Chapter 4

Household energy and water use: an econometric analysis

4.1 Introduction

In the government's policy plans, economic incentives have been major policy instruments in achieving policy objectives. In particular, governments use excises, taxes, subsidies and pricing structures to regulate consumption of particular goods. For instance, the government levies excises on tobacco, alcoholic drinks and car fuels to temper excessive consumption of these goods.

In the last ten years or so, these instruments have also been introduced more and more in the environmental policy plans. One of the target groups are households which have to reduce their energy and water consumption according to the Environmental Policy Plan (VROM, 1994). In particular, the so-called '*ecotax*' has been imposed on natural gas and electricity prices. It is only imposed if the household consumption exceeds a basic consumption level.[1] The effectiveness of such a price incentive is determined by price and income effects on the demands.[2] The effectiveness is often analyzed at an aggregate level, so that the implications of the incentives on the demand for energy and water at the individual household level are ignored. The responses of households with respect to price changes, however, can differ widely. For instance, using micro

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[1] For natural gas, the basic consumption level is defined as 800 m^3; for electricity it is 800 kWh.

[2] Note that we are not interested whether or not the tax is optimal or efficient in general equilibrium setting.

data in their study on household energy demand for the United Kingdom, Baker *et al.* (1989) reported that the demand for natural gas and electricity differs across households regarding particular household characteristics. For example, the energy demand was more elastic for households in the lower decile of income than for households in the top decile of income.

This Chapter aims to estimate the effects of prices and income as well as household characteristics with reduced-form demand equations. We use a pool of Netherlands Expenditure Survey data 1978 – 1994. In the case of electricity consumption, the pricing usually consists of two options: a single tariff – which is standard – and a two-part tariff including a peak-hour and an off-peak-hour tariff.[3] This pricing structure is Pareto efficient with respect to a single electricity rate, because consumers have the opportunity to increase welfare by choosing the two-part rate (see Train and Mehrez, 1994).[4] However, with such a voluntary pricing schedule the electricity price becomes endogenous. In previous studies for the Netherlands, this endogeneity has been neglected when estimating demand equations for electricity. We explicitly include a correction term in our specifications. Note that in the case of natural gas and water consumption the marginal prices are independent from quantities consumed or time of consumption.

Section 4.2 reviews the economic literature on the demand for natural gas, electricity and water. We particularly focus on price and income elasticities found in the literature. In Section 4.3 we derive the demand equations for natural gas, electricity and water for a utility-maximizing consumer given the pricing options for electricity consumption. Additionally, we present our econometric specifications. Section 4.4 summarizes the data and section 4.5 presents the estimation results, in which we pay special attention to two issues. First, we analyze the effects of the presence of insulation on the demand for natural gas, and secondly, we present price and income effects for different household types. Section 4.6 concludes.

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[3] In the economic literature on consumer demand, this pricing structure is known as time-of-use (TOU) pricing. Electricity supplying companies introduced these kind of pricing structures to smooth daily demand for electricity. These pricing structures are also referred to as peak-load pricing.

[4] If consumers choose the two-part rate and their total electricity consumptions remain constant, they can reallocate their daily electricity consumption in such a way that their expenditures on electricity decline.

4.2 Literature

The demand for natural gas, electricity and tap water is best viewed within Becker's theory of household production (see Chapter 1). In his theory, Becker defines commodities and services as household activities, such as cooking, cleaning, and heating, from which utility is generated. With available time and the presence of domestic durable appliances, energy and water are inputs for the production of those commodities. In particular, natural gas and electricity are fuels to power durable appliances which produce services; in fact they are not directly consumable. The total demand for natural gas, electricity and tap water, therefore, is derived from the demand for commodities, and it is jointly determined with the presence of particular durable appliances.

Although this view is widely recognized and agreed on, many studies often imposed simplifying assumptions in order to be able to analyze the demand for energy and water empirically.[5] In addition, the demands for these goods are often analyzed conditional on the consumer durable stock. However, in the long run, the consumer durables stock is endogenous. Raising consumer energy price imply that the prices of commodities requiring energy and water as an input increase as well. As a result the demand for the commodity as well as the demand for energy will decline. In the long run, however, the consumer can also change the production technology of a commodity by replacing the current consumer durables by a more energy-efficient version. As a result, the demand for the commodity increases again. The effect on the demand for energy is ambiguous. Energy consumption will increase if the effect of the production technology change dominates the effect of the energy price increment. An important feature in this mechanism might be the pricing schedule for energy and water consumption as we will see later on this Chapter.

In the literature price and income elasticities of residential demands for natural gas, electricity and water are analyzed and estimated under many different circumstances, such as the time period, the country, the aggregation level of data, and the time horizon of the analyses, which partially explains the differences in the results. Tables 4.1 to 4.3 summarize the studies on the household demands for natural gas, electricity and water, respectively, which have been published in the last ten years or so. The tables report the reference, the period,

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[5] By imposing weak separability for the arguments in the utility function and assuming a quasi-concave utility function, the demand for energy and water is directly derived from a utility function.

the country, the nature of the data as well as price and income elasticities.

As to the aggregation level, we distinguish three aggregation levels. An example of the first type is Pouris (1987), who used aggregate national data to analyze the long-run price effects of the residential electricity demand in South Africa. Secondly, several studies used aggregate regional data. In particular, these kinds of data are provided for households connected to a particular supplying utility or living in a particular region (cf. Dumagan and Mount, 1993; Ryan *et al.*, 1996; Filippini, 1995; Hsing, 1994; Kooreman, 1993; Hansen, 1996; and Dandy *et al.*, 1997). Finally, there are studies using micro data or household data, either experimental or non-experimental. Studies using experimental data often involve analyses of the effects of particular pricing schemes on the demand (cf. Train and Mehrez, 1994; Aubin *et al.*, 1995; and Mountain and Lawson, 1992). Baker *et al.* (1989) and Booij *et al.* (1992) used non-experimental expenditure survey data when estimating the demand for energy and water. Their frameworks are explicitly derived from the theory of consumer demand.

According to Dubin and McFadden (1984), the use of disaggregate data is beneficial, because it avoids the effects of misspecification due to aggregation bias or due to approximation of rate data. In the studies using micro-level data, we distinguish three different classes. In the first class, which has only been applied to the demand for electricity, the demand for electricity is analyzed within the framework of a particular activity, such as air conditioning (see Hausman, 1979) or space and water heating (see Dubin and McFadden, 1984; and Bernard *et al.*, 1996). In particular, they jointly estimated the demand equation for electricity and the demand for durable appliances including the rate of use. The data requirements for these kinds of analyses are strict, and data sets are often not available. Moreover, assumptions about price expectations are imposed, and often these assumptions are only approximately true (see Dubin and McFadden, 1984).

Secondly, there are the studies in which the demands are modelled conditional on the durable appliance stock (cf. Baker *et al.*, 1989 ; Booij *et al.*, 1992; and SCP, 1993). According to Baker *et al.* (1989), this so-called conditional approach allows for a more detailed analysis of the energy demands than in the simultaneous approach as mentioned above (cf. McFadden *et al.*, 1977; Lawrence and Braitwait, 1979; Hausman *et al.*, 1979 ; and Caves and Christensen, 1980). However, in the conditional approach the energy demands are assumed to be separable from the durable appliance stocks.

In their study, Baker *et al.* (1989) analyzed a structural model of demands for natural gas and electricity in a two-stage budgeting framework using quarterly household data. In the first stage the total budget share of energy and water is determined and in the second stage demand equations are estimated given the budget share resulting from the first stage and conditional on the presence of durable appliances.[6] Booij *et al.* (1992) used a pooled sample of annual household data in their study estimating reduced-form demand equations for natural gas and water in the Netherlands. They additionally estimated models for the presence of durable appliances and the presence of several forms of insulations, such as double glazing, wall insulation, roof insulation, and floor insulation). SCP (1993) estimated demand equations for housing, natural gas, electricity and water derived from a structural Almost Ideal Demand System.

The latter class of studies mainly focuses on pricing schedules applying to energy and water consumption. In most pricing schedules the marginal price of consumption is not constant. As a consequence, the marginal price depends on the quantity consumed, and therefore the marginal price is endogenous. Hence, pricing schedules partially determine the model of the demand system. The literature distinguishes two criteria with which pricing varies, namely pricing depending on quantity consumed, and pricing depending on the moment of consumption. As to the first criterion, block rate pricing has the property that the marginal price of a good depends on the quantity consumed. In particular, the marginal prices correspond to predetermined consumption blocks. In progressive block rate pricing the marginal price increases with the quantity consumed, while the opposite holds in regressive block rate pricing. Hewitt and Hanemann (1995) estimated a residential demand model for water of households considering block rate pricing. In particular, they estimated the demand for water in which they explicitly modelled the choice of the marginal rate, according to the method suggested by Burtless and Hausman (1978).

As to the second criterion, the time-of-use (TOU) pricing, which is also known as peak-load pricing, is frequently applied to electricity consumption to smooth the demand for electricity during a day (cf. Aubin *et al.* 1995; Filippini 1995; Booij *et al.*, 1992; and Train and Mehrez, 1994).[7] In TOU pricing, the marginal price of electricity at off-peak-hours is significantly lower

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[6] Baker *et al.* (1987) analyzed the presence of durable appliances.

[7] Initially, electricity producers gain from smoothing the electricity demand during the day. This peak largely determines the production costs: the lower the peak in demand, the lower the production costs. Consequently, the electricity prices may even decline.

Table 4.1: *Review of elasticities on the household demand for natural gas*

Author(s)	elasticities		
country, time	own-price	cross-price[a]	income
HOUSEHOLD SURVEY			
Pooled cross sections data			
Baker *et al.* (1989)	-0.12 to -0.44	-0.81 to -0.02 (E)	-0.09 to 0.21
UK, 1972-83			
Booij *et al* (1992)	-0.1- to -0.41	-	0.15
NL, 1981-87			
Cross section data			
SCP (1993)	-0.12 to -0.58	-0.06 to -0.13 (E)	0.28 to 0.37
NL, 1989		-0.06 to 0.02 (W)	
AGGREGATE MUNICIPAL DATA			
Time series data			
Dumagan and Mount (1993)	-0.23	0.02 (E)	0.775
US, 1960-87			
Ryan *et al.* (1996)	-0.25	0.19 (E)	-
Canada, 1962-89			
Panel data			
Maddala *et al.* (1997)	-1.34 to 1.07	-	-2.75 to 3.34
US, 1970-90	-10.4 to 0.24[b]	-	-5.13 to 1.85[b]

[a] The cross-price variables are given in parentheses: E=electricity rate and W=water rate.
[b] Long-run elasticities

than at peak-hours. Households have the opportunity to reallocate a particular activity from peak-hours to off-peak-hours, resulting in a decline of operating costs of this activity. We distinguish two different TOU pricing schedules. First, TOU pricing is mandatory so that all households consider TOU pricing (see Aubin *et al.*, 1995). Secondly, TOU pricing is optional. Train and Mehrez (1994) discuss and estimate a system of demand equation for electricity including an optional two-part rate.[8]

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[8] If a household considers a two-part rate for electricity, it is charged a high marginal electricity rate at peak-hours and a low marginal rate at off-peak-hours.

Elasticities

In the economic literature, most studies on the demand for natural gas, electricity and water have focused on price and income elasticities. Table 4.1 summarizes elasticities of the demand for natural gas. The own-price elasticities for natural gas are small, i.e. natural gas demand is rather price inelastic. The only exception is the study of Maddala *et al.* (1997). However, the range of their elasticity estimates is rather large. In the other studies, the elasticities for different countries and for different time periods ranged from -0.10 to -0.58. The electricity cross-price elasticities of the demand for natural gas differ across the studies. Baker *et al.* (1989) and SCP (1993) using micro data report a negative electricity cross-price elasticities, while Dumagan and Mount (1993) and Ryan *et al.* (1996) using aggregate data report positive elasticities. This suggests that the particular electricity price elasticities on the natural gas demand depend on the aggregation level of research. On the one hand, natural gas and electricity are often marked as substitutes, because they are both mutually exclusive inputs for the production of similar commodities, such as space and water heating, suggesting that the cross-price elasticity should be positive.[9] On the other hand, there are examples of both goods being complements. An example is a central heating system powered by both natural gas and electricity. Natural gas is used to heat the water in the system, while electricity is used to power the pump which takes care of the water circulation within the system. Another example is when two activities go together, such as the use of the cooker and the extractor. In the Netherlands, the major part of the cookers present in the households use natural gas, while extractors use electricity.

Only the SCP study reports tap water cross-price elasticities of the natural gas demand. These elasticities are within range from -0.06 to 0.02 depending on the number of persons within a household. The direction of the effect is ambiguous.

The natural gas demand is rather income inelastic. Again, Maddala *et al.* show a large range of results, including negative results. Baker *et al.* (1989) show a negative income elasticity for households which have central heating systems powered by electricity, -0.085, while all other households show positive income elasticities in the range from 0.012 to 0.211. In the other studies the income elasticity is positive but less than one; tap water is a normal good.

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[9] Note that switching fuels in commodity production processes is not a short-term decision. Due to longer time spans, it is more likely that this feature appears when using time series data.

Table 4.2: *Review of elasticities on the household demand for electricity*

Author(s)	elasticities		
country, time	own-price[a]	cross-price[a]	income[a]
HOUSEHOLD SURVEY			
Panel data			
Aubin *et al.* (1995)	-0.79 (P)	-0.18 (O)	-
France, Winter 91/92	-0.28 (O)	-0.93 (P)	-
Branch (1993)	-0.20	-	0.23
US, 1985			
Green (1987)	-0.25 to -0.56	-	0.05 to 0.15
US, 1974-79			
Poyer and Williams (1993)	-0.42 to -0.81	-	-
US, 1980, 82, and 87	-0.65 to -0.83[b]	-	0.10 to 0.27[b]
Pooled cross sections data			
Baker *et al.* (1989)	-0.54 to 0.80	0.09 to 0.29 (N)	-0.17 to 0.26
UK, 1972-83			
Bernard *et al.* (1996)	-0.65 to -5.88	0.08 to 0.10	0.11 to 0.14
Canada, 1986-89	-0.05 to -1.29[b]	0.06 to 0.9[b]	0.08 to 0.9[b]
Booij *et al.* (1992)	-0.08 to -0.17 (S)	-	0.18 (S)
NL, 1981-87	-0.08 to -0.13 (T)	-	0.11 (T)
Cross section data			
Dubin and	-0.20 to -0.31	-0.01 to -0.04 (N)	0.01 to 0.03
McFadden (1984)	-0.004 to 0.08	-0.03 to -0.1 (N)	0.02 to 0.08
US, 1975	-0.22 to -0.26[b]	0.35 to 0.40 (N)[b]	0.02 to 0.06[b]
SCP (1993)	-0.10 to -0.22	-0.07 to 0.24 (N)	0.2 to 0.25
NL, 1989	-	-0.02 to 0.00 (W)	-
Train and Mehrez (1994)[c]	-0.15 (P)	-	-
US, 1985-86	-0.25 (O)	-	-

[a] The cross-price variables are given in parentheses: E=electricity rate, N=natural gas, P=peak-hour rate, O=off-peak-hour rate, S=single electricity rate, T=two-part electricity rate, and W=water rate.

[b] Long-run elasticities.

[c] experimental data used.

Table 4.2: *Review of elasticities on the household demand for electricity continued*

Author(s) country, time	elasticities own-price[a]	 cross-price[a]	 income[a]
AGGREGATE MUNICIPAL DATA			
Panel data			
Filippini (1995)	-0.60 (P)	0.91 (O)	
Swiss, 1987-90	-0.79 (O)	0.40 (P)	
	-0.71 (P)[b]	2.16 (O)[b]	
	-1.92 (O)[b]	0.65 (P)[b]	
Hsing (1994)	-0.24		0.40
US, 1981-90	-0.54[b]	0.33 (N)[b]	0.90[b]
Maddala *et al.* (1997)	-0.92 to 0.78		-0.83 to 1.33
US, 1970-90	-10.4 to 0.24[b]		-7.77 to 33.0[b]
Time series data			
Dumagan and Mount (1993) US, 1960-87	-0.07	0.02 (N)	0.72
Ryan *et al.* (1996) Canada, 1962-89	-0.23	0.14 (N)	
AGGREGATE DATA			
Pouris (1987) South Africa, 1950-83	-0.90[b]		

[a] The cross-price variables are given in parentheses: E=electricity rate, N=natural gas, P=peak-hour rate, O=off-peak-hour rate, S=single electricity rate, T=two-part electricity rate,and W=water rate.

[b] Long-run elasticities.

Table 4.2 shows that residential electricity demand is rather price inelastic as well. Most studies report negative own-price elasticities with absolute values smaller than one. In the studies that consider short-run as well as long-run price elasticities, the absolute values of long-run elasticities are higher than the absolutes value of short-run elasticities. The exception is the study of Bernard *et al.* (1996); they report the opposite. Aubin *et al.* (1995), Filippini (1995), and Train and Mehrez (1994) present different price elasticities for different time-of-use electricity rates. According to Filippini and Train and Mehrez off-peak demand is more elastic than peak demand, while the results of Aubin *et al.* indicate the opposite. The results on cross-price elasticities are contradictory. The results of Aubin *et al.* imply that different time-of-use electricity demands are substitutes, while Filippini's results indicate that these demands are complements. Note however that Aubin *et al.* use micro-level data, while Filippini uses aggregated regional data. In the latter case the aggregation suggests that variables are omitted.

In the studies using aggregate regional data, the natural gas cross-price elasticities are positive. In micro-level studies, only Dubin and McFadden (1984) and SCP (1993) present very small negative cross-price elasticities. In the other micro-level studies the short-run cross-price elasticities are less than 0.29, while the long-run elasticities are less than 0.40. According to the SCP (1993), the cross-price elasticity with tap water is negative, but rather low. The income elasticities are mainly positive and rather small. This indicates that electricity is a necessary good.

The water demand is inelastic too. In all studies, except Hewitt and Hanemann (1995), the absolute own-price elasticities reported are much smaller than one. Hewitt and Hanemann report a large value, approximately -1.6, which means an elastic water demand. However, their result might suffer from seasonal bias, because they concentrate on the water consumption in the summer months.

Demand system for energy and water using micro-level data

According to Dubin and McFadden (1984), the use of disaggregate data is beneficial, because it avoids the effects of misspecification due to aggregation bias or due to approximation in rate data. In this Chapter, we derive and estimate a model of the residential demands for natural gas, electricity and water using data from the Netherlands Consumer Expenditure Surveys 1978 – 1994 (DBO is the Dutch acronym). Booij *et al.* (1992) and SCP (1993) previously used data from parts of these surveys, while Baker *et al.* (1989) used similar expenditure survey data for the UK.[10] All studies present estimates for price and income elasticities of the demand for natural gas and electricity, while the SCP study also presented elasticities of the demand for water. In the SCP study, the demand for energy and water are jointly analyzed with the demand for housing. The demands and their elasticities are derived from an Almost Ideal Demand

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[10] Using a sample of the Familiy Expenditure Surveys 1972 – 1983, Baker *et al.* (1989) estimated a two-stage budgeting model of the demands for natural gas and electricity. First, they derived and estimated the budget shares of the demand for energy from a Gorman utility function, and then they estimated the Leontief representations of the coefficients of the demand equations.

Table 4.3: *Review of elasticities on the household demand for water*

Author(s)	elasticities		
country, time	own-price	cross-price[a]	income
HOUSEHOLD SURVEY			
Pooled cross sections data			
Hewitt and Hanemann (1995)	-1.57 to -1.63	-	0.153 to 0.158
US, 1981-85			
Cross section data			
SCP (1993)	-0.09 to -0.19	-0.31 to 0.19 (N)	0.10 to 0.12
NL, 1989		-0.08 to 0.02 (E)	
AGGREGATE REGIONAL DATA			
Panel data			
Kooreman (1993)	-0.10	-	-
NL, 1988-89			
Pooled cross sections data			
Dandy *et al.* (1997)	-0.12 to -0.36	-	0.14 to 0.16
Australia, 1978-92	-0.29 to -0.86[b]	-	0.28 to 0.49[b]
Time series data			
Hansen (1996)	-0.03 to -0.10	-0.21 to -0.22 (E)	-
Denmark, 1981-90			
Cross section data			
Nieswiadomy (1992)	-0.29 to -0.45	-	0.09 to 0.28
US, 1984			
Stevens *et al.* (1992)	-0.10 to -0.69	-	0.14 to 0.28
US, 1988			

[a] The cross-price variables are given in parentheses: E=electricity rate, N=natural gas,and W=water rate.

[b] Long-run elasticities

System utility model. Booij *et al.* estimate reduced form demand equations.[11]

If the electricity pricing options are ignored in the estimation of the demand equation, the results are likely to be inconsistent. In both studies, SCP and Booij *et al.*, the electricity pricing options are not explicitly modeled in the system of demand equations. In our analysis, we jointly model the demand for electricity and the electricity pricing decision. The resulting model is a switching regression model, as suggested by Train and Mehrez (1994). We extend their model in two ways. Firstly, we explicitly model and estimate an electricity pricing decision equation, and secondly, in the case of two-part tariff we distinguish two separate demand equations, peak and off-peak demand. Our data set contains information on the household's choice concerning the electricity pricing options, and data on the expenditures and consumption on electricity given the pricing option chosen. The demand equations are analyzed conditional on the durable stock (cf. Baker *et al.*, 1989), so that the demand for energy and water and the demand for energy-using consumer durables can be estimated separately. Note that contrary to Train and Mehrez we use non-experimental data.

4.3 Reduced form demand equations

4.3.1 The model

As mentioned in the previous section we should analyze the demand for energy and water in the household production framework. Although it is a theoretically valuable model, the empirical applicability is limited because commodity consumption and prices are often – as in our case – not measured, see Chapter 1. Therefore, we substitute energy and water consumption directly in the utility function. As a consequence, we cannot disentangle changes in tastes or technology; see Kooreman and Kapteyn (1987) . The utility function represents individual consumer or household preferences. We assume that it depends on the consumption for natural gas (q^N), electricity (q^E), water (q^W) and other goods (c). Suppose the utility function is

$$U = U(q^N, q^E, q^W, c) \tag{4.1}$$

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[11] Booij *et al.* (1992) estimated two electricity demands; a single rate demand and a two-part rate demand. They implicitely assumed that consumers do not note any other than financial differences between peak and off-peak consumption.

Households maximize their utility subject to their budget restriction:

$$p^N q^N + p^E q^E + p^W q^W + c = y - F_0,$$

where and p^N, p^E, and p^W are the marginal prices of natural gas, electricity and water respectively, y is income, and F_0 is the fixed fee. The price of other goods is unity. Then, the demand equation for good i is a function of prices, income and a vector of utility parameters, θ:

$$q^j = f_j(p^N, p^E, p^W, y - F_0; \theta), \tag{4.2}$$

where $j = N$, E and W.

In the case of electricity the consumer has two pricing options; he pays a proportional rate independent of the time of consumption (single rate) or he pays two different electricity rates depending on the time of consumption (the two-part rate).[12] In particular, at peak-hours the marginal electricity price is high and at off-peak-hours it is low. The fixed fee for the two-part rate option, F_1, is substantially higher the fixed fee for the single rate option, F_0, i.e. $F_1 > F_0$. Following the work of Train and Mehrez (1994), we distinguish two separate demand equations for consumers with the two-part electricity rate: an off-peak demand (q^I) and a peak demand (q^{II}). Both types of electricity are treated as two different goods. In fact, we allow for differences in the marginal utility of electricity consumption at off-peak-hours and at peak-hours. Most consumers, for instance, have higher preferences for electricity consumption at daily hours than for electricity consumption at night hours.

In the case of the two-part tariff, both demands correspond to different marginal prices: off-peak-hour rate (p^I) and the peak-hour rate (p^{II}). By definition, $p^I < p^{II}$. Considering two electricity demands, we can rewrite the utility function,

$$U = U(q^N, q^I, q^{II}, q^W, c) \tag{4.3}$$

Then, the budget restriction is $p^N q^N + p^I q^I + p^{II} q^{II} + p^W q^W + c = y - F_1$, The peak and off-peak demand equations for electricity are:

$$\begin{aligned} q^I &= f_I(p^N, p^I, p^{II}, p^W, y - F_1 : \theta) \quad (4.4) \\ q^{II} &= f_{II}(p^N, p^I, p^{II}, p^W, y - F_1 : \theta) \quad (4.5) \end{aligned}$$

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[12] This electricity pricing scheme is the current pricing scheme for electricity in the Netherlands.

In the case of the single rate option, the consumer considers the utility function in (4.1) and the demand function in (4.2).

The electricity pricing decision, however, is determined by comparing the utilities of both pricing options. We therefore determine the indirect utility functions for both these options.[13] Let D be a dichotomous variable which is one if the consume chooses the two-part electricity rate and zero otherwise. Substituting (4.4) and (4.5) into (4.3) we obtain the indirect utility function conditional on choosing the two-part rate, V_1,

$$V_1 = \Psi_1(p^N, p^I, p^{II}, p^W, y - F_1 : \theta). \tag{4.6}$$

The indirect utility function conditional on the single rate, V_0, is obtained by substituting (4.2) into (4.1),

$$V_0 = \Psi_0(p^N, p^E, p^W, y - F_0 : \theta). \tag{4.7}$$

To compare both pricing options we define a difference function, D^*:

$$D^* = V_1 - V_0. \tag{4.8}$$

Now, a household chooses the two-part rate option, if $D^* > 0$, and the single rate option otherwise. Thus,

$$D = \begin{cases} 1, & \text{if } D^* \geq 0 \\ 0, & \text{otherwise.} \end{cases} \tag{4.9}$$

4.3.2 Econometric specification

Following Booij *et al.* (1992), we use linear approximations for the demand equations in (4.2), (4.4) and (4.5):

$$q^j = \beta_j x^j + \epsilon^j, \tag{4.10}$$

where x^j is a vector of exogenous variables including prices, income and other determinants, such as demographics and dwelling type, and β_j is a vector of parameters. The error term ϵ^j has zero expectation and variance σ_j^2. For natural gas and water, the demand equation in (4.10) can be estimated with Ordinary Least Squares.

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[13] The indirect utility functions are obtained by substituting the demand functions in the utility funtions. The indirect utility functions reflect the given maximum levels of utility as a funtion of prices and income.

As mentioned above, the consumer considers two pricing options for their electricity consumption. Firstly, we consider the case that the consumer chooses the single rate. Then $D = 0$, and the demand equation is similar to the demand equation in (4.10):

$$q^E = \beta_E x^E + \epsilon^E, \tag{4.11}$$

where x^E includes the single electricity rate, income and other determinants, and $E(\epsilon^E) = 0$ with $Var(\epsilon^E) = \sigma_j^2$. However, this demand is only observed if the consumer chooses the single rate. This means that the distribution of ϵ^E is conditional on the tariff decision, $E[\epsilon^E | D = 0]$, which is not equal to zero. As a consequence Least Squares estimates will be biased.

Secondly, if the consumer chooses the two-part tariff, two demands for electricity can be distinguished: an off-peak and a peak demand, denoted by q^I and q^{II} respectively. The consumer considers different marginal prices for both demands. The two demand equations are:

$$q^I = \beta_I x^I + \epsilon^I, \quad \text{and} \tag{4.12}$$

$$q^{II} = \beta_{II} x^{II} + \epsilon^{II}, \tag{4.13}$$

where x^I and x^{II} include prices, income and other determinants.

The consumer chooses the electricity pricing options with the highest revenues in terms of utility. If the difference in indirect utility is positive, $D^* > 0$, the consumer chooses the two-part rate, otherwise he chooses the single rate. Because we assume that the demand equations are linear in the parameters, the indirect utility functions in (4.6) and (4.7) will be non-linear in the parameters. In this study, however, we use approximations of the indirect utility functions which are linear in the parameters:

$$V_D = Z_D \delta + u_D, \tag{4.14}$$

where Z_D includes electricity price, income, and other determinants, and $D = 0, 1$. Then, the difference in utility is

$$D^* = V_1 - V_0 = Z_1 \delta_1 - Z_0 \delta_0 + u_1 - u_0. \tag{4.15}$$

We define u as the difference of u_1 and u_0, and it has zero expectation and variance σ_u^2. A household chooses two-part electricity rate ($D = 1$) if the difference in (4.15) is positive. We now have

$$D = 1 \Leftrightarrow u = u_1 - u_0 > -(Z_1 \delta_1 - Z_0 \delta_0) \tag{4.16}$$

Table 4.4: *Summary statistics of DBO survey* 1978 – 1994

Variable names	Mean	Standard deviation
MARGINAL PRICES AND INCOME		
Two-part rate (1 if present; 0 otherwise)	0.32	0.47
Natural gas price in cents per m^3	53.9	10.4
Single rate in cents per kWh	23.9	5.7
Peak-hour rate in cents per kWh	24.8	5.3
Off-peak-hour rate in cents per kWh	16.5	5.5
Water price in cents per m^3	135.4	48.6
Income in guilders	52,618	21,901
CONSUMPTION		
Natural gas in m^3	2530	1356
Electricity in kWh (single rate)	2650	1226
Electricity in kWh (peak-hour rate)	2132	1379
Electricity in kWh (off-peak-hour rate)	1738	1226
Water in m^3	130.1	70.6
HOUSEHOLD CHARACTERISTICS		
Family size	3.06	1.36
Presence of children younger than 6	0.25	0.43
Presence of children 6-11	0.24	0.43
Presence of children 12-17	0.22	0.41
Presence of children 18 and older	0.14	0.34
HEAD OF HOUSEHOLD		
Age	45.3	14.7
Male	0.87	0.33
Employed	0.71	0.45
Retired	0.16	0.36
Unemployment	0.07	0.25
Education level 21	0.23	0.42
Education level 22	0.24	0.43
Education level 31	0.16	0.36
Education level 32	0.05	0.22
Partner is employed	0.26	0.44
CONSUMER DURABLES		
Refrigerator	0.99	0.10
Freezer	0.51	0.50
Washing machine	0.96	0.20

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Table 4.4: *Summary statistics of DBO survey continued*

Variable names	Mean	Standard deviation
Tumble dryer	0.22	0.41
Dishwasher	0.13	0.33
CHARACTERISTICS OF DWELLING		
Non-detached dwelling	0.15	0.36
Flat or apartment	0.13	0.34
Farm house	0.02	0.15
Other types of dwelling	0.01	0.11
Built before 1944	0.24	0.48
1945-59	0.14	0.35
1960-69	0.20	0.40
1970-79	0.29	0.45
1980-89	0.11	0.31
Home ownership	0.60	0.49
OTHER DUMMY VARIABLES		
Bath	0.44	0.50
Joint space heating system	0.04	0.19
Natural gas is space heating fuel	0.98	0.15
Central heating system (CH)	0.75	0.43
Hot water boiler	0.22	0.41
Hot water geyser	0.48	0.50
Hot water from combined SH/WH system	0.15	0.35
Natural gas is hot water fuel	0.65	0.48
Electricity is hot water fuel	0.10	0.30
Natural gas is cooking fuel	0.75	0.43
Electricity is cooking fuel	0.10	0.30
INSULATION		
Double glazing	0.33	0.47
Wall insulation	0.47	0.50
Floor insulation	0.46	0.50
Roof insulation	0.39	0.49
TEMPERATURE		
Winter in °C	2.97	1.65
Spring in °C	8.88	0.98
Summer in °C	16.5	0.94
Autumn in °C	10.3	0.79

The error term u is likely to be correlated with the error terms of the demand equations (ϵ^j, for $j = N, E, I, II, W$). We impose the restriction that the error terms are normally distributed, which allows us to derive the terms of the selection bias and to estimate the demand equations coefficients with Heckman's two-step estimation procedure. In the Heckman procedure, a probit model for the electricity pricing decision equation is estimated in the first step. With these results, the selection bias terms can be predicted and added to the demand equations. With Weighted Least Squares, the demand equation coefficients can be estimated consistently.[14]

4.4 Data

The reduced-form demand equations are estimated with a pooled sample of 17 cross sections of the Netherlands Expenditure Surveys 1978 – 1994 (DBO is the Dutch acronym) provided by the Statistics Netherlands (CBS is the Dutch acronym). The DBO consists of two parts: the household survey and the expenditure survey. The latter part contains six main expenditure categories: food, housing, clothing, cleaning including housekeeping and personal care, recreation and holiday, and the rest. The household survey contains characteristics on household decomposition, income, dwelling and durable stock. We focus on households, because energy and water consumption are measured at the household level.

The sample contains 28,210 households.[15] Table 4.4 presents summary statistics. The survey contains data on expenditures, consumption as well as the fixed fees. With this information, we calculated individual marginal prices for natural gas, electricity and water. Electricity and water rates differ across regions. These differences are incorporated in the individual marginal prices,

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[14] The conditional covariances of the demand equation error terms are functions of the selection bias terms. Although Ordinary Least Squares provides consistent estimates, Weighted Least Squares is the appropriate estimation method, because it provides more efficient estimates.

[15] Initially, the DBO 1978-1994 contains 41,053 observations. Households are excluded from the sample for a number of reasons. First of all, households facing zero marginal prices for either natural gas, electricity or water are excluded. These household paid either fixed annual amounts for their consumption or their expenditures were included in the rent. Secondly, households are excluded if marginal prices could not be calculated, which was the case for households changing from the single to the two-part electricity tariff or vice versa. Furthermore, if relevant data were missing such as expenditures or consumption data or if households registered extreme expenditure values for their energy and water expenditures, these observations were excluded too. For instance, households with an extrodinary energy or water consumption are excluded from the final sample.

Table 4.5: *The different household types in our sample*

h	description	N_h
1	older single person (household head is 45 years or older)	2,326
2	younger single person (household head is younger than 45)	1,082
3	single parent	1,001
4	older couples without children (household head is 45 years or older)	5,059
5	younger couples without children (household head is younger than 45)	2,756
6	couples with young children (all children younger than 12)	8,461
7	couples with older children (all children 12 years or older)	5,002
8	couples with both older and younger children	2,523

Here, h is the household type index and N_h is the number of observations per household type in our sample.

and they are assumed to be constant for a given household. Natural gas rates do not differ across households in the Netherlands. As, these rates are adjusted each six months and we calculate our marginal prices from the annual expenses and consumption, we actually observe small variations in the marginal natural gas prices. Additionally, we define a variable reflecting the electricity price level. This price variable is constructed by taking the standard price for single rate households and the peak-hour rate for two-part rate households. This variable is included as a proxy for the electricity price in the specifications of the electricity pricing decision, the natural gas demand and the water demand.

From a different source (CBS, 1995a), we obtained data on outside temperature.[16]

Our sample consists of pooled cross sections which implies that households appear only once. As a consequence, individual effects cannot be included in the econometric model. We estimate demand equations for different types of households. We distinguish eight different household types, which are mutually exclusive, based on characteristics, such as age, marital status, and the presence of children. Table 4.5 presents the household types.

4.5 Estimation results

This section presents the results of the estimation procedures for the demand equations. In the specifications, we used logarithms of consumption, prices and income, so that the parameters for prices and income can be interpreted as elasticities. These elasticities are short-run elasticities and we assume that the

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[16] The temperature data are seasonal averages and ignore regional differences.

durable stock is fixed in the short run. In this section we discuss the results for the demand for natural gas, including the insulation dummies, the demand for electricity, including the electricity pricing decision, and the demand for water. Finally, we discuss elasticities disaggregated by household types.

4.5.1 Natural gas

Table 4.6 shows the estimation results for natural gas. The price and income elasticities are significant. The own-price elasticity is -0.324, which is somewhat less than to the result of Booij *et al.* (1992). The income-elasticity is low, 0.132, which means that natural gas is a necessary good. The cross-price elasticity with electricity is negative but insignificant. Note that there is still an autonomous annual decline in natural gas consumption. On average, the natural gas consumption declined with 2.5 percent. This may point at an increasing environmental awareness (note that insulation variables have been included).

The average seasonal outside temperature affects the natural gas consumption negatively, as expected, since natural gas is mainly used for space heating.[17] The coefficient for Winter temperature is -0.033, which implies that if the average temperature is one degree higher in the Winter, the natural gas consumption declines by 3.2 percent. A similar effect was found for Autumn, while the decline in Spring would be 1.8 percent. The effect for Summer is not significant. Unlike water heating and cooking, which are required throughout the year, space heating is hardly required in the Summer.

The results show that there are scale effects with respect to the number of persons within the household. The natural gas consumption of a two-persons household is 17 percent higher than for a single person household. If the household consists of two persons and a third person is added, the consumption increases only 9 percent: if the household size increases, the additional natural gas consumption declines. The presence of young children (younger than 12 years) has no significant effect on the natural gas consumption. The presence of children aged 12 years or older diminishes the natural gas consumption, perhaps because households with older children are more likely to be away from home.

Furthermore, on the one hand there are a number of positive effects. For instance, 'older' households consume more natural gas, probably because of higher temperature settings. Also, if the head of the household is unemployed

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[17] According to our sample, households mainly use natural gas for space heating (98 percent), cooking (75 percent) and water heating (65 percent). In 1993, more than 75 percent of the natural gas consumption was used for space heating (EnergieNed, 1994).

or retired, the household tends to consume more. Obviously the presence of a bath increases natural gas consumption. Dwelling owners, 60 percent of the households in the sample, tend to consume more (7 percent). This probably reflects a size effect: owned dwellings are generally larger than rented dwellings. Households with detached dwellings, which have a larger total wall surface area exposed to open air than semi-detached dwellings, consume more too (24 percent). On the opposite, households living in flats consume less (28 percent). The year of construction of the dwelling has also a positive effect on the natural gas consumption. Households living in dwellings built before 1980 consume significantly more natural gas. The year of construction reflects particular building characteristics within categories of dwellings which are not included in the other variables. These characteristics are the size of the dwelling (number of rooms), composition of rooms and space of rooms. Since the 1970s, there is a tendency towards more compact dwellings; for instance, rooms are smaller in terms of space and kitchen and living room are often integrated. Remarkably, households using natural gas for cooking tend to consume less (2.8 percent), a result which is not easily explained. On the other hand there are also negative effects of which insulation is the most important one; see table 4.7.[18]

Insulation

Natural gas is the most important energy input for space heating. To regulate their demand for space heating, households equip their dwellings with different types of insulations, such as double glazing, wall insulation, floor insulation and roof insulation. The decision of placing an additional insulation type is primarily a trade-off between purchasing costs and lower operating or energy costs in the future. By placing a second type of insulation in the dwelling, there will be negative scale effects on the reduction of the household's natural gas consumption. In other words, the interaction effect of two insulation types will be positive. In particular, the total effect of two insulation types is less than the sum of the marginal effects of both insulation types. Therefore, we included dummies for the presence of particular combinations of insulation types in the

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[18] One explanation for the positive effects of the joint presence of insulation types on the demand for natural gas might be the endogeneity of the insulation variables. In that case we shoud either estimate the demand for natural gas and the demand for insulation types simultaneously, or we should estimate the demand for natural gas with an Instrumtal Variables technique. However, due to the lack of identifying variables (which can be used as instruments) in our sample, we were not able to estimate neither demands simultaneously nor to use instruments for the demand for insulation types.

Table 4.6: *Estimation results of the demand for natural gas and water (absolute t-values in parentheses)*

Variable names	Natural gas[a]	Water
Intercept	7.884 (48.57)	2.652 (20.48)
LOG of natural gas price	-0.324 (13.03)	0.074 (3.984)
LOG of electricity price level	-0.010 (0.457)	0.013 (0.684)
LOG of water price	-0.064 (7.481)	-0.070 (9.373)
LOG of income	0.132 (14.11)	0.113 (13.72)
Trend	-0.025 (19.84)	-0.001 (9.862)
Two persons	0.155 (13.58)	0.538 (47.11)
Three persons	0.231 (14.89)	0.793 (52.45)
Four persons	0.238 (13.85)	0.927 (55.47)
Five persons	0.264 (12.51)	1.032 (51.66)
Six persons	0.313 (10.98)	1.131 (43.26)
More than six persons	0.232 (6.183)	1.274 (37.64)
Children younger than 6	0.013 (1.098)	-0.018 (1.836)
Children 6-11	-0.013 (1.334)	-0.020 (2.387)
Children 12-17	-0.029 (2.730)	0.045 (4.865)
Children 18 and older	-0.035 (2.989)	0.043 (4.102)
Age	0.005 (15.91)	-0.001 (3.393)
Employed	-0.049 (3.516)	-0.005 (0.391)
Retired	-0.062 (4.156)	-0.049 (3.401)
Unemployed	-0.055 (3.386)	0.001 (0.090)
Partner works	-0.036 (4.764)	-0.037 (5.573)
Education level 21	0.001 (0.151)	0.033 (4.453)
Education level 22	-0.026 (2.647)	0.039 (4.677)
Education level 31	-0.011 (1.096)	0.21 (2.312)
Education level 32	0.052 (3.459)	0.044 (3.284)
No washing machine		-0.142 (10.59)
Tumble dryer		0.057 (8.595)
Dishwasher		0.067 (8.169)
Non-detached dwelling	0.218 (25.38)	0.060 (7.969)
Flat or apartment	-0.245 (23.83)	-0.086 (10.36)
Farm house	0.180 (9.212)	0.141 (8.344)
Other type of dwelling	0.014 (0.525)	-0.092 (3.822)
Built before 1944	0.195 (16.87)	
1945-59	0.131 (10.53)	
1960-69	0.125 (10.77)	
1970-79	0.165 (15.42)	

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Table 4.6: *Estimation results of the demand for natural gas and water, continued*

Variable names	Natural gas	Water
Home ownership	0.068 (9.662)	0.013 (2.142)
Bath	0.062 (9.714)	0.066 (11.89)
Joint Space Heating system	-1.817 (101.4)	
SH with natural gas	0.132 (17.70)	
Central Heating system	0.256 (30.61)	
Hot water boiler		0.026 (3.898)
Hot water CH		0.047 (5.988)
Cooking with natural gas	-0.028 (3.091)	
Double glazing	-0.054 (3.796)	
Wall insulation	-0.092 (5.813)	
Roof insulation	-0.079 (5.252)	
Floor insulation	-0.118 (7.468)	
Winter temperature in °C	-0.033 (12.58)	-0.004 (1.722)
Spring temperature in °C	-0.018 (3.595)	0.011 (2.543)
Summer temperature in °C	0.006 (1.425)	-0.022 (5.873)
Autumn temperature in °C	-0.035 (7.053)	0.032 (7.722)
Number of observations	28,210	28,210
Adjusted R^2	0.55	0.49

[a] Insulation variables are included. The results are shown in table 4.7.

demand equation for natural gas. By including interaction dummies for the presence of more than one insulation type in the demand equation for natural gas, we can determine the marginal effects of the different insulation types. Table 4.7 shows the total and marginal effects of the presence of insulation types. The total effects in percentages, given a particular stock of insulation types, are shown in the first column, and these are all significantly negative, which implies that if there is any kind of insulation is present in a household's dwelling, its natural gas consumption is less. For instance, if double glazing is present, the natural gas consumption decreases with 5.4 percent.[19]

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[19] If the dummy variable is equal to one, the change in consumption is (e^{β}-1)*100% with β the coefficient estimated.

Table 4.7: *The total and marginal effects (in percentages) in natural gas consumption given the insulation stock present*

Insulation stock	Share of hh	total effect	Additional insulation			
			double glazing	wall	roof	floor
no insulation	29.7	-	-5.3**	-8.8**	-7.6**	-11.1**
double glazing	5.4	-5.3**	-	-5.9**	0.3	-1.7
wall	4.1	-8.8**	-2.4	-	-1.7	-3.2
roof	4.9	-7.6**	2.6	-3.0$^{\#}$	-	-2.9
floor	4.6	-11.1**	4.1$^{\#}$	-0.9	0.7	
double glazing and wall	3.3	-11.2**	-	-	1.8	6.8*
double glazing and roof	2.0	-5.0*	-	-4.4$^{\#}$	-	-3.5
double glazing and floor	1.9	-7.0**	-	2.5	-1.5	-
wall and roof	6.7	-10.5**	1.1	-	-	-0.9
wall and floor	2.8	-12.0**	7.6**	-	0.6	-
roof and floor	3.3	-10.4**	1.9	-1.0	-	-
double glazing, wall and roof	4.6	-9.4**	-	-	-	4.7
double glazing, wall and floor	2.2	-4.4*	-	-	-0.3	-
double glazing, roof and floor	1.6	-8.5**	-	3.8	-	-
wall, roof and floor	11.3	-11.4**	6.7*	-	-	-
all four types	11.7	-4.7**	-	-	-	-

** significant at 1 percent level, * significant at 5 percent level, and $^{\#}$ significant at 10 percent level.

The total effect of the presence of two insulation types is less than the sum of the marginal effects. For instance, the natural gas consumption decreases with 11.2 percent if double glazing and wall insulation are present, while the marginal reductions are 5.4 percent and 8.8 percent respectively. Column 3 to 6 of table 4.7 presents the marginal effects of adding an insulation type to the initial insulation stock. Adding a new type to the initial stock is not always profitable. For instance, the effects of adding double glazing to a particular insulation stock (with at least one type of insulation) are significantly positive in most cases, as the third column of table 4.7 shows. This implies that the natural gas consumption increases, despite the negative marginal effect of double glazing. In particular, the positive interaction effect of double glazing given the insulation stock present is larger than the absolute value of the negative marginal effect of double glazing. Note that due to an extra insulation type, the marginal costs of space heating decline, so that the demand for space heating increases.

An explanation for the relatively high positive interaction coefficients might be due to misspecification of the model. Large dwellings, for instance, require a lot of space heating and consequently they require a lot of energy. Large dwellings are therefore more likely to have several types of insulation; the presence of insulation types and the characteristics of the dwelling (such as volume of the dwelling) are positively correlated. Thus, if the dwelling characteristics are not properly included in the model, the (interaction) effects of the insulation types are likely to be biased. In our analyses we were not able to include the size of the dwelling. Another possible explanation for the relatively high positive interaction coefficients is that households may become more negligent towards their demand for space heating by the presence of an extra insulation type.

4.5.2 Electricity

The estimation procedure consists of two stages. In the first stage a probit model is estimated, and in the second stage the conditional electricity demand equations including the correction terms are estimated with OLS.

The first column of table 4.8 shows the results for the decision equation in which the parameters represent the effect a variable has on the probability to choose the two-part electricity rate. The electricity price level and income show significantly positive estimates, which implies that higher prices and income induce a higher probability of choosing the two-part tariff. The probability is positively affected by the number of persons in the household. Furthermore, the probability is larger if households are older, or if the partner of the head of the household is employed. If the household head is either unemployed or retired, households are less likely to choose the two-part rate.

Obviously, there are some dwelling characteristics which affect the probability. Households with detached dwellings and farms are more likely to choose the two-part tariff. Only households with dwellings built in the 1970s have a lower probability of choosing the two-part tariff. A similar result was expected for household with older dwellings. In older dwellings a double meter, necessary for two-part tariff, is often not present. Then, the transaction costs

Table 4.8: *Estimation results of the tariff choice and the demand for single rate electricity, peak demand electricity and off-peak demand electricity (absolute t-values in parentheses)*

Variable names	Choice for	Electricity		
	two-part rate	Single rate	Off-peak-hour	Peak-hour
Intercept	-6.509 (20.81)	6.314 (20.35)	3.645 (7.550)	6.847 (17.31)
LOG of natural gas price		-0.039 (2.036)	-0.526 (7.936)	0.127 (2.839)
LOG of single electricity rate	1.123 (21.68)	-0.048 (1.090)		
LOG of peak-hour rate			0.828 (7.402)	-0.173 (2.085)
LOG of off-peak-hour rate			-0.296 (4.780)	-0.025 (0.605)
LOG of water price		-0.046 (5.973)	0.157 (7.198)	-0.164 (9.047)
LOG of income	0.153 (6.170)	0.124 (11.13)	0.213 (8.944)	0.134 (6.456)
Two persons	0.059 (1.670)	0.284 (22.90)	0.213 (6.806)	0.281 (10.75)
Three persons	0.180 (4.002)	0.420 (25.36)	0.337 (8.154)	0.482 (14.32)
Four persons	0.180 (3.652)	0.488 (27.53)	0.380 (8.784)	0.562 (15.62)
Five persons	0.254 (4.235)	0.545 (25.19)	0.413 (7.817)	0.671 (15.42)
Six persons	0.325 (4.047)	0.591 (20.58)	0.393 (5.714)	0.692 (12.07)
More than six persons	0.543 (5.214)	0.669 (17.00)	0.635 (6.730)	0.922 (12.86)
Age	0.005 (4.896)	0.001 (3.394)	0.004 (4.020)	0.003 (4.449)
Dummy variables				
Children younger than 6 present	0.003 (0.089)	-0.002 (0.203)	0.056 (2.220)	-0.044 (2.229)
Children between 6-11 present	-0.054 (1.995)	-0.002 (0.306)	-0.001 (0.054)	-0.049 (2.858)
Children between 12-17 present	-0.058 (1.950)	0.025 (2.687)	0.023 (1.103)	-0.014 (0.772)
Children older than 18 present	-0.084 (2.546)	0.022 (2.003)	0.016 (0.597)	-0.035 (1.549)
Employed	-0.023 (0.565)	-0.002 (0.171)	0.006 (0.189)	0.003 (0.105)
Retired	-0.116 (2.646)	-0.064 (4.091)	-0.045 (1.209)	-0.069 (2.268)
Unemployed	-0.167(3.458)	0.002 (0.090)	-0.067 (1.564)	-0.014 (0.421)
Partner works	0.011 (0.521)	-0.022 (3.145)	-0.030 (1.737)	-0.034 (2.462)
Education level 21		0.001 (0.187)	-0.022 (1.133)	-0.008 (0.548)
Education level 22		-0.032 (3.639)	-0.034 (1.519)	-0.035 (1.986)
Education level 31		-0.051 (5.537)	-0.064 (2.822)	-0.044 (2.480)
Education level 32		-0.049 (3.112)	0.014 (0.470)	-0.021 (0.843)
Freezer present	0.087 (4.981)	0.191 (30.14)	0.127 (8.436)	0.195 (16.34)
No washing machine present		-0.198 (10.39)	-0.76 (1.704)	-0.132 (3.864)
Tumble dryer present	0.180 (8.588)	0.169 (17.68)	0.198 (9.681)	0.174 (10.18)
Dishwasher present	0.261 (10.18)	0.191 (14.67)	0.232 (8.552)	0.224 (10.65)
Non-detached	0.009 (0.375)	0.049 (5.687)	0.029 (1.582)	0.152 (10.13)
Flat apartment	0.054 (1.986)	-0.061 (6.170)	-0.077 (2.990)	-0.124 (6.040)
Farm house	0.748 (13.44)	0.085 (1.960)	0.253 (3.058)	0.321 (4.797)
Other type of dwelling	0.200 (2.686)	0.174 (4.275)	0.059 (0.834)	0.280 (4.215)
Before 1944	-0.002 (0.051)			
1945-59	0.036 (1.074)			
1960-69	0.085 (2.733)			
1970-79	-0.105 (3.627)			

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Table 4.8: *Estimation results of the tariff choice and the demand for single rate electricity, peak demand electricity and off-peak demand electricity continued*

Variable names	Choice for	Electricity		
	two-part rate	Single rate	Off-peak-hour	Peak-hour
Home ownership	0.009 (0.453)	0.016 (2.616)	0.001 (0.088)	0.027 (2.161)
Central heating system		0.205 (27.42)	0.064 (3.204)	0.087 (5.506)
Hot water boiler	0.705 (35.44)	0.032 (1.320)	0.242 (4.377)	0.216 (5.089)
Combined WH/SH		-0.032 (4.715)	-0.008 (0.408)	-0.049 (2.985)
Electric water heating		0.102 (4.713)	0.602 (25.55)	0.095 (5.166)
Cooking with electricity	0.423 (5.58)	0.173 (9.536)	0.213 (5.524)	0.248 (7.797)
Winter temperature		-0.004 (1.826)	-0.024 (3.805)	0.019 (3.842)
Spring temperature		-0.0001 (0.014)	-0.005 (0.415)	-0.031 (3.558)
Summer temperature		0.001 (0.335)	0.062 (6.716)	-.006 (0.827)
Autumn temperature		-0.005 (1.090)	-0.55 (5.423)	-0.016 (1.895)
Trend	0.025 (9.924)	-0.001 (0.948)	-0.005 (1.374)	-0.012 (4.511)
Correction term		0.012 (0.241)	0.507 (3.923)	0.428 (4.202)
Likelihood	-15,777			
LR test χ^2_{28}	3,786.7			
Adjusted R^2	0.55	0.41	0.24	0.35
Number of observations	28,210	19,201	9,009	9,009

when changing to two-part tariff are higher, because a double meter has to be installed as well. These double meters are present in recently built dwellings which is the reference group in the sample. But the results show that households with older dwellings have similar probabilities of choosing two-part rate than households with new houses. Finally, the presence of durable appliances, such as a boiler, freezer, dishwasher and tumble dryer increases the two-part rate probability. Also, the significantly positive coefficient of the trend indicates that annually the probability of choosing the two-part rate increases.

Single tariff

The sample of single rate households is approximately two-third of the whole sample. The own-price elasticity of single demand is -0.05 and insignificant, while the income elasticity is 0.12. The cross-price elasticity with natural gas is negative, -0.04. Furthermore, it is surprising that all four temperature parameters are insignificant. Thus, temperature does not affect electricity consumption in case of single tariff which does not correspond to findings in the literature. For instance, Henley and Peirson (1997) found a nonlinear relationship between temperature and electricity consumption. In the Netherlands, however, electricity is rarely used for space heating or for air conditioning.

The family size results indicate that there are scale effects. Although electricity consumption increases with family size, the marginal effect of the family size on electricity consumption declines if the family size increases. On average, the marginal effect of the second person is an increase of 33 percent, while the marginal effect of a third person is only an increase of 14 percent. Note that this is 14 percent with respect to the electricity consumption of the two-person household. The presence of young children has no particular effect, while the presence of children aged 12 and older increase the electricity consumption. The single person households consume less than more person households. The 'older' the household, the more it consumes, but the effect is small.

Households with detached dwellings consume more electricity, while households living in a flat consume less than the reference group. Trivially, the presence of freezer (21 percent), tumble dryer (18 percent) and dishwasher (21 percent) have significantly positive effects. If the cooking fuel is electricity, the electricity consumption is higher (19 percent), while the presence of a boiler has no effect. Note however that 14 percent of the households choosing the standard tariff have a boiler for hot water, while over 38 percent of the households choosing the two-part tariff do have a hot water boiler.

The correction term coefficient is positive but insignificant. This implies that the hypothesis of a zero covariance between the disturbances of the single demand equation and the decision equation cannot be rejected.

Two-part tariff

Households choosing the two-part electricity rate face a peak and an off-peak demand for electricity with different marginal prices. Both these demands are rather price elastic compared to the demand for single rate electricity. For the peak demand equation the own-price elasticity is -0.173, while the cross-price elasticity with the off-peak-hour rate is insignificant. For the off-peak demand, the own-price elasticity is -0.296, while the cross-price elasticity of the peak-hour rate is significantly positive: 0.828. The results imply that if electricity prices increase, households reallocate their electricity consumption from peak-hours to off-peak-hours. For instance, suppose that both electricity rates are increased with 10 percent. Then, the off-peak demand will increase with 5.3 percent, while the peak demand will decrease with 1.7 percent. In case of the off-peak demand, the own-price elasticity is outweighed by the peak-hour rate cross-price elasticity. For the mean values of peak and off-peak electricity consumption in the DBO sample, this implies that the electricity consumption of households with the two-part rate would even increase. This is a rather implausible result, which suggests possible misspecification of the econometric model.

These estimates are also substantially higher than the estimates reported by Booij *et al.* (1992) which estimated an aggregated demand for two-part electricity rate households (approximately -0.15). The sign of the cross-price effects of TOU rates on the other demands is theoretically undetermined. On the one hand, Filippini (1995) reported positive cross-price elasticities for Switzerland. According to his results, a 10 percent increase in both rates implies a 3 percent increase in the peak demand increases and a 3.9 percent decline in the off-peak demand; see table 4.2. These results are opposite to our findings. On the other hand, Aubin *et al.* (1995) reported negative cross-price elasticities, which means that in the case of price increases, the decline of both electricity demands is strengthened by cross-price effects.[20]

The off-peak electricity demand is more income elastic than the peak demand. The income elasticities are 0.134 and 0.213 for peak and off-peak demand respectively. The income effect of total electricity consumption is just the weighted average of both elasticities values. The weights are the levels of the separate electricity consumptions. Remarkably, the cross-price effect of natural gas on the off-peak electricity demand is significantly negative, -0.562, while the similar effect on the peak demand is positive, 0.127. Electricity consumption at peak-hours and natural gas consumption are substitutes, while the opposite holds for electricity demand at off-peak-hours and natural gas. SCP (1993) reported a negative cross-price effect of natural gas on electricity consumption. The cross-price elasticity of tap water is opposite for peak and off-peak demand but the effect on the total electricity consumption is negligible. The peak demand annually declines with 1.2 percent on average. However, the off-peak demand does not exhibit such a trend.

4.5.3 Water

Table 4.6 shows the estimation results of the water demand equation. The price elasticity is significantly negative, but the absolute value is low. In particular,

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[20] Aubin *et al.* (1995) analyzed a more elaborated version of TOU pricing by experiment. First of all, households participating in the experiment did not have any other option for electricity pricing. Secondly, the TOU pricing consists of six different rates. There were distinguished three different days and two different periods during the day. Finally, an income effect was not included in the analysis.

a 10 percent increase in the water price induces a 0.7 percent decrease in the water consumption.[21] This estimate is somewhat smaller than the result of Kooreman (1993), who found a price elasticity of -0.10, and SCP (1993) that reported elasticities in a range from -0.09 to -0.19 depending on the number of household members. SCP also estimated the income elasticity, which was similar to results we report here: 0.11.

Besides economic aspects, average seasonal temperature play a role in water consumption. The results show that higher average temperatures in Spring and Fall increase the water consumption. The temperature level in Winter does not affect the water consumption, while in Summer the water consumption decreases with higher average temperature. This is surprising, because a positive effect seems plausible: the higher average temperature, the higher water consumption. Probably, this effect includes a vacation effect, as most households are on holiday in the Summer. With respect to family size, the water consumption shows scale effects.

The latter group of determinants relates to dwellings. The type of dwelling is partially related to the presence of a garden. A flat usually has no garden. The results therefore are not surprising. Tenants of a flat or households living above a store consume less, while households living in a detached dwelling or farmers consume more. The ownership of a dwelling has an increasing effect on the water consumption. Furthermore, the water consumption is increased by presence of a bath, dishwasher and tumble dryer. The absence of a washing machine, which is the case for 4 percent of the households in the sample, has a negative effect on the water consumption.

4.5.4 Different household types

The responses of households in terms of energy and water consumption with respect to price and income changes may differ widely. For instance, in their study for the UK, Baker *et al.* (1989) presented elasticities for natural gas and electricity disaggregated by household types. They report own-price elasticities for natural gas demand ranging from -0.444 to -0.117 and electricity demand ranging from -0.797 to -0.540. The income elasticities range from 0.012 to 0.211 for natural gas and -0.172 to 0.263 for electricity. From their results we

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[21] Although the absolute value of the water price elasticity is low, 0.07, a price change may have substantial changes in physical terms. At an average water price of 135 cents per m^3 and at an average water consumption of 130 m^3, a 10 percent price increase (i.e. 13.5 cents) implies a reduction of 0.91 m^3, which is 910 liters.

can conclude that high income households have negative income elasticities; electricity is an inferior good. Own-price and income elasticities decline with household income. Older households hardly respond to income changes, while households with children have relative high responses to income changes and price changes. Table 4.9 presents price and income elasticities for eight different household types in the Netherlands.

The own-price elasticity of natural gas is significant within the range of -0.185 and -0.435. Particularly, the results suggest that the demand of relatively younger households is more sensitive to price changes. Except for younger couples without children, all income elasticities are significant and within a range of 0.105 to 0.216.

The results of the disaggregated price and income effects on single rate electricity demand are diverse. For instance, the demand of the household types with a single electricity rate is hardly affected by its marginal price. Only young couples without children (type 5) and households with only older children (type 7) show significant elasticities, respectively -0.168 and -0.192. The single rate demand changes with income changes for older single persons, single parents, older couples without children, and couples with either younger or older children (types 1, 3, 4, 6, and 7).

In the case of households with the two-part electricity rate, the responses to price and income also differ widely for different households types. The own-price elasticity of the off-peak demand is significantly negative for younger singles (type 2) -0.914, younger couples (type 5) -0.490, couples with older children (type 7) -0.370, and couples with both younger and older children (type 8) -0.596. For all four subsamples, the off-peak demand is more elastic than for the whole sample. The peak-hour rate cross-price elasticity is only significant positive for the three household types including couples with children.

Young singles (type 2) have a relatively high own-price elasticity for their water consumption but their demand for water does not respond to changes in income changes. Older singles (type 1) and single parent households (type 3) have relatively small own-price elasticities. Single parent households have high income elasticities as well as households with older children.

Single person households seem to be indifferent for price changes, while only older single person households respond to income changes on the off-peak demand (0.186). Single parent households slightly change their peak consumption, if their income changes (0.035).

Table 4.9: *Price and income elasticities for different household types*

	All	singles		single	couples
Demand		old^{a}	young^{b}	parents	old^{a}
Price and income		1	2	3	4
Natural gas					
Natural gas	-0.324**	-0.187$^{\#}$	-0.384**	-0.435**	-0.200**
Electricity	-0.010	0.046	-0.239$^{\#}$	0.063	-0.065
Water	-0.064**	-0.005	-0.007	-0.038	-0.059**
Income	0.132**	0.129**	0.105$^{\#}$	0.109**	0.216**
Electricity (single rate)					
Natural gas	-0.039*	0.056	-0.040	0.168$^{\#}$	-0.014
Electricity	-0.048	0.100	0.017	-0.034	-0.032
Water	-0.046**	-0.050	-0.022	-0.010	-0.070**
Income	0.124**	0.121**	0.059	0.219**	0.168**
Electricity (off-peak)					
Natural gas	-0.562**	-0.190	0.069	-0.245	-0.275*
Off-peak electricity	-0.296**	-0.299	-0.914*	-0.372	-0.176
Peak electricity	0.828**	0.352	0.154	-0.161	0.281
Water	0.157**	0.244**	0.070	0.202$^{\#}$	0.127**
Income	0.213**	0.186**	0.206	0.130	0.098*
Electricity (peak)					
Natural gas	0.127**	-0.078	-0.046	0.005	0.156**
Off-peak electricity	-0.025	-0.062	-0.267	0.110	0.120*
Peak electricity	-0.173*	-0.255	0.059	-0.537	-0.885
Water	-0.164**	-0.085	-0.294*	-0.095	-0.144
Income	0.134**	0.104	-0.299	0.035**	0.192**
Water					
Natural gas	0.074**	0.057	0.061	0.060	0.042
Electricity	0.013	0.009	0.071	-0.076	0.038
Water	-0.070**	-0.040	-0.120*	-0.041	-0.070**
Income	0.113**	0.069*	-0.012	0.285**	0.150**

** significant at 1 percent level, * significant at 5 percent level, and $^{\#}$ significant at 10 percent level.

[a] The head of the household is at least 45 years old.

[b] The head of the household is younger than 45 years.

Table 4.9: *Price and income elasticities for different household types continued*

Demand	All	couples	couples with children		
		young[b]	young[c]	old[c]	both[c]
Price and income		5	6	7	8
Natural gas					
Natural gas	-0.324**	-0.435**	-0.336**	-0.185**	-0.186**
Electricity	-0.010	-0.043	-0.042	-0.003	-0.038
Water	-0.064**	-0.113**	-0.079**	-0.088**	-0.061*
Income	0.132**	0.019	0.130**	0.142**	0.203**
Electricity (single rate)					
Natural gas	-0.039	-0.089$^{\#}$	-0.058*	0.029	-0.053
Electricity	-0.048**	-0.168*	-0.014	-0.192	0.110
Water	-0.046**	-0.012	-0.051**	-0.058**	-0.056*
Income	0.124**	0.004	0.077**	0.153**	0.173
Electricity (off-peak)					
Natural gas	-0.562**	-0.397*	-0.682**	-0.300**	-0.306$^{\#}$
Off-peak electricity	-0.296**	-0.490**	-0.075	-0.370**	-0.596**
Peak electricity	0.828**	0.433$^{\#}$	0.684**	0.670**	0.984**
Water	0.157**	0.325**	0.062	0.189**	0.152*
Income	0.213**	0.248**	0.176**	0.113	0.163*
Electricity (peak)					
Natural gas	0.127**	-0.127	0.023	0.402**	0.159
Off-peak electricity	-0.025	-0.246**	0.108	-0.229*	0.065
Peak electricity	-0.173*	-0.014	-0.386	-0.388*	-0.468$^{\#}$
Water	-0.164**	-0.249**	-0.198**	-0.090*	-0.167**
Income	0.134**	0.091	0.078	0.103	0.134**
Water					
Natural gas	0.074**	0.155**	0.105**	0.041	0.074
Electricity	0.013	-0.086$^{\#}$	0.061$^{\#}$	-0.002	0.067
Water	-0.070**	-0.070**	-0.076**	-0.072**	-0.093**
Income	0.113**	0.032	0.129**	0.183**	0.204**

** significant at 1 percent level, * significant at 5 percent level, and $^{\#}$ significant at 10 percent level.

[a] The head of the household is at least 45 years old.

[b] The head of the household is younger than 45 years.

[c] 'Young' =children aged from 0 and 12 present, 'old' = children aged from 12 to 18 present and 'both' = both young and old children present.

4.6 Conclusions

In this Chapter we estimated the household demand equations for natural gas, electricity and water. The own-price elasticities for natural gas were within the range found in earlier studies for the Netherlands. Although the natural gas use increased with family size, there are scale effects with respect to family size. A two-person household consumed 17 percent more natural gas than a single person household, while a three-person household consumed 9 percent more than the two-person household. The natural gas consumption declined with 2.5 percent annually.

A remarkable finding was the effect of different insulation types on the natural gas consumption. Although the total effect of insulation stocks on the natural gas demand was at least a 4.4 percent reduction, the effect of adding an insulation type was diverse. For instance, placing double glazing was only profitable if there was wall insulation present; in any other case the (negative) marginal effect of double glazing was outweighed by (positive) interaction effects. The relatively high positive interaction coefficients suggest that households become more negligent towards their demand for space heating by the presence of an extra insulation type.

In case of the electricity demand the electricity pricing options (either the single or two-part rate) were explicitly modelled and estimated. The probability of choosing the two-part rate was positively affected by income, electricity price level, family size and the presence of electricity-using appliances.

The own-price elasticity of single rate electricity demand was insignificant, while the income elasticity is rather low (-0.12). Furthermore, there was no relationship found between the electricity consumption and the average seasonal temperatures. As with the natural gas demand, there were family size scale effects. Also, the effects of durable appliances on electricity demand are substantial.

The own-price effects of the two-part electricity demands were large, and moreover, the cross-price effect of the off-peak-hour rate on the peak demand was large and positive. These results suggest that households reallocate the electricity consumption in the case of electricity price changes.

The estimates of the household water demand elasticities were similar to the results of earlier studies. The demand is rather price and income inelastic. The water consumption increased with family size, although there are scale effects with respect to family size.

The estimates of prices and income elasticities of the demands for energy and water differed across household types. These differences are reflected in the significance and magnitudes of the elasticities. Particular households respond more to income changes while other households respond more heavily to price changes. For instance, the energy and water consumption of older single person households only respond to income changes. The energy and water consumption of couples with older children are sensitive to price changes with respect to their energy and water consumption. As to the magnitude of elasticities, the response to price changes of 'young' households without children is larger than with children.

Based on our findings we conclude that an energy tax is a helpful instrument to reduce the energy consumption. Since 1996, a reimbursed ecotax has been introduced in the Netherlands in order to regulate the energy consumption. Households pay a tax on the natural gas price as well as on the electricity price and there is a reimbursement via a lower income tax rate.[22] Since the income tax rate decline is rather small the increase due to the income increase is rather small. According to our findings the natural gas consumption will decline. In the case of electricity, the final effect is more complicated to determine, since households may switch electricity pricing regime.[23] If households maintain the single rate, the electricity consumption will decline. If households maintain the two-part rate, the electricity consumption is reallocated from peak-hours to off-peak-hours and the total electricity consumption is ambiguous. Finally, households switch from the single rate to the two-part rate. In that case the effect on the electricity consumption is ambiguous as well. On the one hand the electricity consumption will decline due to higher electricity prices at peak hours, higher fixed fees and transaction costs, and on the other hand the electricity consumption will increase due to sharply declining electricity prices at off-peak hours and lower income taxes. Except the electricity price decline at off-peak hours the changes are probably minor.[24] In addition, according to our findings on elasticities for electricity consumption, households switching regimes are likely to increase their electricity consumption.

Although we assumed that the durable stock was kept constant the energy tax increases the probability that households choose the high-efficiency version

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[22] In the Netherlands individuals face a block income tax rate; the higher the income the higher the tax rate. Only the smallest tax rate was declined.

[23] The transaction costs of switching are rather low.

[24] In the two-part regime, the electricity price at off-peak hours is approximately half the electricity price at peak hours. The single rate is approximately the peak-hour rate.

of a consumer durable; see Chapter 3. As a consequence, energy and water consumption decline through the more energy-efficient durables in the household, although this decline is partly off-set by a *take-back effect* (cf. section 3.3.5).

From an energetic point of view an energy tax seems ineffective with respect to the electricity consumption of households with the two-part electricity rate. According to our findings their electricity consumption does not decrease due to price increases, as it is reallocated between peak hours and off-peak hours. It should be noted, however, that the two-part rate has been introduced by the electricity producing companies to improve load management by smoothing the fluctuations in the demand for electricity throughout the day; see Chapter 2.[25] The decline in the peak demand results in a more efficient production of electricity throughout the day. Since there is still a large discrepancy in the daily total electricity demand at peak and at off-peak hours, the increment in household electricity consumption at off-peak hours is therefore acceptable in energetic terms.

Based on the price elasticities estimated we conclude that a tax on energy and water prices is an effective instrument to reduce – or regulate as in the case of electricity – the consumption of energy and water. However a tax is not sufficient. Information about how to change the current behavior should be available as well. Furthermore, after doing energy-saving investments, the household behavior should not become negligent. An example is the insulation presence and the natural gas consumption; see table 4.7. In this case, higher energy prices encourage households to purchase insulation; Booij *et al.* (1992) report positive effects of the energy price effects on the presence of insulations. The presence of – more than one type of – insulation, however, is often not sufficient to reduce natural gas consumption; in fact the natural gas consumption may increase.

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[25] The capacity of electricity production is determined by the peaks in demand, and the production process is a rigid and continuous process with little or no possibilities for stockpiling.