is interesting because it provides information about whether the demand for one energy carrier can be modelled without taking into account the demand for other energy carriers. Having established this structure it is possible to check if consumers are substituting towards other types of energy following an increase in the price of say, natural gas.

The next section "The Structure of Demand" lays out the structure of demand for electricity and gas respectively. Section "Testing for separability" will address the issue of testing for separability of the demand for one energy carrier from demand for another energy carrier. Issues relating to estimation will be dealt with in the section entitled "Estimation".

The structure of Demand

The interest of the paper is in modelling the demand for energy carriers in the household. This is done by modelling demand for electricity and gas respectively as single equations. Households divide their total budget into different types of consumption. For the present purpose we allocate the budget into *three* types of demand: demand for natural gas, x_{gas}, demand for electricity, x_{el}, and demand for all other goods[6], x_{oth}, and denote the corresponding prices of these goods p_{gas}, p_{el}, p_{oth}. Further, let the function $g^{ij}(X)$ be the demand function for good i, the good of interest, conditional on the demand for good j, the conditioning good. Then the conditional demand for good i is given by

$$x_i = g^{ij}\left(p_i, p_{oth}, c_{-j}, x_j, a\right) \qquad \mathrm{i,j = el,gas} \quad \mathrm{i \neq j} \qquad (1)$$

where $c=p_ix_i + c=p_jx_j + p_{oth}x_{oth}$ is total expenditure of the household on all types of goods, and $c_{-j}=p_ix_i + p_{oth}x_{oth}$, is total expenditure less expenditures on the conditioning good j, cf. Pollak (1969). Also, the demand for good x_i is conditional on a vector, a, of conditioning variables that contain demographics, e.g. age, and family composition.

The conditional demand function is used instead of the unconditional demand function because it is a more convenient vehicle for exploring the structure of consumer preferences and the relations among goods. Applying the conditional demand function has at least two advantages for researchers modelling energy demand. First, the conditional demand function allows modelling demand for an energy carrier while not being occupied with modelling preferences for other goods, including other energy carriers and durables. The possible influence of other goods is taken into account simply by including the quantity consumed. Secondly, it offers a very easy way of testing separability[7].

Testing for Separability

If the good of interest is (weakly) separable from the conditioning good then the conditional demand function is given by

$$x_i = g^{ij}\left(p_i, p_{oth}, c_{-j}, a\right) \qquad \mathrm{i,j = el,gas} \quad \mathrm{i \neq j} \qquad (2)$$

This result is due to Pollak (1971). Comparing equation (2) with (1) suggests a simple test for separability of the good of interest from the conditioning good. The test is given, simply, by testing the significance of the quantity of the conditioning good in the equation for the good of interest. The test is suggested by Browning and Meghir (1991).

In the present context it is possible to test for separability of demand for electricity (natural gas) from demand for natural gas (electricity) by inserting the quantity of natural gas (electricity) into the equation for electricity (natural gas)[8].

The testing procedure has a number of advantages over the procedure based on the unconditional demand function. First, it does not require that preferences for the conditioning good are correctly specified, as do separability tests based on the unconditional demand function. Secondly, it does not require modelling of the budget constraint of the conditioning good. This is of particular value when dealing with labour supply and durables.

Estimation

Returning to issues related to estimation and the practical implementation of the testing procedure, some of the conditioning goods and other explanatory variables may themselves be stochastic, and some may be unobserved.

Firstly, note that no price variation is present in the data. The price terms in (1) thus vanish in the estimating relation. The estimating relation including the conditioning variable can now be written

$$x_i = f\left(c_{-j}, x_j, a \middle| \beta\right) + u_i \qquad \mathrm{i, j = el, gas} \quad \mathrm{i \neq j} \tag{3}$$

where β is the vector of parameters to be estimated and u is the error term.

A second complication for estimation is that the quantity of the conditioning good may be endogenous. That is, x_{el}, may be endogenous in the equation for x_{gas}, and vice versa. The potential endogeneity problem arises because of unobserved components that are potentially important for the demand for energy. The unobserved term (3), u_i, can be divided into a number of components.

$$u_i = D_i + \mu + \varepsilon \qquad \mathrm{i = el, gas} \tag{4}$$

D_i is a vector of unobserved durable components, μ is a component containing information about unobserved household behaviour relevant to the consumption of energy, and ε is random independent error term. First, the complications of the durable vector will be dealt with, and next the complications of unobserved behaviour of the household.

Firstly, in the gas equation the durable vector, D_i, contains information about the unobserved characteristics relating to the efficiency of the heating system, and components of the building shell that are of importance to the consumption of energy for heating purposes. Finally, in the gas equation D_i contains information about the possible existence of a gas-based kitchen stove. Turning to the electricity equation, the durable vector contains information about the stock of electric domestic appliances. This possibly includes an electric kitchen stove, and possibly heating durables. Electric heating durables may be present if installed before the ban on electric heating was put into force, or if supplementary or non-permanent electric heating is present, for example portable electric heating fans, or if electric heating has been installed illegally. Thus, the components of the unobserved durable vectors in the gas and electricity equation that can be present in either, or both, the gas equation or the electricity equation are a kitchen stove and some heating equipment.

If the kitchen stove is electrically based then this will imply a correspondingly lower level of gas consumption. On the other hand, if the kitchen stove is gas based then this will imply a correspondingly lower level of electricity consumption. Expressed compactly, $E[x_j \; D_i] < 0$, for i, j=el, gas. Therefore, the unknown characteristics of the kitchen stove will always contribute with a negative bias in the parameter estimate of the conditioning variable.

All the households in the sample are equipped with a primary heating system that is natural gas based. Some households may, however, for different reasons have some electric heating, so that electric heating substitutes part of the natural gas based heating. Consider two households that are identical except that one household provides all heating by natural gas, and the other provides part of the heating by electricity. In this case, the household with supplementary electric heating will appear with a lower level of gas consumption than the household with only gas-based heating. Expressed compactly, $E[x_j\ D_i] < 0$, for i=el and j=gas. Thus, in the electricity equation, the presence of electric heating durables will contribute with a negative bias in the parameter estimate of the conditioning variable.

The role of the unobserved behaviour of the household may also have important implications for the parameter estimate of the conditioning variable. In this particular case, endogeneity can arise because of people having different unobserved preferences for staying home as an alternative to going out. People having preferences for staying in will need to warm the house and will be likely to use the stock of domestic appliances more. In this way the unobserved component μ will be positively correlated with the conditioning variable. Expressed compactly, $E[x_j\ \mu] > 0$, for i, j=el, gas. This potentially implies a positive bias in the conditioning variable.

Further, different preferences for indoor temperature can cause endogeneity of the conditioning variable, x_{gas}, in the equation for electricity consumption, since a gas boiler uses electricity when producing heat. The potential endogeneity problem arises because the level of electricity used as input in the gas boiler is dependent on the level of intensity under which the boiler is operating.

Summarising, the separability test is expected to indicate that demand for electricity and demand for natural gas are not substituted due to the institutional set up. However, if durables are present that can facilitate substitution, this will bias the parameter estimate of the conditioning variable negatively. If on the other hand differences in in-house behaviour exist then this will bias the parameter estimate of the conditioning variable positively.

In order to identify the parameter of the conditioning variable, other variables that are orthogonal to the unobserved components, but still correlated with the conditional variable must be chosen. These are called instrumental variables. A natural instrumental variable for the conditioning goods would be the market price, since this is surely exogenous. Unfortunately, as already mentioned, the cross-section analysed here does not offer any price variation. The vintage of the house, though, is a potentially good candidate because building regulations impose massive restrictions on the use of energy for heating purposes while not being concerned with consumption of energy for other purposes. Hence, it is assumed that the vintage of the house does not enter the equation for demand for electricity. The validity of this assumption will be tested formally. No immediate candidate instruments appear for x_{el}, in the equation for x_{gas}. Thus, the hypothesis of endogeneity of x_{el} in the equation for x_{gas} cannot be tested.

Finally note, that total expenditure, c, is also likely to be endogenous. As instrumental variable the natural log of household gross income is used.

The vector of parameters, β, of (3) are estimated by minimising u'Pu, where u is the vector of error terms from (3) and $P=(Z(Z'Z)^{-1}Z)$ and Z is a matrix of instrumental variables satisfying $E[u|\ Z]=0$. The covariance matrix is estimated using the form suggested by White (1980) that is robust to general forms of heteroscedasticity. Further, where relevant, two specification tests are provided. First, a Hausman (1978) test for exogeneity is supplied[9]. The second statistic is a Sargan statistic for overidentifying restrictions, cf. Hansen (1982)[10]. This test statistic reports if the instrumental variables are uncorrelated with the errors of the demand equation as is required for the instrumental variable estimator to be consistent.

6. RESULTS

Two equations have been estimated independently. One equation for the demand for electricity and one equation for the demand for natural gas. Estimation results are presented in table 1 at the end of the paper. Column 1 in table 1 contains estimation results for the electricity equation, and column 2 in table 1 contains estimation results for the gas equation. The presentation of the estimation results is divided into two sections. In the first section, the basic model is presented. Then, in the second section the issue of separability in demand for electricity from the demand for gas and *vice versa* is addressed.

The Basic Model

The specification of the estimated demand equations is based on the insights of a non-parametric regression analysis, reported in Leth-Petersen (2001) that preceded the estimation of the model presented here. The preferred specification of the gas demand relation, cf. column 2, table 1, includes a squared term in the natural logarithm of age of the oldest person in the household while keeping the natural logs of income and square metres linear. For the electricity demand relation the preferred specification includes linear term in the natural logarithms of income, square metres, and age of oldest member of the household, cf. column 1, table 1.

Further, a set of dummy variables describing the family composition in terms of children is included in both equations. The family composition variables are specified so that all possible combinations of number and age of children are contained within the set of dummy variables. This is done in order to provide the less restricted specification of the importance of children. Finally, two technical dummy variables are included, describing if the house is two-storeyed and if it is a non-detached house.

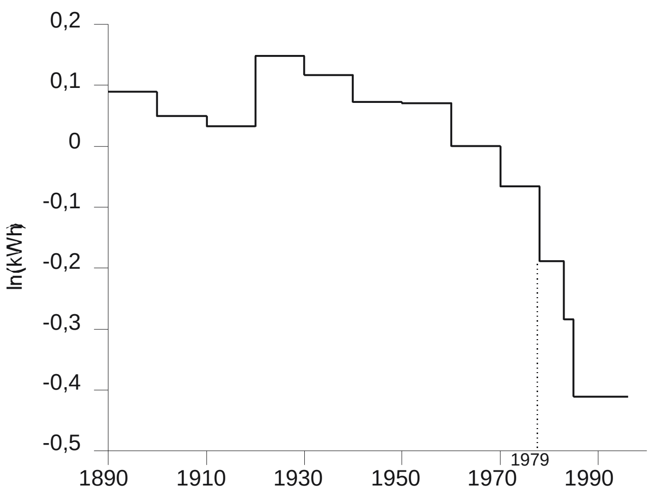
In the gas equation is a set of dummy variables indicating the vintage of the house. The house vintage is categorised into a set of dummy variables, divided into decades up to 1979 where the first building regulation imposing restrictions on the heat loss of the building shell was put into force. Hereafter, the dummy variables are categorised according to time where the subsequent building regulations were put into force, i.e. in 1983 and 1986. First, the electricity demand equation will be commented on, and subsequently the gas equation will be treated.

The preferred specification for the electricity demand relation includes a linear term in total expenditure. The total expenditure elasticity is estimated to 0.28. This is within the range of what is usually found in studies of household electricity demand, e.g. Baker *et al.* (1989), and Branch (1993). Consumption of electricity is also increasing linearly with the size of the house. A doubling of the size of the house is roughly associated with a 25% higher level of consumption of electricity. Estimation results indicate that no age effect is present. This is consistent with the indications given by the non-parametric analysis in Leth-Petersen (2001). Further, in the electricity equation it is seen that children affect the demand substantially. The pattern seems to suggest that the number of children is important to the level of consumption. Families with one child appear to have a level of consumption that is about 14% higher than families without children. Estimates indicate that families with two children are associated with a level of consumption of electricity that is about 20% higher than for families without children. The average contribution per child is thus lower for families with two children than for families with one child. Further, there is some indication that small children do not affect the consumption of electricity as much as older children, although this effect is not statistically significant. Finally, as expected, families living in two-storeyed houses or non-detached houses are not associated with a different level of consumption of electricity than families living in single-storeyed detached houses.

Turning to the gas equation, the non-parametric analysis gave the strongest indication for curvature in the age-consumption relationship. The preferred specification for the gas equation is presented in table 1, column 2. A squared term is included for age of the oldest person in the household whereas only linear terms are included for income and square metres. The linear term in total household expenditure is common to many single equation studies of demand for energy for heating purposes, e.g. Lee and Singh (1994), Garbacz (1985), Klein (1988), Green (1987). The estimated elasticity of 0.39 falls in the upper end of the interval of what is usually found in these studies. This may be explained by the fact that many of these studies enter household income instead of total household expenditure in the demand relation. The linear relation between the size of the house and the level of consumption amounts to an increase in consumption of energy for heating of approximately 50% by doubling the house size. Estimates suggest that consumption is increasing monotonically non-linearly with age. Age effects have been found in a number of studies before, e.g. Baker *et al.* (1989). Once having controlled for the size of the house and the age of the oldest person in the household, families with children appear not to be associated with any higher level of consumption of natural gas than families without children.

The estimated parameters of the technical variables indicate that the consumption of natural gas in non-detached houses is some 5% lower than in detached houses. This is expected, as natural gas is used for space heating, and because this type of houses have relatively less wall area facing outdoor temperature than detached houses. The same considerations should be valid for houses with two storeys. Estimates, however, suggest that there is no effect. This may relate to the second storey being a utilisation of the attic with a lower insulation standard thus neutralising the gain from reducing the surface area facing outdoor temperature. The vintage of the building is of major importance in the demand for natural gas, because of changing building styles, and because of the introduction of building codes. The estimated vintage effect appears to be very robust to the specification of the other parts of the model. Estimated vintage effects are graphed in Figure 1.

Figure 1. Estimated Vintage Effects on Demand for Natural Gas



Note: Variations in the graph should be read as deviations from the level of demand for natural gas in buildings built in the period 1960-1969. Source: Table 1.

The significance of the vintage effect in the demand for energy for heating purposes follows what is found in a study of the demand for energy for space heating in apartment blocks, cf. Leth-Petersen & Togeby (2001). The pattern of the vintage effects for single-family houses, cf. figure 1, indicates that the consumption of energy for heating purposes has been increasingly efficient in houses built after the 1960s. This indicates that energy efficiency improvements were already an issue before the introduction of building codes. However, the figures indicate that gas consumption is significantly lower for buildings built after the introduction of building codes, implying that building codes seem to have had an effect.

Testing for Separability of Energy Consumption from Consumption of Other Energy

In this section the results of the separability tests are presented. As outlined in the section entitled "Testing for separability" of chapter 5, testing for separability of electricity from natural gas is done by testing the significance of the quantity of natural gas in the electricity equation and *vice versa*. In the electricity equation, table 1 column 1, the parameter estimate of the quantity of natural gas is found. The parameter estimate of natural gas consumption in the electricity equation is insignificant indicating that demand for electricity is indeed separable from demand for natural gas. The quantity of natural gas is instrumented with the vintage dummies. The Sargan test does not reject the validity of the vintage dummies as instruments, and the Hausman test rejects exogeneity. The separability of demand for electricity from demand for natural gas is consistent with the heat planning having been successful, i.e. that the households in the sample do not substitute the use of gas for heating with electricity.

A similar procedure has been applied to the gas equation in order to test if the demand for natural gas is separable from the demand for electricity. Assuming that the demand for electricity is exogenous to the gas demand equation the parameter of electricity demand is estimated significantly positive, cf. table 1, column 2, indicating non-separability. Consumption of electricity appears not to be separable from gas consumption. As mentioned before, the demand for electricity is likely to be endogenous to the demand for natural gas, and that this has probably affected the outcome of the test. The positive sign on the parameter estimate is consistent with the in-house behaviour dominating the bias.

Summarising, the demand for electricity appears to be (weakly) separable from the demand for natural gas. The analysis does not resolve definitively if consumption of gas is separable from consumption of electricity. It will therefore be assumed that demand for natural gas is non-separable from the demand for electricity. This means that the allocation of expenditures on electricity and other goods is independent of the demand for natural gas. This corresponds to a situation where expenditure for gas is deducted from the total budget, and the remainder is allocated between electricity and other goods. The other way around is different, though. The allocation of expenditures on natural gas and other goods is not independent of the demand for electricity. The results of the separability tests are based on the assumption that the technology is kept fixed. This means that the results are valid in the short run. In the longer run households may adjust the durable stock, for example by undertaking insulation upgrading or by introducing new heating technology.

In order to develop the understanding of the role of electricity in the gas demand the effects of an increase in the conditioning good on gas demand are explored. The treatment follows Pollak (1971). Taking equation (1) as the starting point the conditional demand function can be written

$$\begin{aligned} x_i &= g^{ij}\left(p_i, p_{oth}, c_{-j}, x_j, a\right) && \mathrm{i,j = el,gas} \\ &= g^{ij}\left(p_i, p_{oth}, \left(c - p_j x_j\right), x_j, a\right) && \mathrm{i \neq j} \end{aligned} \qquad (5)$$

where c is total expenditure and $c_{-j}=c-p_jx_j$. Differentiating (5) with respect to p_j yields

$$\frac{\partial x_i}{\partial p_j} = \frac{\partial g^{ij}}{\partial c_{-j}} \frac{\partial c_{-j}}{\partial p_j} + \frac{\partial g^{ij}}{\partial x_j} \frac{\partial x_j}{\partial p_j} \qquad \mathrm{i,j = el,gas} \quad \mathrm{i \neq j} \qquad (6)$$

In Pollak's terminology the first term is called the *money expenditure effect* and the second term is called the *pure substitution effect*. The substitution effect arises because an increase in the price of the conditioning good implies a change in the demand for the conditioning good which, in turn, causes reallocation of the non-conditioning goods. The money expenditure effect works by a price change of the conditioning good causing the level of expenditures for the non-conditioning goods to change.

The substitution effect $\left(\partial g^{ij}/\partial x_j\right)\left(\partial x_j/\partial p_j\right)$ consists of two terms. The latter term $\left(\partial x_j/\partial p_j\right)$ is the own price effect of the conditioning good. This term is negative if the good is not a Giffen good. The former term $\left(\partial g^{ij}/\partial x_j\right)$ gives the effect on the good of interest of a unit change in the demand for the conditioning good given that the level of expenditures on the non-conditioning goods is kept fixed. Pollak (1969) uses the sign of $\left(\partial g^{ij}/\partial x_j\right)$ to categorise how the conditioning good is related to the non-conditioning good: if $\left(\partial g^{ij}/\partial x_j\right) > 0$ x_i is positively related to x_j, if $\left(\partial g^{ij}/\partial x_j\right) < 0$ x_i is negatively related to x_j, and if $\left(\partial g^{ij}/\partial x_j\right) = 0$ x_i is unrelated to x_j.

In this Pollak (1969) –sense, the demand for natural gas is positively related to the demand for electricity. On the other hand, the demand for electricity is unrelated to the demand for natural gas.

The demand for electricity being unrelated to the demand for natural gas implies that the latter term in (6), the substitution effect, disappears, and that a change in the price of natural gas has an effect on the demand for electricity only through the level of expenditures allocated to the demand for electricity and other goods. This implies that if electricity is a normal good, then an increase in the price of natural gas will cause consumption of electricity to decrease if the demand for natural gas is inelastic, as is often found in empirical studies, e.g. Baker *et al.* (1989).

On the other hand, since the demand for natural gas is positively related to demand for electricity, a change in the price of electricity has both a substitution effect and an expenditure effect. If the demand for electricity is inelastic, as is often found in empirical studies based on micro data, e.g. Branch (1993), then an increase in the price of electricity will decrease the demand for natural gas. This follows because an increase in the price of electricity leads to an increase in the expenditure on electricity leaving less money to be spent on other goods. Now, if natural gas is a normal good then this implies a decrease in the demand for natural gas.

Note, that the pure substitution effect dealt with here implies that if a price increase of the conditioning good leads to a decrease in the demand for the conditioning good then the pure substitution effect leaves utility at a lower level. This is in contrast with the Slutsky-Hicks substitution effect that leaves utility unchanged, cf. Pollak (1969).

The treatment is based on the assumption that the technology is kept fixed. In this way the results of the tests are relevant particularly in the short run. In the longer run it may be expected that households will adjust their stock of technology, e.g. undertake insulation upgrading, adjust the heating technology, etc.

The results have indicated that the households in the sample using natural gas for space heating experience significant welfare effects in the short run from changes in the prices of natural gas. This is because they do not substitute the consumption of natural gas with consumption of electricity and do not have any other alternative source of energy supply. This indicates that increasing substitution possibilities in energy demand for heating purposes is a way of reducing adverse welfare effects of relative price changes in energy carriers.

7. SUMMARY AND CONCLUSIONS

The understanding of household energy demand behaviour is an important task since the household segment of the energy market is subject to extensive price fluctuations stemming from the market and because it is submitted to much regulation by politicians, all likely to have significant welfare effects. In this paper a cross-section of households from 1996 have been analysed. Estimates suggest that electricity consumption depends on the number of children, and depends linearly on the natural logarithm of total expenditure, size of the house, and age level. The consumption of natural gas is found to vary nonlinearly with age, and to depend linearly on total expenditure, and the size of the house. Furthermore, demand for natural gas is found to depend on the technical characteristics of the house. Particularly, it is found that the consumption of energy for space heating depends heavily on the vintage of the house reflecting changing building styles and building codes in force at the time of the construction of the house.

Based on the estimated model separability in demand for natural gas from electricity and *vice versa* was tested using a robust testing procedure. The analysis indicates that demand for electricity is separable from the demand for natural gas. This result is consistent with the extensive planning of the supply of energy for heating purposes in Denmark. The analysis furthermore suggests that the demand for natural gas is positively related to electricity in Pollak's sense. Together, this indicates that market as well as policy induced price changes could have significant welfare effects in the short run since the demand for specific energy carriers is not substituted by demand for other energy carriers.

8. ACKNOWLEDGEMENTS

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10. END NOTES

[1] Energy expenditures make up 6% of the total household budget on average for the whole population, cf. Danmarks Statistik (1998).

[2] A number of studies stress that the heating and housing technology is potentially simultaneously determined with consumption of energy, i.e. endogenous in the econometric terminology. Some studies have attempted to model this, e.g. Dubin and MacFadden (1984). Others, consider the stock of energy consuming durables as predetermined, and model only purchase of durables in the current period, cf. Halvorsen & Larsen (2001). In the present study the appliance stock and purchase are assumed fixed.

[3] Rasmussen (1997) for a more complete description of this part of the sample.

[4] Total expenditures for the household are constructed according to the following identity:

$$c_{96} \equiv y_{96} - t_{96} - s_{96} = y_{96} - t_{96} - ((1/1+r)W_{97} - W_{96})$$

where c_{96} is total expenditure in 1996, y_{96} is gross income in 1996, t_{96} is tax payments in 1996, W_{96} is wealth at the beginning of 1996, W_{97} is wealth at the beginning of 1997, and r is a discount rate. All variables are measured at household level. This approach follows Beach et al. (1988), and is documented in more detail in Leth-Petersen (2001).

5 Consumption may be traded off with leisure as emphasised by Browning and Meghir (1991). This trade off is not modelled here in order to focus on separability from other energy carriers. Further, the modelling of labour supply decisions would have been hampered by only a few observations being present in other labour supply categories.

6 'Other goods' includes food, services, clothing, transport, etc.

7 Note, that testing for separability is only relevant when demand is defined over at least three goods. This follows from the fact that if demand is only for two goods, x_1 and x_2, over a given budget, c, then demand for good two is given as

$(c-p_1x_1)$, and the demand for good one is thereby additive separable from the demand for good two.

8 Note, it is relevant also to test for separability between demand for energy and demand for non-energy goods, for example food. This is, however, not possible in the present context since other goods are defined residually as a composite good. To test for separability between energy and other goods one needs more detailed information about the consumption of other goods.

9 The test statistic is given by $(\beta^{IV} - \beta^0)'[V(\beta^{IV}) - V(\beta^0)]^{-1}(\beta^{IV} - \beta^0)$, where β^{IV} are the parameter estimates obtained using the instrumental variables estimator, β^0 are the estimates obtained assuming exogeneity, and $V(\beta^{IV})$ and $V(\beta^0)$ are the covariance matrices of the respective estimators. The statistic is chi-squared distributed with degrees of freedom equal to the rank of $[V(\beta^{IV}) - V(\beta^0)]$ under the null hypothesis that a given set of variables is exogenous.

10 The Sargan statistic for overidentifying restrictions is given by u'Pu, where u is the vector of errors obtained from instrumental variables estimator and $P=Z(Z'Z)^{-1}Z$. The statistic is chi squared distributed with (r_Z-r_X) degrees of freedom, where r_Z is the number of instrumental variables and r_X is the number of parameters to be estimated.

ANNEX

Table 1. Estimates of Electricity Demand and Gas Demand Equations

Dependent variable, ln(kwh)	1. Electricity	2. Natural Gas
Constant	3.7779**	12.1806**
	0.8327	2.2440
Ln(m^2)	0.2363**	0.4931**
	0.0518	0.0346
Ln(total household expenditure) (1)	0.2788**	0.3856**
	0.0707	0.0453
1 child, aged 0-6	0.1351**	0.0230
	0.0576	0.0266
1 child, aged 7-14	0.1357**	-0.0290
	0.0482	0.0316
1 child, aged 15-25	0.1474**	0.0124
	0.0238	0.0170
2 children, aged 0-6. 0-6	0.0564	-0.0085

	0.0502	0.0280
2 children, aged 0-6. 7-14	0.1830**	0.0213
	0.0461	0.0249
2 children, aged 7-14.7-14	0.1726**	-0.0425
	0.0391	0.0245
2 children, aged 7-14.15-25	0.2011**	-0.0257
	0.0316	0.0271
2 children, aged 15-25.15-25	0.2122**	0.0006
	0.0263	0.0234
House vintage, –1899 (2)	-	0.0890
		0.0654
House vintage, 1900-1909 (2)	-	0.0495
		0.0819
House vintage, 1910-1919 (2)	-	0.0317
		0.0611
House vintage, 1920-1929 (2)	-	0.1468**
		0.0339
House vintage, 1930-1939 (2)	-	0.1157**
		0.0246
House vintage, 1940-1949 (2)	-	0.0722**
		0.0322
House vintage, 1950-1959 (2)	-	0.0700**
		0.0217
House vintage, 1970-1978 (2)	-	-0.0668**
		0.0141
House vintage, 1979-1982 (2)	-	-0.1899**
		0.0324
House vintage, 1983-1985 (2)	-	-0.2854**
		0.0304
House vintage, 1986-1995 (2)	-	-0.4110**
		0.0262
2 storeys	-0.0132	0.0021
	0.0590	0.0340
Non-detached house	-0.0127	-0.0444**
	0.0277	0.0168
Ln(kWh_j)	0.0272	0.0410**
	0.0794	0.0123
Sargan Statistic	0.5959 (3)	-
Hausman Statistic	7.0125 (4)	49.9859 (5)

Note: The reference is a couple without children living in a single-storeyed house built in 1960-69.

Standard errors in small numbers below parameter estimates.** indicates significance at 5% level, *indicates significance at 10% level.

(1) For column 1 total household expenditures are less the cost of gas consumption. For column 2 total household expenditures are less the cost of electricity consumption. Gross household income is excluded from both equations and used as instrument for total household expenditure.

(2) Vintage variables are excluded from the electricity demand equation, and used as instrumental variables for $\ln(kWh_j)$ in this equation.

(3) The test statistic is chi-squared distributed with 10 degrees of freedom.

(4) The Hausman statistic is calculated only for the variables that are suspected endogenous, i.e. for ln(total household expenditure), and $\ln(kWh_j)$. The test statistic is chi-squared distributed with 2 degrees of freedom.

(5) The Hausman statistic is calculated only for the variable that is suspected endogenous, i.e. for ln(total household expenditure). The test statistic is chi-squared distributed with 1 degree of freedom.