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Residential Energy Consumption for Space Heating in Norwegian Households

A Discrete-Continuous Choice Approach

Abstract:
In this paper the demand for space heating energy is estimated by using a discrete-continuous choice model which focuses on the relationship between the choice of heating equipment and energy consumption. The model is estimated on Norwegian micro data, and the two stages of the model are estimated simultaneously. The capital cost and the operating cost of the heating systems are both found to have a significant impact on the choice of heating system. Furthermore, the results show that household characteristics are important variables in residential energy models. Energy price elasticities and income elasticities are estimated.

Keywords: Household energy consumption, space heating system, discrete-continuous choice.

JEL classification: C51, D12, Q41.

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I. Introduction

Many household energy demand studies focus on energy consumption without considering the link between heating equipment and energy use. The pioneering work of Dubin and McFadden (1984) estimates a model where this link was thoroughly investigated.

The main aim of this paper is to apply a version of the model in Dubin and McFadden (1984) on Norwegian data from the 1990 Energy Survey, see Ljones et al. (1992). The approach of this paper is different from the Dubin and McFadden model in several respects. First, more than two-thirds of Norwegian households may use more than one type of energy source. Accordingly, the model specification allow the households to choose between combinations of heating equipment, while in Dubin and McFadden (1984) water and space heating are either both electric or both gas. The Norwegian data give information about heating equipment utilisation in 1990, although the equipment itself was installed between 1971 and 1990. Thus, the choice of space heating equipment at one point in time is estimated jointly with the intensity of use at a later point in time. This is different from the approach in Dubin and McFadden (1984), where both the real capital costs and the operating costs of the heating systems are related to the point in time when the heating system is utilised. Furthermore, this paper focuses on *total* energy use for space heating, while Dubin and McFadden (1984) focus on electricity demand for water and space heating. Finally, in this paper the choice of heating technology (the discrete choice) and the utilisation of the heating technology (the continuous choice) are estimated simultaneously. Dubin and McFadden (1984) estimate the discrete and the continuous choice in two steps, as do Bernard, Bolduc and Bélanger (1996), whose work also is inspired by Dubin and McFadden (1984). This was also done in Nesbakken and Strøm (1993), which is an earlier work applying a model related to the one used in this paper.

The theoretical model and the econometric model are presented in section II. The results follow in section III. Income and energy price elasticities are reported. Concluding remarks are given in section IV. The data are described in appendix A.

II. The Discrete-Continuous Choice Model

When applying discrete-continuous choice models on residential energy demand, the discrete choice is the selection of energy-using equipment, whereas the continuous choice is the energy consumption decision restricted by the investment decision in the discrete choice. Discrete-continuous choice models are characterised by modelling the discrete choice jointly with the continuous choice, see, for example, Hausman (1979), Hanemann (1984) and Dubin and McFadden (1984). In discrete-continuous choice models which focus on consumption of a certain type of energy or total energy consumption in each household, the discrete choice may differ with respect to the specification of feasible alternatives. The discrete choice in Dubin and McFadden (1984), Goett (1979) and Dagsvik et al. (1987) is the choice of heating equipment, while for instance in Dennerlein (1987) it is the choice of electrical appliances. The main modelling idea in this paper is that the demand for *space heating* equipment and its intensity of use are related decisions made by the households. The main aim is to analyse the household's total energy consumption for space heating. Consumption of each fuel type is not taken into consideration.

The choice of heating technology is related to new houses. The household in the model chooses between mixed heating systems, which means that the household, for instance, may choose to combine an electric heater and another type of heating equipment. The household chooses among the following *four mutually exclusive heating technologies*, which are grouped by fuel use:[1]

- *Electricity* (electric heaters)
- *Electricity and oil* (electric heaters combined with stoves for oil/kerosene)
- *Electricity and wood* (electric heaters combined with wood stoves)
- *Electricity, oil and wood* (electric heaters combined with stoves for oil/kerosene and stoves for wood)

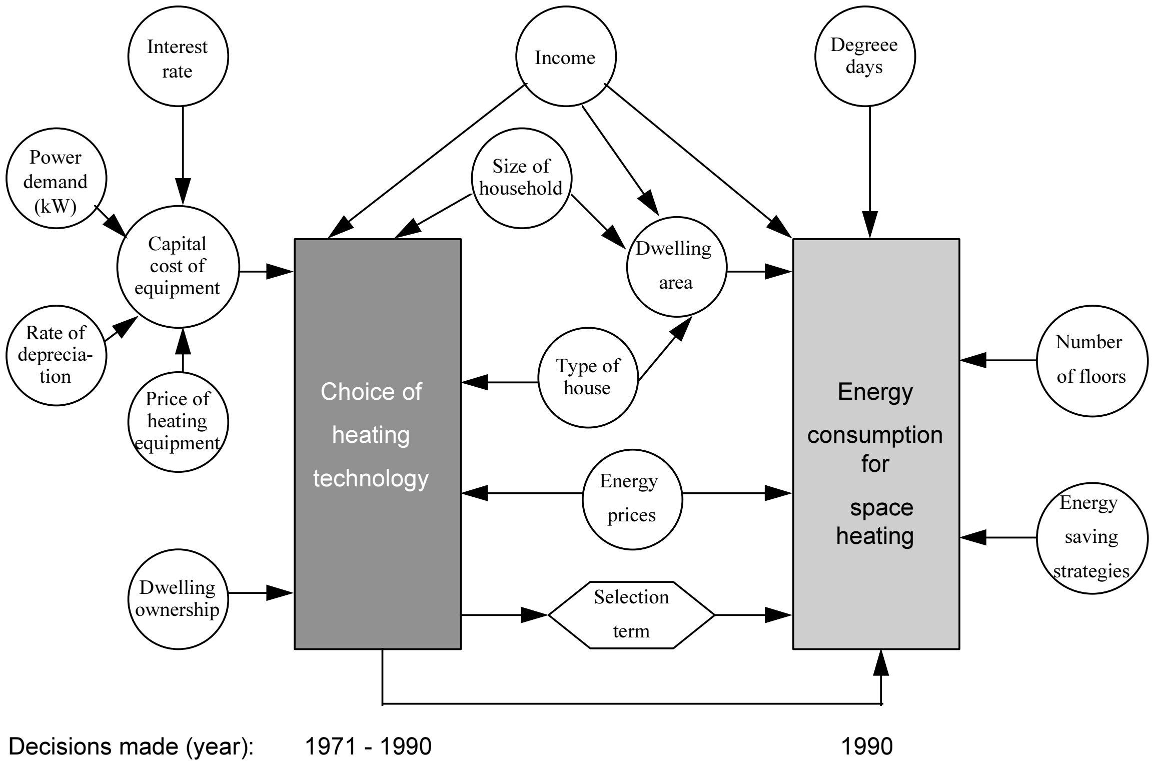
The heating technology observed in 1990 is assumed to be the same as the technology purchased when the house was built. Of course, all available heating equipment that was initially purchased is not necessarily used in 1990.

The specifications of discrete-continuous choice models may differ, since they may address different issues and different data. What is essential to understand about the discrete-continuous choice model applied in this paper is that the choice of heating system for each household is made at one point in time between 1971 and 1990, while for all households the intensity of use is related to 1990.
Figure 1 is an illustration of the model used to analyse the choice of heating technology and the household energy consumption for space heating. According to economic theory, the demand for energy is expected to increase with income, and to be inversely related to the energy price of energy types used by the chosen heating technologies. The discrete choice is an investment decision, and the

[1] Central heating is excluded because cost data are missing. About 11 per cent of the households in 1990 had central heating.

hypothesis is that the probability of choosing a given heating technology is higher the lower the total costs related to this choice are.

Figure 1. Flow diagram for the variables in the model



An *a priori* hypothesis concerning the impact of income on the choice of heating technology is difficult to formulate. The reason is that this choice may depend on factors like house type, power requirements, attitudes to environmental objectives, valuation of time used on operating the heating systems etc., which may vary among households in the same income group. The effect of income on the choice of heating system is therefore an empirical issue, which is left to be tested in the estimations of the model.

A discrete-continuous choice model is used because we assume there is a relationship between the heating technology and the utilisation of this technology. Our model includes observable variables which may influence both the discrete and the continuous choice. In addition, there may be unobservable features of energy demand and choice of heating technologies which are correlated (denoted selection term in figure 1). The null hypothesis in this paper is that unobserved factors influencing the choice of heating system are independent of unobserved factors influencing the intensity of use. This hypothesis was rejected in Dubin and McFadden (1984).

When modelling energy consumption, one should consider the fact that a lot of households do not explicitly choose the heating equipment themselves. Households first select the dwelling they want to buy or rent. This choice, however, may be affected by the kind of heating equipment which is already installed. Furthermore, it can be argued that even though the heating equipment is chosen by the builder of the house, he tries to choose the kind of equipment which the buyer of the dwelling wants.

Another problem with the assumption that the household makes the heating choice itself, is that the household which utilises the heating equipment in 1990 may not be the same as the household who first moved into the house. In this paper, only dwellings in houses built after 1970 are considered. However, it is very likely that the main characteristics of the household may be nearly the same for the household who first moved in as for the household living in the dwelling in 1990.

Theoretical Model

The utility of the household depends on energy consumption, consumption of other goods, observable characteristics of the household and the dwelling, unobservable characteristics of the household and unobservable characteristics of the heating equipment. The household is assumed to choose the heating system j which gives the highest utility. The household is assumed to take all prices, income and the demand for power (kW) from the heating system as given, and it maximises utility with respect to

i) type of heating system

ii) energy consumption, given the heating system.

The preferences of the household given the budget constraint can be represented by an indirect utility. Let V_j denote the indirect utility function, let Z denote observed household characteristics, and let η and ε_j denote unobserved characteristics related to the household's preferences for indoor temperature and heating systems, respectively. The indirect utility function related to the choice of heating system *j* is given by

$$V_j = v(P_1, \dots, P_H, Y - B_j, Z, \widetilde{\eta}, \varepsilon_j) \qquad (1)$$

where P_h, (h=1, .. ,H), denotes the price of energy type h, and Y is gross income. B_j is total cost of heating technology j (j=1, ..., J), consisting of the annualised capital cost and the expected operating cost, expectations taken at the time of installations, see appendix C. The total cost of the heating technology is subtracted from the disposable income to give the income disposable for the consumption of all other goods and services other than energy. This is the case even after the heating technology is chosen and reflects the fact that the annualised capital costs can be interpreted as a rental price of heating system j. In this model energy consumption depends on the heating system choice, and accordingly disposable income conditional on the choice of heating technology, $Y - B_j$, is used as income variable. ε_j is assumed to be known to the household. $\tilde{\eta}$ is an expected value of the variable η which captures both factors which are known to the household and uncertain factors related to the energy demand. Examples of this type of uncertainty are the temperature in the future and uncertainty with respect to attitudes to energy saving behaviour which may change over time.

When the household selects a heating system j which maximises utility, the choice of heating system equals j if

$$V_j = \max_k V_k . \tag{2}$$

The choice of consumption of energy type h, with respect to the chosen heating system j, X_{hj}, is determined by Roy's identity, i.e.

$$X_{hj} = \frac{-\partial V_j / \partial P_h}{\partial V_j / \partial Y} \quad , \tag{3}$$

and total energy consumption conditional on the choice of heating technology j is given by

$$X_j = \sum_{h=1}^{H} X_{hj} \tag{4}$$

The Econometric Model and the Data

Let π_j be the probability of choosing heating system *j*, i.e.,

$$\pi_j = \Pr\left\{V_j = \max_k V_k\right\} \tag{5}$$

The specification of (1) is given by

$$V_j = \left[Z_1^{'}\alpha_{0j} + \sum_{h=1}^{H} \frac{\alpha_h}{\beta} + \sum_{h=1}^{H} \alpha_h P_h + Z_2^{'}a + \beta(Y - B_j) + \gamma_j Y^* + \tilde{\eta} \right] \exp(-\beta P_1) + \varepsilon_j \tag{6}$$

where $Z_1^{'}$ is a vector-variable describing the dwelling and household characteristics, including household size, ownership of the dwelling and type of house. $Z_1^{'}\alpha_{0j}$ allows the choice of heating system to depend on household characteristics that can be observed. The interpretation of the parameters (α_{0j}) is the impact on the probability of different heating choices relative to the reference parameter, which is set to zero. Y^* is income at the point in time when the heating system was purchased. We will now assume that Y^* is a proxy for unobserved factors correlated with income which may influence the household's preferences for different heating systems, and $\gamma_j Y^*$ represents the possible indirect impact of income on the choice of heating technology.

Both the annualised capital costs related to the selected heating equipment and the expected energy costs may influence the choice of heating system in this model, and these costs are captured by B_j. Energy price and energy consumption expectations are not observable. The observed average energy price for heating technology *j* at the point in time when the heating equipment was installed and average 1990 energy consumption for space heating are used in the estimations. The average energy consumption for space heating is calculated for 6 groups of dwelling size and type of house.

The direct effect of income on energy used for space heating is represented by $\beta(Y - B_j)$. $Z_2^{'}a$ accounts for observed dwelling and household characteristics which affect energy consumption. These are the predicted size of the dwelling, heating degree days, the number of floors in the dwelling, temperature regulation and other energy saving strategies. The dwelling size is estimated as a linear function of income when the house was built, (Y^*) the type of house and the household size, see appendix B. Given the choice of heating system, $\sum_{h=1}^{H} \alpha_h P_h$ reflects that the energy prices influence the intensity of heating equipment use.

The random variables ε_j, j=1, ..., J, are assumed to be identically and independently extreme value distributed. To assume independence between different choices of heating technology is restrictive, but convenient to give a model which can be estimated. We allow η and ε_j to be stochastically dependent. The correlation between unobserved characteristics related to the households' preferences for heating system and indoor temperature can be explained by an example. For instance, an environmental concerned household may choose the technology which is supposed to give the lowest CO_2 emissions, and given this heating system the household prefers a low energy consumption. Thus, in this example the heating system choice and energy use may give rise to a positive correlation between η and ε_j.

Equation (5) and the assumption of ε_j being extreme value distributed yield (see McFadden, 1973)

$$\pi_j = \frac{\exp[(Z_1'\alpha_{0j} - \beta B_j + \gamma_j Y^*)\exp(-\beta P_1)]}{\sum_{k=1}^{K} \exp[(Z_1'\alpha_{0k} - \beta B_k + \gamma_k Y^*)\exp(-\beta P_1)]} \tag{7}$$

which means that the heating system choice is given by a generalised version of the multinomial logit model.

The dwelling size is decided when the house is built, and it is assumed to be given in the short run when the household utilises its heating system. By using Roy's identity on (6) and treating the dwelling size as independent of income, total energy consumption conditional on the choice of heating system j is given by

$$X_j = Z_1'\alpha_{0j} + \gamma_j Y^* + \beta(Y - B_j) + \sum_{h=1}^{H} \alpha_h P_h + Z_2' a + \eta \tag{8}$$

Recall that when we look at the intensity of use, the variable η is no longer uncertain. η in equation (8) only includes factors which are known to the household. For instance, when the household has purchased a heating system and we analyse the utilisation of the system at some point in time, the household knows the temperature for certain. Dubin and McFadden (1984) show that the expectation of η conditional on the choice of heating system *j* is different from zero. Thus, when accounting for the possible selection bias associated with the fact that E[η|j]≠0, it can be shown that the energy demand function to be estimated is given by

$$X_j = Z_1^{'}\alpha_{0j} + \gamma_j Y^* + \beta(Y - B_j) + \sum_{h=1}^{H} \alpha_h P_h + Z_2^{'} a - \sigma_j \log \pi_j + \sum_{k \neq j} \sigma_k m_k + \mu_j \qquad (9)$$

where $\sigma_k = \sigma \rho_k$, $m_k = \dfrac{\pi_k \log \pi_k}{1 - \pi_k}$, μ_j is a random variable with zero conditional expectation given that heating system *j* is chosen, and ρ_j is the correlation between η and ε_j. The energy demand function is conditional on the choice of heating system *j*.

The parameter β is a link between the discrete and the continuous parts of the model, because this parameter is common to the *observable* variables income and heating equipment costs. Furthermore, the first two terms in (9) show that the energy consumption conditional on the choice of heating system *j* depends on observed variables and parameters concerning the choice of heating technology. The selection term, $-\sigma_j \log \pi_j + \sum_{k \neq j} \sigma_k m_k$, however, captures the effect of the correlation between *unobservable* characteristics concerning the heating choice and *unobservable* characteristics concerning the utilisation of the chosen heating technology.

The energy consumption conditional on the choice of heating system *j* is linear in prices and income. Equations (7) and (9) are used to estimate the unknown coefficients in this model. The value of all variables used to estimate the heating choice are dated at the point when the heating equipment was chosen (in the period 1971 to 1990), while the values of the variables used to estimate the continuous choice are dated at the point when the utilisation takes place, i.e. in 1990.

The term $\sum_{h=1}^{H} \alpha_h P_h$ in equation (9) represents the effect of prices on energy intensity use. However, because only effects on total energy consumption is studied, the average price of energy types (electricity, oil and wood) used in the selected heating system, $\alpha \overline{P}_j$, is used in the estimation of the model.

As a result, the prices of all types of energy, which are included in the average energy price, have the same estimated impact on energy consumption.

Estimation by a full information maximum likelihood procedure

The discrete-continuous choice model is estimated simultaneously, to ensure consistent estimates of β over the discrete and the continuous stages of the model. Let

$$Y_{ij} = \begin{cases} 1 \text{ } if \text{ } household \text{ } i \text{ } chooses \text{ } heating \text{ } system \text{ } j, \ i = 1,\ldots,N \text{ } and \text{ } j = 1,\ldots,J \\ 0 \text{ } else \end{cases} \tag{10}$$

Then the log likelihood of the simultaneous model is given by

$$L(\theta) = \sum_{i=1}^{N}\sum_{j=1}^{J}\left[Y_{ij}\log(\pi_{ij}(\theta)f_{ij}(X_{ij}))\right] = \sum_{i=1}^{N}\sum_{j=1}^{J}\left[Y_{ij}\log\pi_{ij}(\theta) + Y_{ij}\log f_{ij}(X_{ij})\right] \tag{11}$$

where $\pi_{ij}(\theta)$ is the probability given in equation (7). Furthermore, $f_{ij}(X_{ij})$ is a conditional probability density function following from equation (9), when the error term, μ_j, is assumed to follow from a normal distribution with expectation zero and constant variance, given the heating system *j*,

$$\mu_{ij} \sim N(0, \tau_j)\,. \tag{12}$$

III. Results

The empirical results are given in table 1. The first part of the table is related to both the discrete and the continuous part of the model, while the second and the third parts of table 1 are related to the discrete and continuous stages of the model, respectively. Most of the parameter estimates differ significantly from zero, including the important coefficient β, which is related to the costs of the heating equipment and income. The results are as expected *a priori* with regard to energy price and income. An increase in the average price of energy used in the chosen heating technology is estimated to give reduced energy consumption, and the estimated effect of increased income is increased energy consumption. Furthermore, the results indicate that the higher the annualised capital costs and the operating costs of choosing a heating system, the lower is the probability of choosing that system.

Income, Y^*, is a proxy for unobserved factors correlated with income which may influence the preferences for different heating choices. The partial effect of this proxy variable on the choice of heating system indicates that electricity alone and electricity combined with wood are preferred to other heating systems when income is high. It may be argued that since income in 1990, Y, is highly correlated with Y^*, the estimated impact of income given by β will be biased when Y^* is included in addition to Y. However, when the model is estimated without the term $\gamma_j Y^*$, the parameter estimates are only slightly different from the results presented in table 1. In particular, the estimate of the parameter β is not significantly different from the estimate presented in the table.

Table 1. The choice of heating system and energy consumption for space heating in dwellings from 1971-1990. The reference choice is electricity (parameter=0). 550 dwellings

Variable	Estimate	t-ratio
Income, Y and heating system costs (Nkr[1]/year). (β)	0.16	2.78
Dwelling ownership		
Choice of heating system:		
Electricity + oil	-1.82	-2.33
Electricity + wood	-1.08	-3.56
Electricity + oil + wood	-3.52	-3.66
Type of house		
Choice of heating system:		
Electricity + oil	1.36	2.01
Electricity + wood	2.59	6.42
Electricity + oil + wood	2.19	4.85
Size of household		
Choice of heating system:		
Electricity + oil	-0.02	-0.08
Electricity + wood	0.38	3.78
Electricity + oil + wood	0.36	2.94
Income, Y*		
Choice of heating system:		
Electricity + oil	-0.64	-2.52
Electricity + wood	-0.13	-1.46
Electricity + oil + wood	-0.44	-3.45
Constant	-5.68	-2.23
Predicted size of the dwelling[2]	0.07	6.35
Degree days	2.79	7.91
Energy price of technology j	-9.39	-1.99
Temperature regulation	1.32	2.87
Number of floors in the dwelling	1.01	2.99
Energy saving strategies	0.36	0.82
Selection term		
Choice of heating system:		
Electricity	0.59	1.37
Electricity + oil	1.93	3.89
Electricity + wood	3.62	4.04
Electricity + oil + wood	3.93	5.48
Residual variance		
Choice of heating system:		
Electricity	3.16	12.98
Electricity + oil	5.04	5.52
Electricity + wood	6.13	25.16
Electricity + oil + wood	7.19	13.82

[1]US$ 1 = Nkr 7.5 (July 1998)

[2]Income at the point in time when the heating technology was purchased, the type of house and the size of household are used as instruments when estimating the dwelling area.

The estimates related to the effects of house type show that, in detached houses and farm houses, the combination electricity and wood most likely will be preferred. The impact of household size on the utility following from choosing different heating systems is estimated to be highest for the heating system which uses electricity and wood, relative to the reference choice (electricity).

Households in housing co-operatives or owner-tenant accommodations are more likely to choose only electricity than electricity combined with oil/kerosene or wood, and they are least inclined to choose heating technologies which use electricity, oil and wood. The reason is probably that these households often live in apartment buildings or undetached houses and do not need as much energy for heating as households in detached houses. In addition, there is no chimney in many of these dwellings.

When estimating the energy consumption, the predicted area is used as a variable, and our results confirm the assumption that energy consumption increases with the area of the house.

In this model, the effect of a colder climate (more degree days) is increased energy consumption. Even though people living in cold areas probably insulate their houses well, they still use more energy than people in other parts of the country.

According to the results, energy consumption seems to be affected by how the dwelling temperature is regulated. If the temperature is manually regulated, the energy consumption is higher than if the temperature is regulated by thermostat or centrally regulated. Installing thermostats is one of many ways to conserve energy. When testing the impact on energy consumption of different energy saving strategies and variables expressing attitudes to energy saving, no significant effects were found.

When the number of floors in a home increases, the energy consumption is estimated to increase. One reason is that the living room, which households often want to be well heated, is usually situated on the groundfloor, while the sleeping rooms are usually on the first floor. In particular, if a house is open through a staircase between the floors, and thus the heat moves upwards, energy consumption may be high if a relatively high temperature is desired for the groundfloor.

The estimation results for the selection terms of the different possible heating choices indicate that energy consumption depends on the choice of heating technology. If the probability of choosing a technology which uses electricity, oil and wood increases, the partial impact on energy consumption will be higher than if the probability of the other choices increases. The reason may be that households with the heating technology electricity, oil and wood often live in bigger houses and use more energy for space heating than do households with other combinations of heating equipment, and especially households with electricity alone. However, the impact of the selection term on the energy consumption comes in addition to the impact of the dwelling size. This result suggests that there is a relationship between unobserved characteristics of the heating technology choice and energy consumption.

Income and Energy Price Elasticities

Mean Income Elasticities

The short run income elasticity only includes the direct effect of income on energy consumption, see the left column of table 2. In the long run, however, income may have an indirect impact on energy consumption through the size of the dwelling. The dwelling size may be thought of as endogenous at the point in time when the heating equipment is chosen, and after then the size of the dwelling is assumed to be given in the short run. However, it can be argued that in the long run, the household may increase the size of its house or may move into another house of the same type with the same type of heating equipment, but with larger floor space. The impact of income on the dwelling size, and accordingly on energy consumption at some point in the future, is assumed to be highly correlated with the impact of income on dwelling size and energy consumption when the house was built. The estimated income elasticity may be interpreted as an *approximate long run income elasticity* given the choice of heating system, see the right column of table 2.

Table 2. Mean income elasticities

Heating system based on	Short run Dwelling size constant	Approximately long run Area as a function of income
Electricity	0.08	0.46
Electricity + oil	0.04	0.23
Electricity + wood	0.04	0.19
Electricity + oil + wood	0.03	0.17
All households (average)	0.04	0.21

Due to the results an increase in income by 1 per cent will increase energy consumption for space heating by only 0.04 per cent if the dwelling size is assumed to be given. However, if the dwelling size may increase, too, as a result of increased income, the residential energy consumption for space heating may increase by more. The interpretation of the average elasticity of 0.21 is that an increase in income of 1 per cent may increase energy consumption for space heating by about 0.21 per cent in the long run.

Mean Energy Price Elasticities

The model is used to estimate energy price elasticities, both conditional and unconditional on the choice of heating technology. When estimating the *conditional* energy price elasticity, it is assumed that only the energy prices (in 1990) change. The effect of increased energy prices is represented by the parameter α, estimated to be -9.39, see table 1. The conditional energy price elasticities may be interpreted as short term energy price elasticities.

If it is assumed that the energy price at the point in time when the heating system was chosen changes too, then we are looking at the effect both on the heating choice and on the energy consumption of the energy prices increasing by 1 per cent during the whole period from 1971 to 1990. This *unconditional* energy price elasticity includes the indirect effect on the energy consumption of the changes in estimated probabilities for different choices, in addition to the direct effect of increased energy prices in 1990. Furthermore, when the energy prices increase, the total costs of all heating technologies increase, and the income net of these costs decreases. Accordingly, energy consumption falls due to this income effect.

To find the conditional and unconditional effects of increased energy prices, the model is first simulated with no increase in the energy prices and then with an increase of 1 per cent, see table 3.

Table 3. Energy price elasticities. Simulation results. Change in energy consumption when energy prices increased by 1 per cent

Heating system based on	Conditional on the choice of heating system. Short run	Unconditional on the choice of heating system
Electricity	-0.43	-0.53
Electricity + oil	-0.23	-0.34
Electricity + wood	-0.22	-0.29
Electricity + oil + wood	-0.17	-0.24
All households (average)	-0.24	-0.32

As can be seen from table 3, the average short run energy price elasticity, given the choice of heating technology, is estimated to be -0.24. The estimated energy price elasticity increases (in absolute terms) to -0.32 when we also consider the effect of increasing the energy prices at the point in time when the heating choice was made. The households might have chosen another heating technology if the energy prices had been higher at the point when the heating technology was chosen. However, once installed the households do not change technology unless the energy prices change much, or the heating system should be changed in any case due to depreciation. Accordingly, the elasticities in table 3 can not be interpreted as long run elasticities, and only indicate the maximum possible effect on the energy consumption if all households theoretically changed their heating technology due to energy price increases.

The results from this analysis are within the range of the results found in the literature. For instance, Branch (1993), who uses expenditure survey data, estimates the short run price elasticity for electricity consumption to be -0.20. Parti and Parti (1980) also using household data, estimate a static reduced form model and find the short run price elasticity for electricity to be -0.58. The estimate of Dubin and McFadden (1984) is -0.26.

Results Dependent on Heating Technology

According to the results given in table 2 and 3, the income and energy price elasticities depend on the heating technology. Households having a technology which uses electricity only are characterised by relatively low income, they often have small dwelling area and low energy consumption relative to the dwelling size and they often live in apartment buildings. The sensitivity in energy consumption of changes in both income and energy prices is estimated to be higher for this household group than for households with other heating technologies. However, one should be careful to relate this result to differences in income only, because of the heterogeneity in the household groups. The low effect of prices on total energy consumption for those having a heating technology which uses more than one type of energy, might be due to the fact that substitution between different energy types used in the chosen technology has taken place.

Households Expectations

Both the annualised capital costs related to the purchase of the heating equipment and the expected energy costs may influence the choice of heating system in the empirical model of this paper. The expected operating cost is the expected energy price at the point of time when the heating system is chosen multiplied by the expected, typical energy consumption of the household. The energy price and the typical energy consumption are included in the estimation of the model, without making any assumptions of how the households form their expectations. It is often argued that the individual agents make use of all available information in an efficiently way when forming their expectations (the rational expectation hypothesis). Lark (1989) concludes that people make use of information when forming their expectations, but they do differ in the way they use it and in their abilities to process it. A competing hypothesis on the formation of expectations is the extrapolative hypothesis. According to this hypothesis only the information embodied in the history of the variable to be predicted is used. The most well-known version of the extrapolative expectation model is the adaptive expectations, with static expectations as a special case (see Fisher, 1930). According to Pesaran (1987), among others, one should expect the way agents form their expectations to be more complicated than both the models of rational and extrapolative expectations assume. In a survey of methods and results of empirically testing the formation of expectations, see Svendsen (1993), it is reported that the results from testing expectation hypotheses are as much in favour of expectations being formed of some sort of extrapolative mechanism as of a rational expectation mechanism.

Different hypotheses on expectation formation might have been tested in his paper. However, the estimations were executed using an alternative energy price variable to find out whether the results were sensitive to this change. While the energy price variable used in this paper includes the energy prices at the point when the heating system was purchased, the alternative energy price variable includes the energy prices in 1990. These two price variables might be thought of as related to static expectations and rational expectations, respectively. The estimation results showed relatively stable parameter estimates for most variables when the alternative energy price was substituted for the reference energy price. The short run income elasticity did not change significantly, while the energy price elasticity conditional on the choice of heating technology was reduced (in absolute terms) by about 20 per cent. These results indicate that the energy price elasticity of the model used in this paper may depend on what is assumed about energy price expectations.

IV. Concluding Remarks

Traditionally, household income and energy prices have been considered as the most important variables when modelling household energy consumption. The analysis of this paper indicates that variables such as house type, dwelling size and degree days also are important for explaining energy consumption in households. Furthermore, the relationship between the choice of heating system and the utilisation of the system is important to account for in estimation of energy demand. To find out how robust the results of this analysis are, it would have been interesting to use the model on cross-sectional data for other years to compare the results. This is done in Nesbakken (1998).

It should be noted that the results in this paper follow from estimating on a sample of households, which may not necessarily be representative for all households. For instance, households with central heating are not included in the sample. Furthermore, the results are only valid for studying the impact of increased energy prices on energy consumption for space heating, which is estimated to be about 57 per cent of total residential energy consumption, see Ljones et al. (1992).

In the model of this paper energy prices at the point in time when the heating equipment was purchased are used, without assuming how the households form their expectations. In future work it would be interesting to test different hypotheses regarding formation of expectations.

If, e.g., the price of electricity increases relative to other energy prices, substitution effects away from the use of electricity towards the use of other energy types are possible for households which have a combined heating technology. However, the parameters α_h of the model (see equation 9) are not identified, and short run substitution elasticities can not be calculated. Total energy consumption is the focus of this paper, and therefore only the parameter α is identified. One aim of future work in this field is to estimate short run substitution effects between different fuels, given the heating technology. Another specification of the indirect utility function than the one used in this paper and in Dubin and McFadden (1984) should be used to derive a system of energy equations covering all fuel types.

Appendix A

Data

The main data source is the energy survey in 1990. All energy use (supplied) is measured in the same unit, kWh. Only energy consumption for space heating, which is calculated as given shares of observed energy consumption, is used in this analysis. The shares of energy used for space heating and other purposes are calculated by Energidata A/S, see Ljones et al. (1992).

The price of electricity in 1989/1990 is based on information from the electric utilities. The price of kerosene, oil and wood is estimated by using information from the Energy Survey 1990 on energy consumption, both in physical terms and values. The source of electricity prices for the period 1971 to 1990 is the NOS Electricity Statistics, with electricity prices varying by county. The historical prices of oil/kerosene and wood respectively are the list prices from the Norwegian Petroleum Institute and an index for the development in the price of birch from Statistics Norway. Information about purchasing prices of different heating equipment are provided from the producers of the equipment.

All values of price, cost and income variables are at constant 1989-prices. Gross income is used because income net of tax may not be observed. House specific demand for power (in kW), which depend on dwelling size, house type and construction year, is taken into account when calculating the annual costs. Furthermore, we have used the observed real interest rate net of tax and a constant depreciation rate of 4 per cent per year for electric heaters and 2.5 per cent for stoves for wood or oil/kerosene, see IFE (1995).

Degree days are the difference between outdoor and indoor temperature, summed up for all days from the point of time when the outdoor temperature reaches 11 degrees Celsius in the autumn until it reaches 9 degrees Celsius in the spring. The colder the climate, the higher the degree days.

The following dummy variables, which are included in the estimations, are equal to 1 when satisfying the conditions below. Otherwise these variables are equal to 0.
Ownership: The household lives in a housing co-operative or owner-tenant flat.
House type: The household lives in a detached house or a farm dwelling.
Temperature regulation: The temperature is regulated manually on the electric heaters (opposite to regulation by using thermostat or centrally regulation of temperature).

Energy saving strategies: At least one of the following actions are carried out in the period 1980-90: Thermostat for space heating or some automatic system for lowering the indoor temperature is installed, the indoor temperature is lowered, a smaller part of the house is heated, the use of heated water is reduced, the light is switched off in rooms which are not in use.

Table A1. Summary statistics[1] for variables included in the model. 550 observations

	Min	Mean	Max	Standard dev.
Share with heating system based on:				
Electricity	0	0.19	1	0.39
Electricity and oil	0	0.03	1	0.17
Electricity and wood	0	0.60	1	0.49
Electricity, oil and wood	0	0.18	1	0.38
Energy consumption, (10^{-3} kWh)	0.107	13.03	46.61	7.44
Annual capital costs (10^{-2}) for heating system based on:				
Electricity	8.95	9.77	10.60	0.82
Electricity and oil	16.36	17.27	18.90	0.89
Electricity and wood	10.90	11.74	12.30	0.61
Electricity, oil and wood	15.18	16.08	17.37	0.76
Demand for power (kW)	1.5	8.22	30.80	3.37
Income in 1990, Y (10^{-5})	0.37	3.01	5.57	1.38
Income when the heating system was purchased, Y* (10^{-5})	0.34	2.62	5.57	1.28
Energy price (Nkr/kWh) in 1990 for heating system based on:				
Electricity	0.18	0.36	0.50	0.04
Electricity and oil	0.22	0.32	0.45	0.02
Electricity and wood	0.19	0.32	1.06	0.05
Electricity, oil and wood	0.22	0.31	0.79	0.03
Energy price (Nkr/kWh) when purchasing the heating system based on:				
Electricity	0.20	0.31	0.40	0.06
Electricity and oil	0.30	0.39	0.50	0.06
Electricity and wood	0.45	0.50	0.55	0.02
Electricity, oil and wood	0.43	0.48	0.57	0.04
Ownership	0	0.14	1	0.34
Type of house	0	0.70	1	0.46
Size of household (occupants)	1	3.22	7	1.26
Age of the dwelling (10^{-1} years)	0.2	0.10	1.5	0.53
Degree days (10^{-3})	2.40	3.20	5.66	0.70
Observed area (m^2)	30	119.7	400	43.5
Temperature regulation	0	0.42	1	0.49
The number of floors	1	2.05	5	0.72
Energy saving strategies	0	0.49	1	0.50

[1]Energy prices, income and the capital cost are in constant 1989 prices. US$ 1 = Nkr 7.5 (July 1998).

Appendix B

Results from estimating the dwelling size

Variables	OLS-estimates	t-ratio
Constant	53,28	10,28
Income*	10.27	8.00
Type of house	19.88	5.46
Size of household	7.99	5.86

*Income when the house was built in Nkr · 10^{-5}.

Appendix C

Capital Cost and Expected Operating Cost

Let B_j denote the total costs associated with purchasing the heating system *j* and operating it. B_j is the sum of the annualised capital cost, denoted I_j, and the operating cost, denoted b_j, i.e.

$$B_j = I_j + b_j \qquad \text{(C1)}$$

The annualised capital cost is given by

$$I_j = [r + d]Q_j \qquad \text{(C2)}$$

where *r* denotes the real rate of interest, *d* is the depreciation rate and Q_j is the cost of purchasing the equipment used in system *j*. The price of the heating technology *j* in Nkr per kW, $\overline{q}_j$ is estimated as an average of the purchasing prices of the heating equipment which uses fuel h in system k, q_{hj}.

$$\overline{q}_j = \frac{1}{H_j}\sum_{h\in j} q_{hj} \qquad \text{(C3)}$$

The demand for power in kW is exogenous to the households and assumed to be independent of the heating system choice, i.e. $E_j = E$. The cost of the different heating technologies is given by

$$Q_j = \overline{q}_j E \qquad \text{(C4)}$$

Let $\widetilde{P}_h$, *h=1,2,....,H,* denote the expected real price of fuel *h*, and $\widetilde{P}_j = \frac{1}{H_j}\sum_{h\in j}\widetilde{P}_h$. In the model of this paper the choices consist of combinations of heating equipment. Accordingly, the expected operating cost of heating system *j* is an average over the fuel prices of fuels which may be used in this technology. The expected typical energy consumption, $\widetilde{X}$, is not assumed to vary with different heating technologies. However, the expected energy consumption for each household depends on the type of house and the dwelling area. Thus, the expected operating cost is given by

$$b_j = \widetilde{P}_j \widetilde{X} \qquad \text{(C5)}$$

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