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The Choice of Space Heating System and Energy Consumption in Norwegian Household

Discussio

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Abstract:
The procurement of space heating equipment is modelled jointly with the intensity of use. Annualized capital cost ("user cost of capital") is found to have a significant impact on the procurement decision. This impact constitutes an important part of the effect of income on intensity of use; i.e. on energy demand. In the model other indirect effects of income are accounted for. The total income elasticity in energy demand is found to be rather low. The energy price elasticity is within the range of estimates reported in recent studies.

Keywords: Energy, demand, econometrics, discrete-continuous choice

JEL classification: C51, D12, Q41

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1. Introduction

In this paper we report the results of estimating the demand for energy in space heating. The main modelling idea is that we consider the demand for space heating equipment and its intensity of use to be related decisions made by the households. Thus, the procurement of space heating equipment at one point in time is estimated jointly with the intensity of use at a later point in time. This approach is inspired by Dubin and McFadden (1984). Related works are Goett (1979) and Dagsvik et al. (1987).

In section 2 we discuss the theoretical model. The econometric specification is introduced in section 3 and in sections 4-6 it is demonstrated how this specification can be estimated on procurement observations covering the period 1971-1990 and intensity of use observations from 1990. The empirical results are given in section 7. Data are described in Appendix A.

2. Theoretical model

The household can choose between K possible space heating systems. A heating system k, where k=1,....,K, consists of one or more types of heating equipment using different kinds of fuel. There are h=1,....,H different types of fuel.

The household's decisions of heating system and intensity of use are assumed to follow from the maximization of a utility function under budget constraints. Utility is assumed to depend on the consumption of energy related to space heating - which is a substitute for indoor temperature - and on the consumption of all other goods and services.

Let X_{hk} denote the consumption of fuel h in space heating system k and let X_k denote total energy consumed; thus

$$X_k = \sum_{h=1}^{H} X_{hk} \quad ;k = 1,2,\ldots,K. \tag{1}$$

Only one heating system can be chosen by each household.

Let B_k denote the total cost associated with the procurement and operation of heating system k. B_k is the sum of annualized capital costs, denoted I_k, and operating costs, denoted b_k; i.e.

$$B_k = I_k + b_k \quad ;k = 1,2,\ldots,K \tag{2}$$

Let $P_h, h = 1,2,\ldots,H,$ denote the real price of fuel h. Thus, the operating costs are given by

$$b_k = \sum_{h=1}^{H} P_h X_{hk} \quad ;k = 1,2,\ldots,K \tag{3}$$

Annualized capital costs are defined in (4),

$$I_k = (r(Y)+d)Q_k, \quad ;k = 1,2,\ldots,K. \tag{4}$$

where $r(Y)$ is the real rate of interest, d is the depreciation rate - assumed to be the same for all kinds of equipment-, and Q_k is the procurement costs of the equipment used in system k.

Y denotes the gross income of the household. The rate of interest may vary with income for two reasons. First, interest payments on loans are tax deductible. Since the marginal tax rate increases with income, the effective rate of interest decreases with income. Second, the trustworthiness when applying for loans may increase with income, and hence the banks may charge a lower rate of interest the higher the income is. To keep the model simple we assume a linear relationship,

$$r(Y) = r_0 - r_1 Y; \text{where } \mathrm{r}_0 > 0, r_1 > 0. \tag{5}$$

The procurement costs are given by

$$Q_k = \sum_{h=1}^{H} q_{hk} E_{hk}; \quad k = 1,2,\ldots,K, \tag{6}$$

where q_{hk} is the procurement cost in NOK per kW for heating equipment using fuel h in system k, and where E_{hk} is the effect capacity - measured in kW - needed for using fuel h in heating system k.

We assume that the household takes all prices and the effect capacities of heating equipments as given and that they maximize utility with respect to

i) type of heating system

ii) energy consumption, given the heating system.

The consumption of all other goods and services, denoted C, follows from the budget constraint, i.e. the consumption of all other goods and services equals

$$C = f(Y) - B_k, \tag{7}$$

where $f(\cdot)$ is a function that transform gross income into disposable - or after-tax - income.

From (2) and (7) we note that the annualized capital costs is deducted from disposable income to give the amount available for the consumption of all other goods and services, and to cover the operating costs of space heating. This is the case even in periods after the procurement of the heating equipment and reflects the fact that we can consider the annualized capital costs as a rental price of heating system k.

At the time of the procurement of a space heating portfolio the houshold makes its procurement decision on the basis of given and known values of q_{hk} and E_{hk}, together with expectations of future energy prices and typical energy consumption. When operating a given portfolio of space heating equipment only current energy prices matter. We do not have any reliable data that allow us to model price expectations and expectations of future typical energy consumption when space heating investments take place. We therefore assume that the procurement of space heating equipment as well as the operation of a given space heating system follow from the same indirect utility function.

Let V denote the indirect utility function, let Z denote observed household charachteristics and let η and ε_k denote unobserved charachteristics of the household and a taste shifer varying across households and heating systems, respectively. The distinction between η and ε_k will be discussed later. The indirect utility function related to the choice of heating system k is given by

$$V_k = V(P_1, P_2, \ldots P_H, f(Y) - I_k, Z, \eta, \varepsilon_k); \; k = 1,2,\ldots,K. \tag{8}$$

If the choice of heating system j is optimal, then it follows that

$$V_j = \max_k V_k. \tag{9}$$

Given the procurement of the heating system the indirect utility function related to this optimal choice is $V(P_1, P_2, \ldots, P_H, f(Y) - I_j, Z, \eta, \varepsilon_j)$, and the optimal choice of energy consumption, given heating system j, is determined by Roy's identity, i.e.

$$X_{hj} = \frac{-\partial V / \partial P_h}{\partial V / \partial Y}; \; h = 1,2,\ldots,H, \tag{10}$$

and total optimal energy consumption is given by

$$X_j = \sum_{h=1}^{H} X_{hj}. \tag{11}$$

3. The econometric model

The household regards (9) and (10) as deterministic conditions. For the econometrician, however, they are probability statements. Let π_j be the probability of heating system j being the optimal choice.

$$\pi_j = \text{ Prob } \{V_j = \max_k V_k\} \tag{12}$$

The indirect utility function is specified to get a model which can be estimated. As already noted the data for expected energy prices and typical energy consumption are not satisfactory. Because of that the cost related to obtaining heating equipment, I_k is the only cost influencing the choice of heating system in our empirical model. Furthermore we observe only gross income and not income net of tax. Accordingly the indirect utility function we have chosen is the same at the moment of procuring the heating system as when the heating system is used. The specified utility function is given by

$$V_k = \{Z_1' \alpha_0^k + \sum_{h=1}^{H} \frac{\alpha_h}{g} + \sum_{h=1}^{H} \alpha_h P_h + Z_2' a + \beta(Y - I_k) + \beta_k Y + \eta\} e^{-gP_1} + \varepsilon_k. \tag{13}$$

Z_1' is a vector-variable describing the dwelling and household characteristics. $Z_1'\alpha_0^k$ allows the choice of heating system to depend on household characteristics that can be observed. Given the choice of heating system, $\sum_{h=1}^{H}\alpha_h P_h$ reflects that the energy prices influence the intensity of use, and $Z_2' a$ accounts for observed dwelling and household charachteristics which affect energy consumption. The vectors Z_1' og Z_2' may contain different variables, but some variables are the same. $-\beta I_k$ is the effect on the choice of heating system k of annualized capital costs related to procuring heating system k. Some heating systems are easier to operate and cleaner than others, and this is accounted for by $\beta_k Y$. The reason why the choice of heating system depends on household income is that the income is a proxy for the value of using time for alternative purposes. The higher the income, the higher is the cost of spending time on operating a heating system.

The gross income (Y) is explicitly present in the indirect utility function. However, other variables depend on this income. Two of the variables in Z_2' (which will be explained later) and I_k depend on income.

$\sum_{h=1}^{H}(\alpha_h / g)$ is a technical term which has a scaling effect in (13).

We assume that ε_k is identically and independently extreme value distributed for all choices k, (k=1,..., K), given the household; and for all households given the choice k, i.e.

$$\text{Prob}\,(\varepsilon_k \leq \varepsilon) = \exp(-e^{-\varepsilon}), \quad \forall \quad \text{k and households.} \tag{14}$$

The unconditional expectation and variance of ε_k are Eulers γ and 1 respectively. To assume independence between different choices is quite restrictive, but necessary to give a model which can be estimated. The household characteristics that cannot be observed are represented by η which is distributed with expectation zero and variance σ^2. We allow for a correlation between η og ε_k. The stochastic variable η accounts for unobserved characteristics related to the household's preference for indoor temperature while ε_k accounts for unobserved charachteristics related to the household's preference for a specific heating system. For a given system ε_k varies across households, and given the household, ε_k varies across heating portfolios. To give an example of a positive correlation between η and ε_k we can consider a household that prefers a higher indoor temperature than the specified observed variables can explain while at the same time a portfolio which includes open fire places is preferred to all other portfolios. Book reading romantic households may serve as an example.

Following Dubin and McFadden (1984) the distribution of η conditional on $(\varepsilon_1,\ldots,\varepsilon_K)$ has expectation

$$\sigma\sum_{k=1}^{K}\rho_k\varepsilon_k,$$

and variance

$$\sigma^2(1-\sum_{k=1}^{K}\rho_k^2),$$

where σ og ρ_k are unknown coefficients and where

$$\sum_{k=1}^{K} \rho_k = 0 \quad and \quad \sum_{k=1}^{K} \rho_k^2 < 1.$$

Dubin and McFadden (1984) show that the expectation of η conditional on the choice of heating system j is given by

$$E[\eta|j] = \sum_{k \neq j} \sigma\rho_k (\frac{\pi_k \ln \pi_k}{1-\pi_k} + \ln \pi_j). \tag{15}$$

According to (13) the part of the indirect utility function depending on k is given by

$$V_k = [Z_1'\alpha_0^k - \beta I_k + \beta_k Y] e^{-gP_1} + \varepsilon_k, \tag{16}$$

Let the term in the brackets be W_k, i.e.

$$W_k = Z_1'\ \alpha_0^k - \beta I_k + \beta_k Y. \tag{17}$$

Then (12) and (14) yield, see McFadden (1973),

$$\pi_j = \{\text{Prob}[\varepsilon_k - \varepsilon_j < e^{-gP_1}(W_j - W_k)]\ \forall\ k \neq j\} = \frac{e^{\text{W}_j \exp(-gP_1)}}{\sum_{k=1}^{K} e^{\text{W}_k \exp(-gP_1)}}\ , \tag{18}$$

which means that the choice of heating system is given by a multinomial logit model. Using Roy's identity on (13) it can be shown (see Nesbakken and Strøm (1993) that *the energy consumption conditional on the choice of heating system j* is given by

$$\begin{aligned} X_j &= \sum_{h=1}^{H} X_{hj} = W_j + \beta Y + Z_2'\,a + \sum_{h=1}^{H} \alpha_h P_h + \eta \\ &= Z_1'\,\alpha_0^j + \sum_{h=1}^{H} \alpha_h P_h + Z_2'\,a + \beta(Y - I_j) + \beta_j Y + \eta. \end{aligned} \tag{19}$$

Thus the conditional demand for energy is linear in prices and income. Our main aim is to analyse the household's total energy consumption, and we do not consider consumption of each fuel type.

To account for the possible selection bias associated with the fact that $\text{E}[\eta|j] \neq 0$, cf (15), we will estimate the following energy demand function:

$$X_j = \text{Z}_1'\,\alpha_0^j + \sum_{h=1}^{H} \alpha_h P_h + \text{Z}_2'\,a + \beta(Y - \text{I}_j) + \beta_j Y + \sum_{k \neq j} \sigma\rho_k (\frac{\pi_k \ln \pi_k}{\text{I} - \pi_k} + \ln \pi_j) + \mu \tag{20}$$

where μ is assumed to be white noise.

Given the assumption of $\sum_{k=1}^{K} \rho_k = 0$ and the definition of W_j, (20) can be written

$$(X_j - W_j - \beta Y) = Z_2' a + \sum_{h=1}^{H} \alpha_h P_h + \sigma_1 \ln \pi_j + \sum_{k \neq j} \sigma_k m_k + \mu, \tag{21}$$

where

$$\sigma_1 = -\sigma\rho_1, \ \sigma_k = \sigma\rho_k \text{ and } m_k = \frac{\pi_k \ln \pi_k}{I - \pi_k}.$$

The equations (18) and (21) will be used when estimating the unknown coefficients in our model.

4. The choice heating system

The households can choose between the following 5 heating systems:

k=1: Electricity
k=2: Wood
k=3: Electricity and oil/kerosine
k=4: Electricity and wood
k=5: Electricity, oil/kerosine and wood

According to (17) and (18) the choice depends on

1) Household characteristics Z_1';
   a) Ownership of the building (housing cooperatives/owner-tenant accommodation versus other type of ownership)
   b) Type of building (detached house versus other type of building)
   c) The number of occupants per dwelling
   d) The age of the house
2) Household income Y. There are two effects;
   -the direct effect, $\beta_k Y$, between income and the choice.
   -the indirect effect, $\beta r_1 Q_k Y$, which reflects the effect of income on the interest rate which in turn affects the costs of the heating equipment.
3) The cost of the heating system, except the part which is affected by income, see 2) above. This cost, $(r_0 + d)Q_k$ consists of the purchasing cost Q_k and the annuity factor $(r_0 + d)$.

All the variables used in estimating the heating system choice are related to the purchasing year of the equipment, which varies from 1971 to 1990. The equipment may be purchased by another household than the one living in the dwelling in 1990. However, it is assumed that income and the size of the household does not vary much between different households in a given dwelling.

5. The demand for energy

When estimating (21) we take into account that W_j and βY are estimated already. Thus the left side of (21) is calculated by using the results from the estimation of the choice of heating system. The *conditional* energy consumption depends on

1) Household characteristics Z_2'. These are the area of the dwelling, insulation of the walls, heating degree days and the age of the house. As mentioned before the impact of income on the choice of heating system and on energy consumption is both direct and indirect. As a consequence of this observed values are replaced by predicted values for the two variables connected with income. These two variables are area and insulation. The area is estimated as a linear function of income and the household size. The estimation method is Ordinary Least Squares (OLS). A Logit model is used to estimate the relationship between insulation of the walls (a dummy being one if insulated, and zero else) and income and heating degree days.

2) The energy price, P_j. Instead of using the prices of different fuel types, a price index reflecting the possible fuel types for a given heating system is constructed.

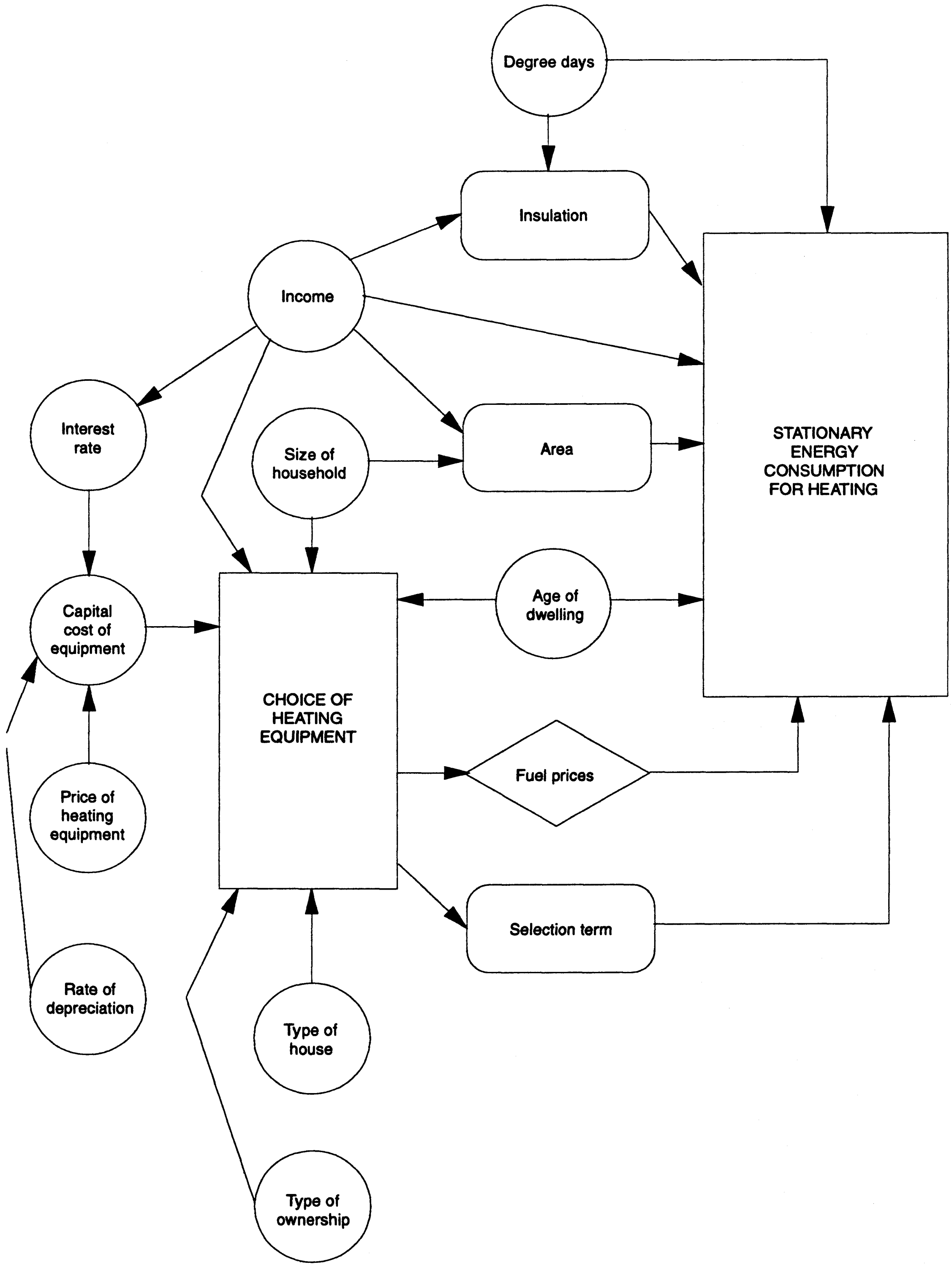
3) Selection term $\sigma_1 \ln \Pi_j + \sum \sigma_k m_k$

Figure 1 shows the factors influencing the choice of heating system and intensity of use.

6. Estimating method

Estimating the discrete and continuous choice simultaneously is the best estimating method. However, complicated computer programs have to be developed to do this, and we have estimated in two steps for simplicity. The computer package LIMDEP (version 5.1) is used in the first step to estimate the choice of heating system. The second step is estimated by OLS.

Figure 1. Flow diagram for variables included in the model



Source: Statistics Norway

7. Empirical results

The choice of heating system

The empirical results from estimating the first stage of the model are given in table 1. Most of the parameter estimates are significant, including the important coefficient β which is related to the annualized capital costs of the heating equipment. β is estimated to be 0,006. The higher the costs of choosing a heating system are, the lower is the probability of choosing that system.

The coefficient βr_1 related to the interaction between costs of heating equipment and income is estimated to be $0{,}51 \cdot 10^{-9}$. By using the estimate of β, this gives an estimate of r_1 and the household-specific real interest according to (5). We found that the real interest rate is reduced from 1,95 per cent to -0,60 per cent (the period 1986-1990) when income rises from 100 000 NOK to 400 000 NOK (1989-NOK).

The parameter estimates are significant for the income variable for all the choices. This direct effect of income 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.

Households in housing cooperatives or owner-tenant accomodations are more likely to choose only electricity than electricity combined with oil/kerosine. The results are more uncertain for the other choices.

The estimates related to the effects of house type show that in detached houses there are a greater probability of choosing alternatives where wood is used than other alternatives.

The results related to the age of the building shows that the probability of choosing electricity or electricity combined with wood is greater the older the house is. Only houses built later than 1970 are included, and one should have this in mind when interpreting the results. High probability of choosing electricity in houses from the 1970s may be explained by building regulations which permitted houses to be built without a chimney. After 1979 chimneys were ordered in new houses.

The impact of household size on the choice of heating system is estimated to be significant. Households with many occupants most often live in large houses. Thus the effect of household size is consistent with the results for house types.

In an alternative estimation we only considered houses built in the 1980s. 270 households are included, while 565 households were included when houses from the 1970s were considered in addition. Furthermore in this smaller sample only two heating systems can be chosen; electricity alone and electricity and wood. Ownership, house type, household size and costs related to the heating system are included. The results of estimation are given in table 2. The estimated coefficients in the two models varying with the choice (dummy variables) cannot be compared because the number of choices differ. However, the coefficient for the annualized capital cost of heating system can be compared. *The striking result is that this parameter estimate is the same;* β *= 0,006*, which indicates that the estimate of this key parametre is robust with respect to the data generating process.

Table 1. Estimates[1) for the choice of heating systems in dwellings from 1971-1990. The reference choice is electricity. 565 dwellings

Variables	Estimates	t-values
1. Ownership:		
Wood	-1,55	-1,43
Electricity + oil	-2,50	-2,34
Electricity +wood	-0,61	-1,86
Electricity + oil + wood	-2,10	-1,95
2. Type of house:		
Wood	1,61	2,73
Electricity + oil	0,70	1,46
Electricity + wood	1,75	6,69
Electricity + oil+ wood	1,58	3,11
3. Size of household:		
Wood	0,18	0,92
Electricity + oil	0,11	0,64
Electricity + wood	0,44	4,80
Electricity + oil + wood	0,18	1,15
4. Gross income (in NOK):		
Wood	$-0{,}66 \cdot 10^{-5}$	-3,05
Electricity + oil	$-0{,}68 \cdot 10^{-5}$	-2,82
Electricity + wood	$-0{,}28 \cdot 10^{-5}$	-3,11
Electricity + oil + wood	$-0{,}79 \cdot 10^{-5}$	-3,53
5. The age of the dwelling:		
Wood	-0,14	-3,27
Electricity + oil	-0,03	-0,72
Electricity + wood	-0,09	-4,31
Electricity + oil + wood	-0,06	-1,65
6. Capital costs (NOK/year) ($-\beta$)	-0,006	-4,22
7. Capital costs*income (βr_1)	$0{,}51 \cdot 10^{-9}$	1,96

1) McFaddens correlation coefficient = 0,39. McFaddens correlation coefficient is defined as 1-L1/L0, where L1 is the likelihood value in the estimated relation and L0 is the likelihood value under a null hypothesis where all the coefficients are zero. The correlation coefficient varies between 0 og 1; near 1 means that the estimated relation fits the actual relation quite well.

Table 2. Estimates[1)] for the choice of heating system in dwellings from 1981-1990. The reference choice is electricity. 270 dwellings

Variables	Estimates	t-values
1. Ownership:		
Electricity + wood	-1,57	-3,52
2. Type of house:		
Electricity + wood	2,56	5,39
3. Size of household:		
Electricity + wood	0,30	2,93
4. Capital costs (NOK/year) (-β)	-0,006	-2,25

1) McFaddens correlation coefficient = 0,52.

Energy consumption

The parameter estimates for energy demand, given the choice of heating system, are presented in table 4. Area, size of household and income all affect energy consumption, according to figure 1. Since these variables are interdependent, this must be taken into account in the estimation. The area is estimated to increase with the size and income of the household, see table 3. The estimated area is used as a variable in estimating the energy consumption, and the results confirm our assumption that energy consumption increases if the area increases.

Similarly we have estimated the relationship between insulation of the walls of the dwelling, income and degree days. Degree days express how cold it was during the preceding year. The results show a greater probability of the walls beeing insulated the colder it is in the region and the higher the income of the household is. If one ignores the correlation between insulation on the one hand and outside temperature on the other, the striking result is that energy consumption is higher in insulated than in uninsulated dwellings. The explanation often suggested for this result is that the households "take out" the effect of better insulation in terms of higher indoor temperature and greater comfort. According to our results, this explanation is wrong, since it is based on an incorrect specification of energy consumption and insulation. By using the estimated relationship for insulation, we find that energy consumption is *lower* in an insulated than in an uninsulated dwelling, provided that all other variables are the same.

In our model, a colder climate has two opposing effects on energy consumption. The first and direct effect says that the colder the climate is, the higher is energy consumption. The second and indirect effect is due to the impact of a colder climate on insulation. The colder the climate is, the higher is the probability of insulation of walls. The direct effect of more insulation on energy consumption is negative, and hence the indirect effect of a colder climate - coming from a higher insulation probability - on energy consumption is negative. Our estimates imply that the direct effect dominates the indirect effect, and hence the net effect of a colder climate on energy consumption is positive.

The calculations show that energy consumption increases with the age of the dwelling. This may be due to other elements of the construction that are not included when studying the insulation of walls. An example is the standard of windows. Although new as well as old dwellings are insulated, new dwellings may be even more tightly sealed. Another reason for the high energy consumption in the oldest dwellings could be that the heating equipment is less effective than in newer dwellings.

The price of the different sources of energy is connected to the chosen heating equipment. If the household has chosen electrical heating alone, the price of energy is the same as the price of electricity, while the energy price for a household with a combination of several types of equipment is the average price of the sources of energy used. On the basis of estimated coefficients and average values for the price of energy and energy consumption, the long-term price elasticity is calculated to -0.46. This means that if the price of energy increases by 10 per cent, energy consumption is reduced by 4.6 per cent.

The selection term is not significant. Thus we do not find any significant relationship between characteristics of the household that can not be observed (η) and unobserved qualities of the chosen heating system (ε_k). However, β is an important link between the choice of heating system and the utilization of the system.

Income has a direct effect on energy consumption, given the choice of heating system, and it is given by β estimated in the first stage. The direct conditional income elasticity is estimated to 0.14 (calculated for sample averages). Income also has an indirect effect on energy consumption, since it influences the choice of heating system by affecting the interest rate, which in turn affects energy consumption. Moreover, income has an indirect effect on energy consumption by affecting the area of the dwelling. The higher the income, the larger is the area, and thus also the energy consumption. Finally, income also affects energy consumption through insulation of walls. The higher the income, the greater is the probability that the walls are insulated, and the lower is the energy consumption. The total effect of income on the conditional energy consumption can be expressed by the long-term income elasticity, which for an average household is estimated to 0.09. According to our results, a 10 per cent increase in income would increase the conditional energy consumption by about 1 per cent, conditional on the heating system chosen, see Appendix B.

Table 3. Area and insulation

	Area*		Insulation**	
Variables	**Estimates**	**t-values**	**Estimates**	**t-values**
Constant	61,1	11,7	-	-
Size of household	10,2	7,6	-	-
Income***	8,6	7,0	0,42	3,59
Heating degree days	-	-	$0{,}37 \cdot 10^{-3}$	3,64

* Estimated by OLS

** Estimated by LOGIT

*** Income is NOK $\cdot 10^{-5}$.

*Table 4. Energy consumption, given the choice of heating system**

Variables	**Estimates****	**t-values**
Constant	21854,7	3,13
Predicted area	134,3	5,90
Predicted insulation	-39 610,8	-3,81
Degree days	4,20	8,38
The age of the dwelling	200,89	3,67
Price of energy	-181,24	-3,49
Selection term	217,93	0,69
R^2	0,21	

* The left side variable is $X_j - W_j - \beta Y$.

** OLS-estimates

The unconditional expected total energy demand is given by

$$EX = \sum_{j=1}^{5} \pi_j \, EX_j \tag{22}$$

where π_j is given in (18) and estimated in table 1. EX_j, the conditional expected energy demand, follows from (20).

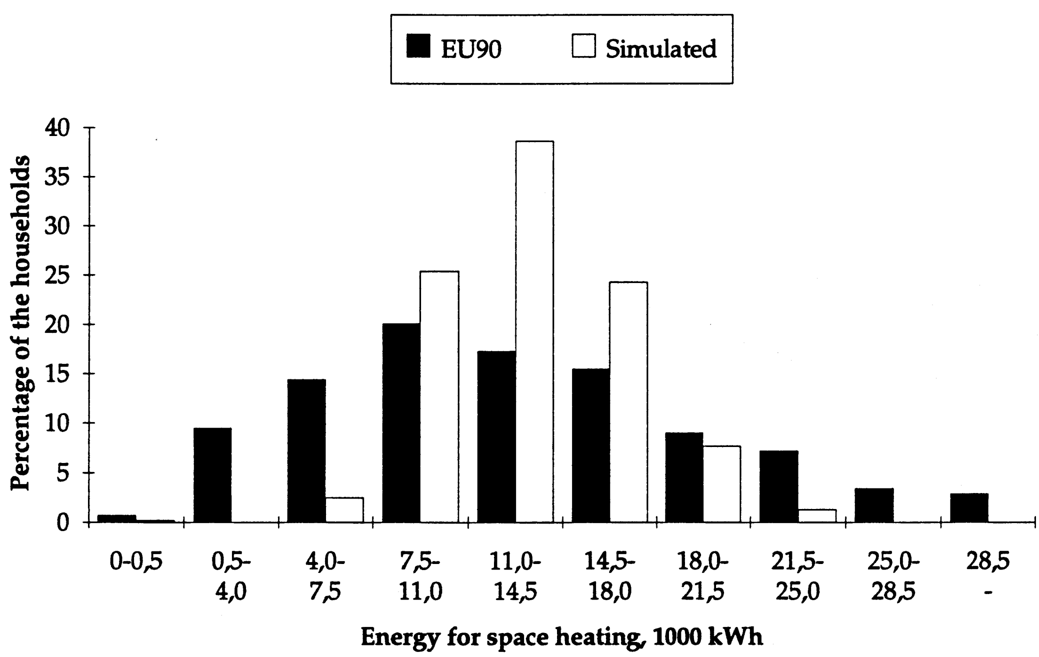
The elasticity of income in the unconditional demand for energy is estimated on the basis of (22), see appendix B. Area, probability of insulation, expected total energy demand and elasticity of price on energy demand are simulated. The results are given in table 5. Income is varying between 100 000 NOK and 400 000 NOK, while the variables which are independent of income are kept constant at their mean sample values. The table shows that the income elasticity is increasing with income.

Table 5. Simulation results. Income and price elasticities.

Income: 10^5 NOK (1989-NOK)	Simulated area in m^2	Simulated prob. of insulating the walls	Simulated unconditional expected total energy consumption in kWh	Total unconditional income elasticity	Price elasticity
1,0	102,4	0,83	12 770	0,03	-0,47
2,0	111,0	0,88	12 488	0,05	-0,48
2,98[3]	119,4	0,92	12 755	0,08	-0,47
4,0	128,1	0,95	13 481	0,10	-0,44

Figure 2 shows energy for space heating based on observed total energy consumption in the households, according to the Energy Survey 1990 (Ljones et al. (1992)). Furthermore the figure shows energy for space heating simulated by using our model. The low corrrelation coefficient of 0.21, see table 4, is illustrated by how the fitted values differ from the observed values. The simulated energy consumption is more concentrated around the mean value than the observed energy consumption .

Figure 2. *Energy for space heating, according to the Energy Survey 1990 (EU90) and estimated shares for space heating, and simulated energy for space heating. 1990.*



[3] Mean income for the households

Appendix A. Data

The data utilized in the estimations in this paper are mainly from the Energy Survey 1990 (Ljones et al. (1992)). Households with central heating are not included in the estimation. Moreover, only data for households in houses built in the period 1971 to 1990 are used. Data for 565 households in stage I and 556 households in stage II are included in the estimation.

All variables at stage I are related to the point of time when the heating equipment was procured. The variables at stage II are related to 1990.

The cost of the heating system

The purchasing costs of the equipment are related to the year the equipment was procured and are at constant 1989-prices. The price of combinations of equipment using different kinds of fuel are calculated as an average price in NOK per kW. When calculating the annual costs we have taken into account housespecific energy capacity, see Norsk Standard NS 3032 (1984). Furthermore we have used the observed real interest rate and a constant depreciation rate of 5 per cent per year.

Ownership of the dwelling

ownership = 1 if the household lives in a housing cooperative or owner-tenant flat, else ownership = 0.

The type of house

House-type = 1 if the household lives in a detached house or a farm dwelling, else house-type = 0.

The age of the dwelling

The age of the dwelling is the difference between 1990 and the middle of the period in which the house was built.

The size of the household

The number of occupants in the household.

The household income

Gross household income in 1989 is observed. The income variable used at stage I is *calculated* gross income at the point of time the heating equipment was procured, while gross income in 1989 is used at stage II. The fixed cost of using electricity is deducted from the gross income.

Energy consumption

To get all energy use (delivered) in the same unit, kWh, conversion factors are used, see Statistics Norway (1992b)

Only energy consumption for space heating is used in this analysis. This kind of energy use is not observed, but calculated as given shares of observed energy consumption in the households. 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 energy

The prices are the ones prevailing in 1989/90. The price of electricity is based on information from the electric utilities. The price of kerosine, oil and wood is estimated by using information from the Energy Survey 1990 on energy consumption, both in physical terms and value.

Degree days

Degree days are the difference between outdoor and indoor temperature, according to Energy Statistics 1991 (Statistics Norway (1992a)). The difference is summed up for all days from the point of time when the outdoor temperature decreases to 11 degrees Celsius in the autumn until it increases to 9 degrees Celsius in the spring. The degree days are higher the colder the climate is.

Insulation of walls

Insulation = 1 if the walls are insulated, else insulation = 0.

Area

The area of the dwelling includes any fitted up attic storey and expels cellars.

Table A1 gives summary statistics for variables included in the model. For further information about the data used in the analysis, see Nesbakken and Strøm (1993).

Table A1. Summary statistics[1])

	Observ.	Min	Mean	Max	Standard dev.
Share with:					
Electricity	565	0	0,30	1	0,46
Wood	565	0	0,04	1	0,19
Electricity and oil	565	0	0,05	1	0,22
Electricity and wood	565	0	0,55	1	0,50
Electricity, oil and wood	565	0	0,06	1	0,24
Energy consumption, kWh	556	107	13 027	46 611	7 414
Capital costs[2)](1989-NOK/year)					
1971-80:					
Electricity	565	17,94	96,10	368,43	39,82
Wood	565	23,70	126,92	486,61	52,60
Electricity and oil	565	29,08	155,73	597,06	64,53
Electricity and wood	565	20,82	111,51	427,52	46,21
Electricity, oil and wood	565	27,28	146,13	560,24	60,55
1981-85:					
Electricity	565	63,90	227,45	504,99	86,47
Wood	565	91,27	324,85	721,23	123,50
Electricity and oil	565	116,50	414,64	920,60	157,63
Electricity and wood	565	77,59	276,15	613,11	104,98
Electricity, oil and wood	565	108,09	348,71	854,15	146,25
1986-90:					
Electricity	565	125,19	622,62	1437,68	258,81
Wood	565	200,05	994,96	2297,43	413,58
Electricity and oil	565	264,35	1314,77	3035,89	546,52
Electricity and wood	565	162,62	808,79	1867,56	336,20
Electricity, oil and wood	565	242,92	1208,17	2789,74	502,21
Need for energy capacity (kW)	565	1,5	8,20	30,80	3,34
Income (10^5 1989-NOK/year)	565	0,37	2,98	5,56	1,38
Income when procuring the heating equipment in:					
1971-80	565	0,56	2,16	4,29	1,04
1981-85	565	0,34	2,89	5,18	1,30
1986-90	565	0,73	3,21	5,57	1,38
Energy price (øre/kWh)	556	17,90	32,84	106,30	5,78
Ownership, (dummy)	565	0	0,14	1	0,34
Type of house (dummy)	565	0	0,70	1	0,46
Size of household, (occupants)	565	1	3,2	7	1,3
Age of the dwelling (years)	565	2	9,94	15	5,30
Degree days	556	2398	3 211	5 662	699
Area (m^2)	556	30	120	400	43
Insulating (dummy)	556	0	0,91	1	0,29

1) All the figures except those for the capital costs and income are valid for 1990.

2) Capital costs are defined as $\sum_{h=1}^{H} (r_0 + d)E_{hk}q_{hk}$.

Appendix B. Estimating the conditional and unconditional income elasticities

$$\frac{\partial EX_j}{\partial Y} = \hat{\beta} = 0{,}006 \tag{23}$$

$$\begin{aligned}\frac{dEX_j}{dY} &= 134{,}3 \cdot 8{,}6 \cdot 10^{-5} - 39610 \cdot 0{,}42 \cdot 10^{-5}(1-\pi_l)\pi_l \\ &+ 0{,}006(1+8{,}5\cdot 10^{-8} Q_j) + \hat{\beta}_j \approx 0{,}004 \ \ \forall\, j \text{ and } Y.\end{aligned} \tag{24}$$

$$\text{Direct conditional income elasticity} = \frac{\partial EX_j}{\partial Y}\frac{Y}{EX_j} = \frac{0{,}006 \cdot 298000}{13027} = 0{,}14 \tag{25}$$

$$\text{Total conditional income elasticity} = \frac{dEX_j}{dY}\frac{Y}{EX_j} = \frac{0{,}004 \cdot 298000}{13027} = 0{,}09. \tag{26}$$

The unconditional expected total demand for energy is given by

$$EX = \sum_{j=1}^{5} \pi_j \, EX_j, \tag{27}$$

where π_j is given in (18) and esimated in table 1. EX_j follows from (20).

The total income derivative in the unconditional demand for energy is

$$\frac{dEX}{dY} = \sum_{j=1}^{5}\left(\frac{\partial \pi_j}{\partial Y} EX_j + \frac{\partial EX_j}{\partial Y}\pi_j\right) \quad . \tag{28}$$

The partial derivative $\frac{\partial EX_j}{\partial Y}$ in the unconditional demand is the same as the total derivative in the conditional demand.

It is easy to show that

$$\frac{\partial \pi_j}{\partial Y} = \pi_j\left[\left(\beta r_1 Q_j + \beta_j\right) - \sum_{k=1}^{5}(\beta r_1 Q_k + \beta_k)\pi_k\right], \tag{29}$$

$$\frac{dEX}{dY} = 0.004 + \sum_{j=1}^{5} \pi_j \left(\beta r_1 Q_j + \beta_j\right)\left(EX_j - EX\right). \tag{30}$$

Applying the estimates for βr_1 og β_j, (30) gives the following expression for the income elasticity in the **unconditional** energy demand

$$\frac{dEX}{dY}\frac{Y}{EX}=\frac{0,004Y}{EX}+\sum_{j=1}^{5}\pi_j\left(0.51\cdot 10^{-9}Q_j+\hat{\beta}_j\right)Y\left(\frac{EX_j}{EX}-1\right). \qquad (31)$$

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