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Possibility for hedging from price increases in residential energy demand

Abstract:
Liberalisation of the Norwegian electricity market has given more short-term variation in the electricity price. Since almost three quarters of Norwegian households have heating equipment using more than one energy carrier, we would expect them to be able to hedge from price increases and benefit from low prices by switching between energy carriers. In many studies estimates of the cross price derivatives in Norwegian residential energy consumption give a negative sign. The question is whether hedging is possible despite this negative sign, that is, if energy goods are alternatives and not separable in consumption. To answer this question, we estimate a conditional demand model on a sample of 2438 households to decompose the cross price derivatives. We find that the negative cross price derivatives are mainly due to budget effects. We also reject the hypothesis of weak separability, indicating that Norwegian households are able to hedge from energy price variations.

Keywords: Residential energy demand, empirical microanalysis, separability test

JEL classification: D12, Q41

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1. Introduction

Liberalisation of energy markets has been on the political agenda in several countries during the last two decades. One consequence of liberalisation of the Norwegian electricity market in 1991 was increased short-term variation in the end-user electricity price over time (see appendix, figure A1). For consumers facing increased price volatility, it is important to be able to hedge from short-term price increases and to benefit from periods with low prices. When the household has more than one type of heating equipment, it may use alternative fuels for space heating in periods when, say, the electricity price is high relative to other fuels and switch back in periods when the electricity price is low. Thus, if different energy sources are alternatives in consumption, households are able to hedge from fluctuations in relative energy prices.

Approximately three quarters of Norwegian households have heating equipment using more than one energy carrier. This should enable them to switch between energy carriers when relative prices change. Thus, we have reason to believe that electricity, firewood and fuel oils are alternatives in consumption. However, in econometric analyses on Norwegian household data, the estimated cross price derivatives are often negative, implying that the consumption of e.g. electricity increases even if the price of heating oil decreases (see e.g. Halvorsen and Larsen, 2001). There may be several reasons for the negative cross price derivatives. One reason may be that the goods are not alternatives in consumption. Another reason may be that the goods are alternatives, but negative budget effects dominate the positive substitution effects. Thus, negative cross price effects are not necessarily in conflict with energy carriers being alternatives in consumption.

The main aim of this paper is to decompose the cross price derivatives to determine the reasons for the negative signs. We apply a conditional demand model on a cross-sectional data set of 2438 households to decompose the cross price derivative into a “pure substitution” and a “money expenditure” effect. The pure substitution effect differs from the Slutsky effect and consists of a two components, one of which indicates whether the different energy carriers are separable, alternatives or complementary. This decomposition enables us to test for separability in the consumption of energy goods. If the hypothesis of separability between energy carriers is rejected, the households are able to hedge from changes in relative energy prices even if the cross price derivatives are negative.

The theoretical literature on separability is quite extensive (see e.g. Gorman's work on separability in Gorman, 1995, Blackorby et al., 1970, 1977, 1991, 1998, or Deaton and Muellbauer, 1980). Here, we apply an empirical test for separability developed by Browning and Meghir (1991) based on the theoretical work of Pollak (1969). Pollak presents a theoretical test for separability of goods within a conditional demand model, where the conditioning good is preallocated.[1] Browning and Meghir (1991) use the conditional demand approach to test for separability of commodity demands from labour supply, applying UK family expenditure data. Allowance is made for endogeneity in the conditioning labour supply variables. In contrast to Browning and Meghir (1991), who develop the conditional demand model from the conditional cost function, we develop this model from the household utility maximisation problem.

In the literature on household energy consumption, it is often assumed that energy demand is conditioned on variables that have a durable nature, namely dwelling size, heating system and other characteristics of the house, stock of electric appliances and family composition (see e.g. Baker et al., 1989, Baker and Blundell, 1991, Branch, 1993, Dubin et al., 1986, Garbacz, 1985, Green, 1987, Morss and Small, 1989, Parti and Parti, 1980 and Halvorsen and Larsen, 2001). However, very few studies condition on other energy types, using a conditional demand model to decompose the cross price derivatives and/or test for separability in household energy consumption. To our knowledge, only one study tests for separability explicitly (Leth-Petersen, 2002). This study examines the relationship between the consumption of electricity and natural gas for households in the Copenhagen area in Denmark. Leth-Petersen discusses the possibility of decomposing the cross price derivative, but no attempts are made to calculate the various components.

This paper is organised as follows. The theoretical foundation of our analysis is given in section 2. The conditional demand model is deduced, followed by a discussion of how to decompose the cross price derivatives and test for separability and hedging possibilities. In section 3 our data are presented. The econometric specification follows in section 4, and the results are presented in section 5. Finally, in section 6, some concluding remarks are made.

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[1] See also Deaton and Muellbauer (1980), p. 127 - 128, for more information about the relation between the definition of weak separability and the conditional demand functions.

2. Theoretical foundation

In this section, we derive the conditional demand model, and show how to use this model to decompose cross price derivatives and to test for separability in household energy consumption.

2.1. The conditional demand function

The households may use electricity, fuel oil, firewood or a combination of the three for space heating. The consumption of these energy carriers is decided simultaneously. The conditional demand model is a way of decomposing this simultaneous optimisation problem to identify a component enabling us to test whether goods are alternatives, compliments or separable in consumption. The main reason for using the conditional demand model, and not changes in energy consumption due to changes in energy prices when testing for separability, is twofold. First, such testing within the conditional demand approach is theoretically consistent (see e.g. Deaton and Muellbauer, 1980, chapter 5.2). Second, as many households in our sample do not have consumption of all three energy carriers, the conditional demand model provides a framework that is robust with respect to corner solutions (see the discussion in Pollak, 1969).

We assume that the household derives utility (U) from the consumption of electricity (x_1), consumption of other energy carriers (x_2) and consumption of other goods (x_3), given the characteristics of the household (a),

$$U = U(x_1, x_2, x_3; a) \ . \qquad (1)$$

We denote the corresponding prices of these goods as p_i ($i = 1, 2, 3$). The household is assumed to maximize its utility, subject to the budget constraint $Y - p_1 x_1 - p_2 x_2 - p_3 x_3 = 0$. The maximization problem leads to the following first order conditions:

$$U'_{x_i} - \lambda p_i = 0 \ , \qquad (2)$$

where Y is the household's gross income and λ is the Lagrange multiplier for the budget constraint. In order to derive the conditional demand function, we solve all first order conditions except one.

Solving equation (2) for $i = 1$ and 3 with respect to λ, we have $\frac{U'_{x_1}}{U'_{x_3}} = \frac{p_1}{p_3}$. Solving this with respect to electricity consumption (x_1) gives $x_1 = f\left(x_2, x_3, \frac{p_1}{p_3}; a\right)$. From the budget constraint we find that $x_3 = \frac{Y - p_2 x_2 - p_1 x_1}{p_3} \equiv \frac{c_{-2} - p_1 x_1}{p_3}$, where $c_{-2} \equiv Y - p_2 x_2$. Inserting the expression for x_3 into the demand for x_1, and solving with respect to x_1, gives the conditional demand function for electricity:

$$x_1 = x_1\left(x_2, \frac{p_1}{p_3}, \frac{c_{-2}}{p_3}; a\right), \tag{3}$$

where p_1 is the price of electricity and c_{-2} is the expenditures excess of expenditures on other energy carriers than electricity. In equation (3), electricity demand (x_1) is conditional on the demand for other energy carriers (x_2). Electricity demand is also conditional on a vector of household characteristics, *a*, containing demographic variables, e.g. age and family composition, and variables indicating the presence of durables. Only durables that use electricity should be included in *a*, because the conditioning variable (x_2) contains the effect of durables fed with energy type 2 on the demand for electricity. In optimum, this equals the conditional demand function defined by Pollak (1969), Browning and Meghir (1991) and Deaton and Muellbauer (1980), where the demand for the good of interest is a function of its own price, prices of all goods except the conditioning goods, total expenditures excess of expenditures on the conditioning goods and the quantities of the conditioning goods.

Since we cannot observe a price for "all other goods", we assume the consumption of energy and other goods to be separable in consumption, excluding the price of all other goods and services (p_3) in all demand functions. Thus, we express the conditional demand function for electricity by:

$$x_1 = x_1(x_2, p_1, c_{-2}; a). \tag{4}$$

2.2. Decomposition of the cross price derivative

Solving all first order conditions with respect to x_2, we get the ordinary (Marshallian) demand function for x_2 as a function of all prices, income and household characteristics. Inserting this demand function for x_2 into the conditional demand function for electricity given by equation (3), we get the ordinary demand function for electricity as a function of all prices, income and household characteristics. Using this property, the cross price derivative of the ordinary demand function for the good of interest can be expressed by the derivatives of the conditional demand for the good of interest and the derivatives of the ordinary demand for the conditioning good. This is seen by differentiating equation (4) with respect to p_2, inserting the ordinary demand function for x_2 and using that $c_{-2} = Y - p_2 x_2$. This yields:

$$\frac{\partial x_1}{\partial p_2} = \frac{\partial x_1}{\partial x_2}\frac{\partial x_2}{\partial p_2} + \frac{\partial x_1}{\partial c_{-2}}\frac{\partial c_{-2}}{\partial p_2}$$
$$\Updownarrow \qquad (5)$$
$$\frac{\partial x_1}{\partial p_2} \equiv \frac{\partial x_1}{\partial x_2}\frac{\partial x_2}{\partial p_2} - x_2\left(1+e_{22}\right)\frac{\partial x_1}{\partial c_{-2}}$$

where $\frac{\partial c_{-2}}{\partial p_2} = -x_2\left(1+\frac{\partial x_2}{\partial p_2}\frac{p_2}{x_2}\right)$, and e_{22} is the own price Cournot elasticity for x_2. The effect on consumption of x_1 due to an increase in p_2, that is the ordinary cross price derivative, is divided into two components. In Pollak's terminology, the first term on the right hand side in equation (5) is called the *pure substitution effect*, and the second term is called the *money expenditure effect*. The pure substitution effect arises because an increase in the price of the conditioning good (p_2) implies a change in the demand for the conditioning good (x_2), which, in turn, causes a change in the consumption of the good of interest (x_1). The money expenditure effect arises because an increase in the price of the conditioning good implies a change in the level of expenditures for the non-conditioning goods (c_{-2}), which, in turn, causes a change in the consumption of the good of interest.[2]

This decomposition shows that the cross price derivative may be negative for several reasons. The pure substitution effect is negative if the goods in question are complements ($\frac{\partial x_1}{\partial x_2} > 0$) and positive if they are alternatives ($\frac{\partial x_1}{\partial x_2} < 0$), given that good 2 is not a Giffen good ($\frac{\partial x_2}{\partial p_2} < 0$). If good 2 is a Giffen good ($\frac{\partial x_2}{\partial p_2} > 0$), the pure substitution effect is negative if the goods are alternatives and positive if they are complements. The money expenditure effect will be negative if the own price

[2] See Pollak (1969) for more information.

elasticity of x_2 is less than one in absolute terms when x_1 is a normal good ($\frac{\partial x_1}{\partial c_{-2}} > 0$). If x_1 is inferior ($\frac{\partial x_1}{\partial c_{-2}} < 0$) or the own price elasticity of the conditioning good (e_{22}) is larger than one in absolute terms, that is if x_2 is a luxury good, the money expenditure effect is positive. Thus, both the pure substitution effect and the money expenditure effect may be negative or positive, and the total effect depends on the sign and the magnitude of the two terms.

2.3. The separability test

Separability between two goods exists if utility of consuming one good does not change when the household consumes more of the other good (see Deaton and Muellbauer 1980, chapter 5.2 for more information about separability). Pollak (1969) shows how to use the sign of the partial derivative of the conditional demand for the good of interest with respect to a change in consumption of the conditioning good to examine how the utility of consuming these goods are related, and thus test for separability in the consumption of goods. In our case, we focus on the relationship between electricity (x_1) and other energy carriers (x_2).

Pollak (1969) discusses three different cases: (i) If $(\partial x_1 / \partial x_2) = 0$, x_1 is unrelated to x_2. (ii) If $(\partial x_1 / \partial x_2) < 0$, x_1 is negatively related to x_2 and (iii) if $(\partial x_1 / \partial x_2) > 0$, x_1 is positively related to x_2. If the good of interest is unrelated to the conditioning good, the good of interest is weakly separable from the conditioning good (Pollak, 1971). If the derivative of the conditioning good is negative, the good of interest is negatively related to the conditioning good and the goods are alternatives in consumption. The hypotheses for alternativity in consumption are thus given by:

$$\begin{aligned} &H_0 : \partial x_1 / \partial x_2 = 0 \\ &H_1 : \partial x_1 / \partial x_2 < 0 \end{aligned} \qquad (6)$$

When testing empirically, an insignificant parameter of the conditioning good indicates that we cannot exclude the possibility that the consumption of the good of interest is weakly separable from the consumption of the conditioning good. If the parameter of the conditioning good is negative and significantly estimated, the good of interest and the conditioning good are with a high probability alternatives in consumption, and the household is able to switch between these two goods. This test, suggested by Browning and Meghir (1991), is applied in our analysis to test for separability in Norwegian household energy consumption.

3. The data

The data used in this analysis originate from five different sources. The main source is the annual Survey of Consumer Expenditure (SCE) (see Statistics Norway, 1996). The SCE includes information about consumption for individual households obtained by interviews and book keeping over a 14-day period and scaled to annual levels. The SCE also contains information about heating technology, dwelling characteristics, i.e. type, size, and vintage, and information about the household members, i.e. age, income and total consumption of the household. Moreover, information is available about ownership of major domestic appliances, e.g. freezers, washing machines, tumble dryers etc., held by each household. The data analysed in this paper contain information about 2,438 individual households observed in either 1993 or 1994.

Information about electricity consumption from the electric utilities is applied. When this information is missing, electricity consumption is calculated by dividing the electricity expenditures from the SCE, net of the fixed amount, by the marginal electricity price. Information about consumption of oil and wood is taken directly from the SCE. Information on prices is collected from different sources. Oil prices are obtained from the Consumer Price Index (CPI) survey. The CPI survey collects monthly oil prices in most municipalities, which gives variation in oil prices across households. When CPI data for a municipality are missing, average prices by county are calculated from the CPI data and applied for households in that municipality. Wood prices are calculated as expenditure divided by physical amount for households reporting both in the SCE. Based on these wood prices average prices by municipality are calculated and applied for all households in the respective municipality. Information on municipal electricity prices is collected from the Norwegian Water Resources and Energy Directorate. The Norwegian Institute of Meteorology provides annual information about regional variations in temperature for all municipalities applied in the SCE. The variation in temperature is measured in heating degree-days, which are defined as the difference in the number of °C between the outdoor temperature and 17°C, summed over days when the outdoor temperature is less than 17°C, for each year. Thus, cold weather will result in high heating degree-day values.

The sample includes 2 438 households using electricity, wood, and oil for space heating. Heating systems based on more than one energy carrier are quite common. For instance, 57% have heating equipment based on electricity and wood. This means that households in this group have electric heaters, electric floor heating or electric individual central heating in combination with stoves for wood, stoves for oil and wood or wood-based individual central heating. Usually, electric heaters and central heating radiators are not located in the same room. However, portable electric units may be used when outdoor temperature is not low enough for it to be profitable to start the central heating system. The share of households having heating equipment based on electricity in combination with equipment using fuel oil or wood or both is 86% in our sample, while 14% have heating systems based on electricity only.[3] Thus, Norwegian households are often equipped with multiple heating technologies, and are expected to be able to switch between different energy carriers to exploit relative energy price changes.

4. Econometric specification

For simplicity, we describe the econometric specification of the conditional demand function for electricity only, where x_2 in equation (4) consists of fuel oil and firewood. However, since it does not imply that if x_i is positively (negatively) related to x_k, x_k is positively (negatively) related to x_i, we also estimate the conditional demand functions and test for separability using the consumption of fuel oil and firewood as goods of interest. We approximate the conditional demand function for electricity by:

$$EL = \alpha_0 + \alpha_1 OIL + \alpha_2 WOOD + \alpha_3 PEL + \alpha_4 INC + \sum_{s=1}^{18} \alpha_{5s} HC_s + u \,, \qquad (7)$$

where *EL* is the household's total electricity consumption (kWh), *OIL* is household consumption of oil and kerosene, *WOOD* is household consumption of wood, *PEL* is the electricity price and *INC* is household gross income minus expenses for wood and oil. The variables *OIL* and *WOOD* are endogenous to the household. To avoid biased estimates, we estimate instruments for these variables using the predictions from the Marshallian demand functions for fuel oil and firewood (see equations 8 and 9). All price- and income variables are normalized by the consumer price index (CPI) for 1995. HC_s are variables representing household characteristics, such as the number of electric heating equipment, dummies for whether the household has different domestic appliances, age and size of the dwelling, heating degree-days, number of children, one-person household dummy, dummy for block of flats, dummy for free electricity (bill paid by employer or others) and dummy for whether the household has moved during the year of interest and thus has not recorded energy consumption for a whole year (see also table 1 for a list of variables). α_i are the parameters to be estimated, and *u* is a

[3] Households with district heating, other types of common central heating systems and a few other non-common heating technologies are left out of our sample.

stochastic error term. We assume the error term to be identically and independently distributed with zero mean and constant variance.

In order to decompose the cross price derivatives of the electricity demand into a pure substitution effect and a money expenditure effect, we need estimates from the ordinary demand functions for fuel oil and firewood. These estimates are available from the instruments for the consumption of other energy carriers in the conditional demand function for electricity. The ordinary demand functions (instruments) for fuel oil and firewood are approximated by:

$$OIL = \beta_0 + \beta_1 POIL + \beta_2 PWOOD + \beta_3 PEL + \sum_{k=1}^{15} \beta_{4k} HC_k + v \quad , \qquad (8)$$

$$WOOD = \gamma_0 + \gamma_1 PWOOD + \gamma_2 POIL + \gamma_3 PEL + \sum_{k=1}^{15} \gamma_{4k} HC_k + w \quad , \qquad (9)$$

where *POIL* and *PWOOD* are the prices of oil and wood (normalized by the CPI), and the vectors β and γ are the parameters to be estimated. v and w are stochastic error terms with the same characteristics as the error term of equation (7). HC_k are household characteristics such as gross income, age of head of household, dummy for one-adult household, heating degree-days, type of house, number of heating appliances for oil and wood (respectively) and capacity of the different heating appliances (see appendix table A2 for a list of variables).

5. The results

We start this section by presenting the results when electricity is the good of interest. Then, we discuss the results when firewood and fuel oil are the good of interest. Finally, we quantify the pure substitution and money expenditure effects, in order to illustrate the reason for the negative estimates of the cross price derivatives, and test for separability in Norwegian household energy demand.

5.1. The conditional demand functions

Conditional electricity demand

The estimation results for the conditional demand for electricity are reported in table 1. The estimated parameters are given in the first column, and the p-values in the second column.[4]

[4] Summary statistics for variables included in the model are given in the appendix, table A1.

Table 1. Estimated conditional residential electricity demand, 1993-94

Variable	*Estimated parameter*	*p-value*
Intercept	7993	0.00
Estimated oil consumption, kWh	**-0.23**	**0.00**
Estimated wood consumption, kWh	**-0.26**	**0.00**
Electricity price (NOK/kWh)	-10422	0.00
Income excl. estimated oil/wood expenditures (1000 NOK)	**5.86**	**0.00**
# electric heaters	502	0.00
# rooms with electric floor heating	842	0.00
# electric individual central heating	774	0.00
Dwelling size (m^2)	43	0.00
Age of dwelling (years)	19	0.00
Apartment (0,1)	-3302	0.00
Detached house (0,1)	2188	0.00
Farmhouse (0,1)	2529	0.01
# heating degree-days	0.74	0.00
# children	533	0.00
Children age 16-20 years (0,1)	2038	0.00
Single person household (0,1)	-2670	0.00
Oslo (0,1)	-1283	0.06
Washing machine (0,1)	1277	0.11
Tumble dryer (0,1)	1076	0.00
Dishwasher (0,1)	1713	0.00
Moved last year (0,1)	-1645	0.00
Free electricity (0,1)	4023	0.00

Note: Income and prices are measured in 1995 NOK. 1 NOK is approximately 0.11 US$.

Table 1 shows that all variables are estimated at high levels of significance, except for the dummy variable Washing machine, which is significant at 11% level. Consumption of electricity is negatively related to both oil consumption and wood consumption. Household income net of the predicted oil and wood expenditures is estimated to have a positive effect on electricity consumption, and the estimated parameter of the electricity price also has the expected sign. Technical characteristics of the house, the heating equipment and household characteristics are important for the electricity demand. Parameter estimates indicate that the number of electric heaters, the number of rooms with electric floor heating and the presence of electric central heating have a positive and significant impact on electricity consumption. We find that electricity consumption increases with dwelling size, age of house, number of children, heating degree-days (that is cold weather) and ownership of tumble dryer, dishwasher and washing machine. Households living in detached houses and households having free electricity also use significantly more electricity. Furthermore, we find that households living in apartments, households living in Oslo and single person households use significantly less electricity than other households. Some households have moved during the last 12 months, implying lower electricity consumption than annual consumption.

Conditional demand for firewood and fuel oil

The results from the estimations of the conditional demand for oil and wood are reported in table 2. The estimated parameters are given in the first and third column, and the p-values in the second and fourth column.

Table 2. Estimated conditional residential demand for oil and wood, 1993 - 94

	Oil demand		*Wood demand*	
Variable	*Estimate*	*p-value*	*Estimate*	*p-value*
Intercept	2354	0.39	3064	0.04
Estimated electricity consumption, kWh	**-0.29**	**0.00**	**-0.15**	**0.00**
Estimated oil consumption, kWh			**-0.22**	**0.00**
Estimated wood consumption, kWh	**-0.28**	**0.00**		
Oil price (1995 NOK/litre)	84	0.91		
Wood price (1995 NOK/kWh)			-4310	0.00
Income excl. estimated electr./wood exp. (1000 NOK)	**2.79**	**0.00**		
Income excl. estimated electr./oil exp. (1000 NOK)			**-0.65**	**0.56**
# stoves for oil/kerosene	3374	0.00		
# stoves for oil/kerosene and wood	1529	0.00	-515	0.26
# oil-based individual central heating	8250	0.00		
# wood stoves			956	0.00
# wood-based individual central heating			1717	0.14
Dwelling size (m^2)	17	0.00	5.59	0.14
Age of dwelling (years)	-0.53	0.88	9.32	0.11
Apartment (0,1)	-1605	0.00	-1030	0.18
Detached house (farmhouse excluded) (0,1)	2113	0.00	2516	0.00
Farmhouse (0,1)	3660	0.00	10222	0.00
# heating degree-days	0.32	0.06	0.20	0.51
# children (below 21 years)	-211	0.03	244	0.13
Children age 16-20 years (0,1)	563	0.02	-86	0.84
Single person household (0,1)	-1609	0.00	-1964	0.00
Oslo (0,1)	-582	0.19	-893	0.24

Note: Income and prices are measured in 1995 NOK. 1 NOK is approximately 0.11 US$.

Variables with a significant positive effect on the conditional demand for oil are household income, number of heating equipment based on fuel oil, dwelling size, detached house, farmhouse, number of heating degree-days and the presence of children age 16-20. The variables with a negative significant effect on the conditional demand for fuel oil are the consumption of other energy carriers (the conditioning goods), apartment, number of children below 21 years and single person households.

The variables with a significant positive effect on the conditional demand for firewood are the number of wood stoves, detached house and farmhouse. The variables with a negative significant effect on the conditional demand for firewood are the consumption of other energy carriers (the conditioning goods), the wood price and single person household.

5.2. Decomposition of the cross price effect

In section 2.2 we discussed theoretical reasons for negative cross price derivatives based on the decomposition using the conditional demand model. In order to investigate empirically the reasons for negative signs, we have decomposed the cross price derivatives of Norwegian household energy demand using equation (5). We apply the estimates of the ordinary demand functions for the conditioning goods (see appendix table A2), mean values for all prices and energy consumption (see appendix table A1) in addition to estimates from the conditional demand functions (see tables 1 and 2) in order to calculate these effects. All coefficients used in the calculations are presented in bold printing in the tables. These results for all combinations of energy carriers are presented in table 3. In the first column of table 3, the calculated pure substitution effects are presented, in the second column the calculated money expenditure effects are presented, and in the last column the sums of these cross price effects (that is the cross price derivatives) are given.

Table 3. Decomposition of cross price effects on energy demand due to increased energy prices. KWh/øre

Demand for	*Pure substitution effect*	*Money expenditure effect*	*Total cross price effect*
1) Electricity			
Price of fuel oil	-1.34	-21.32	-22.66
Price of firewood	1.00	-21.11	-20.10
2) Fuel oil			
Electricity price	3.29	-57.17	-53.88
Price of firewood	1.08	-10.05	-8.97
3) Firewood			
Electricity price	1.70	0.79	2.49
Price of fuel oil	-1.28	3.65	2.37

Looking at the total effects presented in the last column of table 3, we find negative cross price derivatives in the demand for electricity with respect to both the price of fuel oil and firewood, and in the demand for fuel oil with respect to the price of electricity and firewood. Looking at the pure substitution effects, reported in the first column of the table, we see that they have all positive signs except the pure substitution effect of the price of fuel oil on the electricity demand. The reason for this negative sign is that the estimated own price derivative of the consumption of fuel oil is positive (see appendix table A2), indicating that the consumption of fuel oil is a Giffen good. This estimated coefficient does, however, not differ significantly from zero. One reason why fuel oil is estimated to be a Giffen good may bee that, after the oil price shocks in the seventies (OPEC I and II) many households wanted to change their heating portfolio to reduce consumption of fuel oils. The investments involved in changing the stock of heating equipment are, however, expensive. Thus, high-income households had a larger possibility of doing this transition and reduce oil consumption than households with less income. If this is the case, the consumption of fuel oil may be higher in low-income households than in high-income households ceteris paribus, making the estimated fuel oil demand inferior.

The money expenditure effect is estimated to be negative in the demand for both electricity and fuel oil. We see from the table that the negative cross price derivatives in the electricity and fuel oil demands are due to large negative money expenditure effects. This is also the case for the cross price derivative of electricity demand with respect to the price of fuel oil, since even if the pure substitution effect had been positive, the total effect would probably have been negative due to the large negative money expenditure effect.

When decomposing the cross price effects of the firewood demand into a pure substitution and a money expenditure effect, several of the estimates used in the calculation do not differ significantly from zero. The signs of total cross price effect, as well as each of the components, are thus uncertain and will not be commented further.

5.3. The separability test

From the decomposition of the cross price derivative in section 2.2, it follows that the pure substitution effect consists of two components; the own price derivative of the conditioning good and the effect on consumption of the good of interest of a marginal change in the consumption of the conditioning good. The sign of the pure substitution effect does thus not only depend on whether or not the goods are alternatives or complements in consumption. In order to determine if the goods actually are alternatives in consumption, we use the estimated coefficients of the quantity derivatives in the conditional demand functions presented in tables 1 and 2 (printed in bold) to test the hypotheses discussed in section 2.3.

Looking at the coefficients in table 1, we find that the consumption of fuel oil and firewood both are negatively and significantly related to consumption of electricity. When estimating oil and wood as the goods of interest, we also find significant and negative relations, as the conditional fuel oil demand is negatively related to demand for electricity and firewood and the conditional firewood demand is negatively related to demand for fuel oil and electricity. Thus, we have clear indications that all the three energy carriers are alternatives in consumption for Norwegian households, i.e. the households have the possibility of hedging from energy price increases.

Our results indicate the magnitude of the switching between energy carriers. E.g. from table 2 it follows that if the consumption of electricity decreases by 1000 kWh, the conditional oil demand and the wood demand increases by 290 and 148 kWh respectively, in total 438 kWh. This means that approximately half of the reduction in electricity consumption is compensated by an increase in other energy carriers.

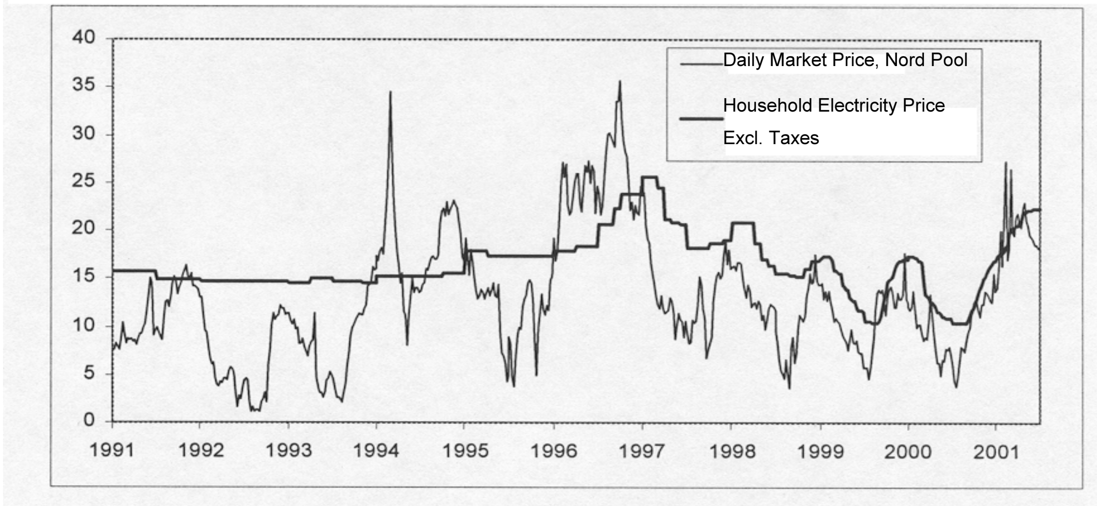
Note that our estimations are based on cross-sectional annual data. Thus the interpretation of a negative relationship between e.g. electricity and firewood is that households with high electricity consumption have lower wood consumption than households with low electricity consumption, ceteris paribus.

6. Conclusion

About three quarters of Norwegian households have heating systems enabling them to use more than one energy carrier for space heating. Despite this, estimations of residential energy consumption often indicate that the cross price derivatives may be negative. In this paper, we find that the main reason for the negative cross price derivatives is large negative budget effects. We have also tested for separability in consumption between different energy carriers. Our results show that all combinations of consumption of electricity, fuel oil and firewood are alternatives in consumption. Thus, our results indicate that the households actually do switch between different energy carriers, and the significance of these results is convincing. In conclusion, the variety of heating equipment in Norwegian households allows them to hedge from price increases and benefit from changes in relative energy prices when energy markets are liberalised or energy taxes are changed.

Appendix

Figure A1. Daily market price at Nord Pool and the electricity price for Norwegian households for the period 1991-2001, Norwegian øre/kWh



Source: Statistics Norway/Nord Pool.

Table A1. Summary statistics, Norway 1993 and 1994. 2,438 observations

	Mean	*Std. dev.*	*Minimum*	*Maximum*
Electricity consumption, kWh	**21624**	9529	0	75932
Oil consumption, kWh	**1741**	5689	0	70397
Wood consumption, kWh	**3781**	8593	0	159600
Estimated electricity consumption, kWh	21557	6238	2676	5315
Estimated oil consumption, kWh	1760	3697	-2043	75298
Estimated wood consumption, kWh	3791	3877	-8506	25942
Electricity price (1995 NOK/kWh)	**0.43**	0.04	0.25	0.53
Oil price (1995 NOK/litre)	**3.45**	0.13	2.86	3.79
Wood price (1995 NOK/kWh)	**0.17**	0.16	0	3.11
Gross income	272496	192930	0	3484083
Income excl. estimated oil/wood expenditures	266433	192327	-159502	3427674
Income excl. estimated electricity/wood expenditures	263213	191763	-11671	3464804
Income excl. estimated electricity/oil expenditures	257665	190845	-168172	3407394
# electric heaters	5.29	2.99	0	30
# rooms with electric floor heating	1.52	1.87	0	12
# electric individual central heating	0.10	0.82	0	22
# stoves for oil/kerosene	0.14	0.38	0	3
# stoves for oil/kerosene and wood	0.15	0.38	0	3
# oil-based individual central heating	0.05	0.38	0	12
# wood stoves	1.13	1.19	0	31
# wood-based individual central heating	0.02	0.14	0	2
Dwelling size (m^2)	129	57	11	600
Age of dwelling	31	31	0	264
Apartment (0,1)	0.08	0.27	0	1
Detached house (farmhouse excluded) (0,1)	0.61	0.49	0	1
Farmhouse (0,1)	0.09	0.29	0	1
# heating degree-days	4155	577	3284	6277
# children (below 21 years)	1.16	1.16	0	6
Children age 16-20 years (0,1)	0.21	0.41	0	1
Single person household (0,1)	0.10	0.30	0	1
Oslo (0,1)	0.06	0.24	0	1
Washing machine (0,1)	0.95	0.21	0	1
Tumble dryer (0,1)	0.46	0.50	0	1
Dishwasher (0,1)	0.59	0.49	0	1
Moved last year (0,1)	0.08	0.27	0	1
Free electricity (0,1)	0.01	0.11	0	1
Age of interviewed person	45	14	18	83
Age of interviewed person, squared	2194	1354	324	6889
Household with only one adult (0,1)	0.16	0.36	0	1
Min. 50% of the dwelling may be heated by electricity-based equipment (0,1)	0.76	0.43	0	1
Min. 50% of the dwelling may be heated by oil-based equipment (0,1)	0.14	0.35	0	1
Min. 50% of the dwelling may be heated by wood-based equipment (0,1)	0.42	0.49	0	1

Table A2. Instrumental variable estimations for electricity, oil and wood consumption

	Electricity		*Oil*		*Wood*	
Variable	*Estimate*	*p-value*	*Estimate*	*p-value*	*Estimate*	*p-value*
Intercept	10249	0.03	-1179	0.68	954	0.85
Electricity price (1995 NOK/kWh)	**-11348**	0.00	-1266	0.57	5065	0.20
Oil price (1995 NOK/litre)	-1595	0.17	**583**	0.40	1026	0.40
Wood price (1995 NOK/kWh)	2075	0.03	-71	0.90	**-3858**	0.00
Gross income (1000 NOK)	6.93	0.00	0.72	0.19	-1.76	0.05
# electric heaters	700	0.00				
# rooms with electric floor heating	1181	0.00				
# electric individual central heating	772	0.00				
# stoves for oil/kerosene			1639	0.00		
# stoves for oil/kerosene and wood			380	0.16	-523	0.26
# oil-based individual central heating			6797	0.00		
# wood stoves					772	0.00
# wood-based individual central heating					1449	0.19
Min. 50% of the dwelling may be heated by electricity-based equipment (0,1)	245	0.53	-1756	0.00	-1823	0.00
Min. 50% of the dwelling may be heated by oil-based equipment (0,1)	-1339	0.00	5227	0.00	-2488	0.00
Min. 50% of the dwelling may be heated by wood-based equipment (0,1)	-552	0.09	-1285	0.00	2493	0.00
Apartment (0,1)	-3372	0.00	-143	0.71	-104	0.88
Detached house (farmhouse excluded) (0,1)	2576	0.00	562	0.02	1363	0.00
Farmhouse (0,1)	2847	0.00	82	0.83	8418	0.00
# heating degree-days	0.26	0.33	0.26	0.10	-0.19	0.50
Age of head of household	388	0.00	-6.85	0.87	-114	0.14
Age of interviewed person, squared	-4.01	0.00	0.34	0.43	1.23	0.11
Household with only one adult (0,1)	-2171	0.00	-251	0.35	-1765	0.00
Oslo (0,1)	-1354	0.06	-322	0.44	-525	0.47
Washing machine (0,1)	1323	0.10				
Tumble dryer (0,1)	1576	0.00				
Dishwasher (0,1)	2347	0.00				
Moved last year (0,1)	-1360	0.02				
Free electricity (0,1)	4500	0.00				

Note: Income and prices are measured in 1995 NOK. 1 NOK is approximately 0.11 US$.

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