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Changes in the Pattern of Household Electricity Demand over Time

Abstract:
Empirical estimates of long run effects on residential electricity demand from changes in the electricity price are usually estimated by cross-sectional variation in the current stock of electric household appliances across households at a certain point in time. Here, we use a discrete-continuous approach modeling the long run effects by investments in new appliances. We apply the annual Norwegian Survey of Consumer Expenditure for the period 1975 to 1994 to estimate the short and long run own price elasticities in the two approaches. We find the estimated long run elasticity only slightly more price elastic than the short run. We also find that the long run elasticity does not differ significantly between the two approaches. The reason for both results is that, since there is no alternative source of energy for these appliances, there are no substitution effects.

Keywords: Residential electricity consumption, household production, dynamic analysis, micro data

JEL classification: D13.

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1. Introduction

Analyses of the sensitivity of residential electricity demand with respect to price changes may give the authorities important information on the potential for regulation of residential energy use. The characteristics of residential electricity demand, as derived from the household's production of services, give rise to a number of modeling options applying either data of individual household behavior or macro data. Recent examples of macro data applications are Chang and Hsing (1991), Hsing (1994), and Haas *et al.* (1998). When applying micro data, reduced-form static models are one of the most commonly used approaches (see e.g. Parti and Parti 1980, Baker and Blundell 1991, and Branch 1993). These models focus on the utilization of a given stock of electric household appliances. A shortcoming of this approach is the lack of dynamic adjustments of electricity consumption appliances. It ignores that households may alter their stock of electric appliances due to changes in the electricity price, which will influence their future consumption of electricity. Several studies model these dynamic properties of the residential electricity demand based on cross-sectional household data to elicit both the short and long run effects of price changes (see e.g. Hausman 1979, Dennerlein 1987, Wilder *et al.* 1992 and Bernard *et al.* 1996). Two of the most influential studies from this tradition are McFadden, Puig and Kirshner (1977), and Dubin and McFadden (1984). They apply a discrete-continuous micro-econometric approach where the short run price elasticities are derived from an appliance utilization model. They then deduce the long run elasticities from the sum of the utilization rate elasticities and the appliance saturation demand elasticities. All these models use cross-sectional variations in the current stock of electric household appliances and the current electricity price to elicit the dynamic properties of electricity consumption. In order to interpret the effect of the current electricity price on the current stock as the long run effects, assumptions must be made concerning both the household's expectation about future prices and the relationship between cross-sectional variation in the stock and investments in new appliances.

In this paper, we present an alternative to the approach in McFadden *et al.* (1977), in that we develop a two-step discrete-continuous model to estimate the utilization of the stock and the investments in new appliances. We express the dynamic property of residential electricity demand in terms of the household's investment in new appliances rather than predicting the cross-sectional differences in the current appliance stock. This is done to avoid making any assumptions about price expectations and the flow of household appliances. We also compare our estimated long run elasticity with the elasticity when applying McFadden et al.'s methodology on our data.

To identify the properties of residential electricity demand we apply data from the annual Survey of Consumer Expenditure (SCE) for Norwegian households in the period 1975 to 1994. The SCE yields information on each household's electricity consumption, the purchase of new household appliances as well as the current stock, and detailed information about household characteristics. In addition, disaggregated information about prices and temperature is available. The pooled data over the period 1976-1993 give a sample of 23,284 households.[1] We find that the estimated long run own price elasticity is only slightly more elastic than the short run elasticity, both in the pooled data and for each year. The reason is that the long run effects of changes in the electricity price on investments in new electric appliances are not significant. For the same reason, we find that the estimated long run elasticity does not differ significantly between our approach and the approach commonly used in the literature. However, we do believe that these differences will increase when alternative fuel sources are available, e.g. for space heating equipment.

[1] In the estimations, we include the leaded and lagged prices. Thus, the estimation results only cover the period 1976-93.

In the next section, we present the theoretical framework for the residential electricity demand, modeled as a household production function. We focus on the dynamic properties in the residential electricity consumption due to changes in the stock of household appliances used as input in the household's production of services. In section three, we describe the data and the econometric specification of the model. In section four, we present the results from our analysis, both the determinants of electricity consumption and the price and income elasticities for the period 1976-1993. We also compare the result from our approach with the results from the approach in McFadden *et al.* (1977). In the last concluding section, we discuss our choice of approach and plans for future research on this topic.

2. The theoretical framework

In the current literature, the individual's decision problem is often discussed in less detail, even when the econometrics is modeled carefully. We find this a problem both in the original paper by McFadden *et al*. (1977), but also in the more recent studies by Dennerlein (1987) and Bernard *et al.* (1992). In this paper, we discuss the consumer's decision problem in more detail in order to elicit the long-term effects on the residential electricity consumption due to price changes based on the household's investments in new appliances.

We start by describing the household's decision problem determining the demand for electricity and electric appliances. Then, we show how to elicit the short and long run own price elasticities from this decision problem.

2.1. The household's optimization problem

The consumption of electricity does not give the household utility *per ce*, but may rather be viewed as an input in the household's production of services. Thus, the household is assumed to derive utility (U_t) from a vector of services produced by the household ($\vec{T}_t$), and a vector of other goods ($\vec{X}_t$), given the characteristics of the household (β_t) in each period ($t = 1, .., N$):

(1) $$U_t = U_t\left(\vec{X}_t, \vec{T}_t; \beta_t\right)$$

We assume that the household's production of service *j* in period *t* (T_{jt}) is a function of the use of electricity in the production of service *j* (E_{jt}), and the appliance stock used to produce the service (A_{jt}). Furthermore, we assume that the production of each service only require one category of household appliances, i.e. the service produced applying a microwave oven is microwave food, not hot food. The household production function is given by:

(2) $$T_{jt} = T_{jt}\left(E_{jt}, A_{jt}; \beta_t\right)$$

The household's investment expenditures on appliance *j* (I_{jt}) is defined as the difference between the value of the current stock and the value of last years stock measured by the purchase price in a competitive market (p_{jt}), and corrected for physical capital depreciation at rate δ, i.e. $I_{jt} \equiv p_{jt}\tilde{I}_{jt} = p_{jt}\left(A_{jt} - (1-\delta)A_{jt-1}\right)$, where $\tilde{I}_{jt}$ is the purchase of new appliances.

The optimal level of household production is determined by maximizing utility with respect to the service production level and the consumption of other market goods, conditional on the minimization of production cost with respect to electricity consumption and purchases of household appliances.

2.1.1. The minimization of production costs

The household is assumed to minimize the present value of the production cost for service *j* with respect to the electricity consumption and the desired stock of appliances, discounted at an interest rate (*r*) over the expected life span of appliance *j* (q_j). This minimization is carried out subject to achieving a desired production level ($\overline{T}_{jt}$) and conditional on the electricity price (p_{Et}) and price on appliance *j* (p_{jt}), for all *j = 1, .., J+K*:

$$(3) \qquad \min_{E_{jt}, A_{jt}} \sum_{j=1}^{J+K} \left[\sum_{t=1}^{q_j} \frac{p_{Et} E_{jt} + p_{jt} \left(A_{jt} - (1-\delta) A_{jt-1}\right)}{(1+r)^{t-1}}, \qquad s.t. \quad T_{jt}\left(E_{jt}, A_{jt}; \beta_t\right) = \overline{T}_{jt} \right],$$

where *J* is the number of electric household appliances and *K* is the number of other services produced by the household that require input of electricity, e.g. space and water heating services. This minimization problem leads to the following first order conditions for the electricity consumption and the investments in new appliances, for all *j = 1, .., J+K,* and *t = 1, ..., N*:

$$(4) \qquad p_{Et} = \lambda \frac{\partial T_{jt}\left(E_{jt}, A_{jt}; \beta_t\right)}{\partial E_{jt}},$$

$$(5) \qquad \rho_{jt} \equiv p_{jt} - \left(\frac{1-\delta}{1+r}\right) p_{jt+1} = \lambda \frac{\partial T_{jt}\left(E_{jt}, A_{jt}; \beta_t\right)}{\partial A_{jt}},$$

where λ is the Lagrange multiplicator for the minimization problem, and ρ_{jt} is the user cost of capital of investing in new appliances. Solving the first order conditions with respect to the endogenous variables, using the first order condition for the Lagrange multiplicator (λ) and that $A_{jt} = \tilde{I}_{jt} + (1-\delta) A_{jt-1}$, yields the household's demand for electricity (E_{jt}) and the purchase of electrical appliances ($\tilde{I}_{jt}$). These demand functions will depend on the electricity price, the user cost of investments in new appliances, last year's appliance stock, the household production level and household characteristics, for all *j = 1,.., J+K*:

(6) $$E_{jt} = E_{jt}\left(p_{Et}, \vec{\rho}_t; \vec{A}_{t-1}, \vec{\vec{T}}_t, \beta_t\right)$$

(7) $$\tilde{T}_{jt} = \tilde{T}_{jt}\left(p_{Et}, \vec{\rho}_t; \vec{A}_{t-1}, \vec{\vec{T}}_t, \beta_t\right)$$

where variables with an arrow indicate vectors of appliances, e.g. $\vec{\rho}_t$ is a vector of user costs of appliances. We focus on the purchase of new appliances and not on the investment expenditures, since we apply the purchase variable as the dependent variable in the econometric model.

Inserting these demand functions into the service production expenses function yields the expenditure function of the household's production of service *j*: $p_{Et} E_{jt} + p_{jt} \tilde{T}_{jt} = C_{jt}\left(p_{Et}, \vec{\rho}_t; \vec{A}_{t-1}, \vec{\vec{T}}_t, \beta_t\right) \equiv C_{jt}$. We define the *unit cost* as the expenditure of producing the desired level of the service *j* (C_{jt}) divided by the level of production ($\bar{T}_{jt}$), i.e. $c_{jt}\left(p_{Et}, \vec{\rho}_t; \vec{A}_{t-1}, \vec{\vec{T}}_t, \beta_t\right) \equiv C_{jt}\left(p_{Et}, \vec{\rho}_t; \vec{A}_{t-1}, \vec{\vec{T}}_t, \beta_t\right) / \bar{T}_{jt}$.

2.1.2. The maximization of utility

We assume that the household is maximizing its utility with respect to the consumption of service *j* (T_{jt}) and market good *x* not used in any household production (X_{xt}), subject to the budget constraint restricted by the household's gross income (Y_t). Furthermore, this maximization is conditional on the price of good *x* in period *t* (p_{xt}) and on the unit cost of producing service *j* from the cost minimization problem (c_{jt}), for all *x = 1, ..., m*, *j = 1, .., J+K*, and *t = 1, ..., N*:

(8) $$\max_{T_{jt}, X_{xt}} U_t = U_t\left(\vec{X}_t, \vec{T}_t; \beta_t\right), \quad s.t. \quad Y_t = \sum_{x=1}^{m} p_{xt} X_{xt} + \sum_{j=1}^{J+K} c_{jt}\left(p_{Et}, \vec{\rho}_t; \vec{A}_{t-1}, \vec{T}_t, \beta_t\right) T_{jt}$$

This maximization problem leads to the household's demand for service j (T^*_{jt}) and other market goods (X^*_{xt}) as a function of all prices and gross income, given the value of last year's appliance stock and the household characteristics.

The optimal purchase of electric household appliances ($\tilde{T}^*_{jt}$) and the electricity demand in the production of service j (E^*_{jt}) is found by inserting the optimal level of production (T^*_{jt}) from the utility maximization problem into the functions (6) and (7). Thus, the demand for inputs in household production depends on all prices ($\vec{p}_t, p_{Et}, \vec{\rho}_t$), last year's appliance stock ($\vec{A}_{t-1}$), gross income (Y_t) and the household characteristics (β_t) only:

(9) $$E^*_{jt} = E^*_{jt}\left(p_{Et}, \vec{p}_t, \vec{\rho}_t; \vec{A}_{t-1}, Y_t, \beta_t\right)$$

(10) $$\tilde{T}^*_{jt} = \tilde{T}^*_{jt}\left(p_{Et}, \vec{p}_t, \vec{\rho}_t; \vec{A}_{t-1}, Y_t, \beta_t\right)$$

2.2. Short run and long run Cournot elasticities

To model the difference between the short run and the long run own price elasticity we deduce a ($J+K+1$)-equation model consisting of one structural utilization function and $J+K$ reduced-form demand functions for household appliances. The utilization function is found by solving the first order conditions for electricity (4) and the Lagrange multiplier (λ) with respect to the electricity consumption. By aggregation over all $j=1, .., J+K$, we may express the household's total electricity consumption at the optimal level of production (T^*_{jt}) and consumption of (other) goods (X^*_{jt}) as a function of the purchase of new household appliances, a vector of last year's appliance stock, annual gross income, household characteristics and prices on electricity and (other) goods. The electricity utilization function is given by:

(11) $$E_t = \sum_{j=1}^{J+K} E_{jt}\left(\tilde{I}_{jt}, A_{jt-1}, \delta, \vec{p}_t, p_{Et}, Y_t, \beta_t\right) = E_t\left(\tilde{\vec{I}}_t, \vec{A}_{t-1}, \delta, \vec{p}_t, p_{Et}, Y_t, \beta_t\right)$$

In optimum, the total derivative (long term effect) of the electricity consumption with respect to the electricity price equals the partial derivative (short term effect) of the electricity consumption with respect to the electricity price, plus the changes in the desired stock of household appliances caused by changes in the electricity price. Since, by definition, the partial derivative of the demand for new appliances with respect to the desired current stock equals one, that is $\partial \tilde{I}_{jt} / \partial A_{jt} = 1$, we can define the coherence between the long run (e_t^l) and short run (e_t^s) electricity price elasticities as:

(12) $$e_t^l = \frac{dE_t^*}{dp_{Et}} \frac{p_{Et}}{E_t^*} = \left(\frac{\partial E_t^*}{\partial p_{Et}} + \sum_{j=1}^{J} \frac{\partial E_t^*}{\partial \tilde{I}_{jt}^*} \frac{\partial \tilde{I}_{jt}^*}{\partial p_{Et}} \right) \frac{p_{Et}}{E_t^*} = e_t^s + \left(\sum_{j=1}^{J} \frac{\partial E_t^*}{\partial \tilde{I}_{jt}^*} \frac{\partial \tilde{I}_{jt}^*}{\partial p_{Et}} \right) \frac{p_{Et}}{E_t^*}$$

McFadden *et al.* (1977) also derive the short run own price elasticity from the partial derivative of the electricity utilization function with respect to the electricity price. The long run effect is derived by substituting the number of appliances owned by the households with the predicted appliance ownership shares derived from cross-sectional variation in the appliance stock. In order to interpret this as long run effects of a price change on the electricity consumption, we have to make several assumptions. First, we must assume that the households have rational expectations about future prices. The reason is that the present stock of appliances is determined in previous periods, whereas the appliance saturation equation estimates the present stock as a function of the present electricity price. Furthermore, in order to interpret cross-sectional variation in the appliance stock as long-term effects, we need to assume that all investments in new appliances will increase the current stock, and that old equipment is as energy efficient as new equipment. In order to avoid making such assumptions, we have modeled the flow in the stock explicitly as investments in new appliances.

3. Data and econometric model

3.1. The data[2]

The data set used in our analysis originates from five different sources. The main source is the annual Survey of Consumer Expenditure (SCE) selected among all private households in Norway. The aim of the SCE is to provide a detailed description of the consumption in various groups of households, including the consumption of electricity and household appliances. The households are classified according to such characteristics as type of household, income, demographic status, region, area of residence, etc. Among the households originally drawn, approximately 60 per cent complete the survey. The main cause of non-response is ‘refused to answer’. The SCE consists of four different questionnaires; an introductory interview, two account books, and a closing questionnaire concluding the survey. In this analysis, we mainly apply information from the closing questionnaire on electricity expenditures and expenditures and the number of units purchased of electrical household appliances during the last 12 months. The expenditures on durable goods correspond to the difference between the expenses in purchasing new goods and income resulting from any sale of old goods. The electricity expenses include expenses related to the household’s permanent dwelling as well as to holiday houses. Information regarding annual household gross income is derived from tax assessment registers.

Information on prices is collected from three different sources. For respondents who have not purchased any appliances during the last 12 months, we use the prices from the Consumer Price index (CPI) survey. The CPI survey collects monthly regional prices of the most important consumer goods in different Norwegian municipalities, which gives us variation in the appliance prices across households. For respondents who purchase appliances during this period, we have information about

[2] To give an overview of the data used in the econometric analysis, we have included summary statistics for the most important variables in Appendix Table A2.

the actual price on the appliance from the SCE. Information on municipal electricity prices is collected from the Norwegian Water Resources and Energy Administration.

We also have monthly information about regional variations in temperature for all municipalities applied in the SCE, provided by the Norwegian Institute of Meteorology. The variation in temperature during the month is measured in degree-days. Degree days is defined as the number of C° in difference between the outdoor temperature and 17 C°, summed up over days when the outdoor temperature is less than 17 C°, for each year. Thus, cold weather will result in high degree-day values.

3.2. The econometric specification of the model

When modeling the household's decision problem, two main approaches have been applied in the literature; either to parameterize the utility function or the demand function (see e.g. Dubin and McFadden (1984) and Dennerlein (1987) for examples of the two different approaches). In the analysis presented in this paper, we have chosen to parameterize the demand functions.

We estimate the utilization function (11) and the appliance demand functions (10) to identify the partial (short term) and total (long term) effect on the electricity consumption due to a change in the electricity price. We then use the results from this estimation to calculate the long run and short run own price elasticities. We approximate the utilization function and demand functions for appliances by the following model:

$$EL = \alpha_0 + \sum_{j=1}^{5} \alpha_{1j} F_j + \sum_{j=1}^{5} \alpha_{2j} S_j + \sum_{f=1}^{3} \alpha_{4f} FP_f + \sum_{s=1}^{10} \alpha_{3s} HC_s + (\alpha_5 + \alpha_6 HC_{11} + \alpha_7 HC_{14}) GI + + \alpha_8 HDD + \alpha_9 T + u \tag{13}$$

$$F_j = \gamma_{0j} + \sum_{k=1}^{5} \gamma_{kj} P_j + \gamma_{6j} HC_{10} P_j + \gamma_{7j} LP_j + \gamma_{8j} FP_1 + (\gamma_{9j} + \gamma_{10j} HC_{11} + \gamma_{11j} HC_{14}) GI + \sum_{s=6,10}^{13} \eta_{sj} HC_s + w_j \tag{14}$$

where EL is the household's total electricity consumption (kWh), F_j is the number of household appliance j purchased by the household during the last 12 months, S_j is the number of household appliance j owned by the household, FP_f is prices on electricity and heating fuel, GI is the household's annual gross income, HC_s are variables for household characteristics, HDD is heating degree-days, T is a trend variable, P_j is the price of appliance j, LP_j is the leaded price of appliance j, and u and w_j are stochastic error terms.[3] We include the leaded price on household appliances because we know from equation (5) that it is included in the user cost of capital formula. Thus, γ_{7j} will reflect the effects on electricity demand of discounting and depreciation of the appliance stock.

In this estimation we only apply electrical appliances $(j = 1, ..., 5)$ for which we have price information, i.e. j = (1) freezers, (2) refrigerators, (3) washing machines, (4) dishwashers, and (5) kitchen stoves.

During the period we study, the total electricity expenses were billed to the household quarterly for all uses combined based on last year's consumption profile, adjusted for actual consumption once a year. Since the household will not learn about the total electricity expenditure until the annual settling of accounts, the actual marginal electricity price is unknown to the household during most of the year. Therefore, even highly rational households may make decisions based on simple models of cost inferred from historical experience, and it is likely that electricity consumption will depend on last year's electricity price as well as the current electricity price. In the estimation, we thus apply the mean of last year's and the current electricity price (FP_1). Since the electricity consumption is likely to be sensitive towards prices on supplementary or alternative fuels, we also include the price of kerosene (FP_2) and heating oil (FP_3) in the estimation of the utilization function.

[3] See Appendix Table A1 for a complete list of variables.

Here, we seek to isolate the electricity used for electric household appliances only. Thus, we have included several household characteristics (HC_s) to control for variation in the total electricity consumption due to e.g. lighting, space and water heating: s = (1) a dummy for households with a central heating system, (2) a dummy for households living in a block of flats, (3) the net floor space of the residence, (4) a dummy for one-person households, (5) a dummy for households moving to the current place of residence during the last 12 months, (6) the number of persons living in the residence, (7) the construction year of the residence, (8) a dummy for households with a bathroom in the residence, (9) a dummy for households receiving free electricity, and (10) a dummy for an additional sample of benefit recipients. The independent variables approximating the household characteristics are chosen according to their significance and explanatory power.

We introduce dummy variables for households that have moved to their current place of residence during this year (HC_5) and newly established households (HC_{11}). Here, a household is defined as newly established if the main income contributor is less than 35 years old and have moved to the current residence during the last three years. We also introduce a dummy for households spending more than 40 percent of their annual gross income on electricity (HC_{14}). There are several reasons for including these dummies. First, households who have moved to the current place of residence during this year will have lower electricity consumption than others since they are not registered with a whole year's consumption. Thus, we include the dummy for moving to the current residence the present year directly into the utilization function. Secondly, newly established households often have a different consumption pattern than better-established households, in particular regarding purchase of electrical appliances, since they are often first-time buyers. To correct the estimation for differences in behavior between newly and well established households concerning price and income changes, we introduce an additive component to the price and income coefficients for newly established households. Finally, we correct the estimation for budget shares on electricity exceeding 40 percent of annual household gross income. This is done by introducing an additive component to the income coefficient. The reason for some of these high budget shares is that annual household gross income is defined as pensionable earnings, which is defined as employment income and self-employment income.[4] Not all income is liable to retirement insurance tax payments, like for example pension income, child support payments, children's allowance, disabled pensions, social benefits, etc. These benefits are thus not covered by our definition of household gross income. For this reason, some households have a very low registered annual gross income compared to their expenses on electricity.

When estimating the utilization function (13), we have modeled the electricity consumption as a function of the demand for new appliances, which are endogenous in the household's decision problem. We may thus experience problems with biased estimators in the utilization function due to simultaneity problems. To avoid this, we apply a two-stage estimation procedure. In the first step, we assume the error term w_j to be Normally distributed for all reduced form demand functions for household appliances.[5] Since no household purchased more than one unit of any appliance during the last 12 months, we model the purchase of appliance *j* as a binary discrete variable. That is, the purchase of appliances is estimated by a Probit model. The second step is an OLS estimation of the utilization function, where the predictions from the first step provide as instruments for the endogenous purchases of appliances.[6]

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[4] In Norway, we have a system of public retirement insurance, where the insurance premium is collected in advance as a retirement insurance tax on common income. Pensionable earnings are the income liable to such tax payments. The reason for applying this conception of household income is that this definition is used in the Consumer Expenditure survey.

[5] We have tested the estimations regarding this assumption, and the estimated elasticities are stable. Since the consumer is assumed to be a price taker, the demand function (14) will represent the reduced form of the problem as it does not depend on any variables endogenous to the consumer

[6] See e.g. Greene (1993), Maddala (1988), or Wonnacott and Wonnacott (1979) for a more detailed discussion of problems with simultaneous equations. See Battacharyya and Johnson (1977), or Greene (1993) for more information on Probit models.

4. Empirical results

We start this section by presenting the results from an estimation on the pooled data for the entire period, focusing on the determinants of electricity consumption. Secondly, we discuss the variation in short and long run price elasticities and in income elasticities over the period 1976 to 1993. We also compare the estimated long run Cournot elasticities from the two approaches.

4.1. Determinants of electricity consumption

In Table 1, we present the estimation results for the households' electricity demand from the pooled data. The estimated parameters are given in the first column, the t-ratios in the second, and the probability that the estimated parameter equals zero (p-value) are given in the third column of the table.

As shown in Table 1, the estimated coefficients for the *purchase* of new appliances are negative for some appliances and positive for others, although all but one do not differ significantly from zero. The purchased new appliances may either be replacing old and more inefficient appliances, or increasing the stock. The insignificance of the purchase variables may thus be a result of these two effects neutralizing each other. Unfortunately, we are not able to separate these effects in our data set. Furthermore, the electricity consumption increases significantly with the *stock* of appliances, except for the coefficient for the stock of freezers, which does not differ significantly from zero.[7]

The mean of the current and last year's electricity prices has a negative and significant effect on the electricity consumption. The coefficient for the heating oil price is negative and significant. The coefficient for the kerosene price is positive and significant at a 10 percent level.

[7] Using current ownership to predict the long run effects (as in McFadden *et al.*) may thus not be appropriate here, as these coefficients do not reflect the increase in energy efficiency of the new appliances; neither when replacing old equipment nor when increasing the current appliance stock.

Table 1. The estimated utilization function of the Norwegian residential electricity demand based on a two-stage estimation on the pooled data (1976-93): i) A Probit estimation of the purchase of electrical appliances, ii) an OLS estimation of the utilization function applying the predicted values from stage one

Variable	*Coefficient*	*t-value*	*p-value*
Intercept	-31212	-8.56	0.0001
Predicted purchase of household appliances:			
Freezer	-519	-0.87	0.3863
Refrigerator	459	0.48	0.6306
Washing machine	1174	2.09	0.0365
Dishwashing machine	418	0.76	0.4489
Kitchen stove	-2103	-1.56	0.1188
Current stock of household appliances:			
Freezer	102	0.79	0.4304
Refrigerator	571	3.58	0.0003
Washing machine	1213	5.77	0.0001
Dishwashing machine	2706	17.69	0.0001
Kitchen stove	885	2.65	0.0082
Price of electricity, 2-year mean (øre/kWh)	-200	-16.91	0.0001
Price of kerosene (øre/liter)	10	1.76	0.0777
Price of heating oil (øre/liter)	-13	-2.22	0.0268
Household gross income (10,000 NOK)	79	16.85	0.0001
Newly established household gross income (10,000 NOK)	-48	-6.89	0.0001
Social welfare household gross income (10,000 NOK)[a]	3744	12.81	0.0001
Central heating	-4500	-25.36	0.0001
Block of flats	-2839	-10.07	0.0001
Net floorage (m^2)	50	34.87	0.0001
One-person household	-462	-2.20	0.0275
Moved to the present residence the current year	-1775	-4.80	0.0001
Number of household members	714	12.45	0.0001
Year of residence construction	19	10.19	0.0001
Bathroom	2574	9.39	0.0001
Free electricity	-3347	-4.58	0.0001
Dummy for additional sample	-1345	-3.15	0.0017
Temperature (heating degree-days*100)	9	1.00	0.3157
Trend	345	9.60	0.0001
R^2	0.3544		
Adjusted R^2	0.3533		

[a] Households where annual electricity expenses exceed 40 percent of annual household gross income.

The household gross income is significant and with the expected sign. Again, we have separated the income effect for newly established households, which have a considerable less sensitive electricity consumption relative to income.[8] This is reflected in the income elasticities, where electricity is considered more of a necessity good by newly established households than other households, with an Engel elasticity of 0.06 and 0.13 respectively. We also see from Table 1 that the coefficient for the income variable for households with a budget share of electricity exceeding 40 percent of annual gross income is very high and significant. It is not meaningful to interpret this coefficient, as it was only included to correct the estimation for problems with the definition of household gross income.

The trend variable is positive significant, while the dummy for additional samples is negative because respondents on disability benefits have, on average, a lower electricity consumption.

Finally, all the variables correcting the electricity consumption for space and water heating came out significantly and with the expected signs. The electricity consumption is relatively higher for households living in newly built houses where the wiring capacity is generally higher, households that have a bathroom, households with a high net floorage, and households with many household members. In households with installed central heating technology, the electricity consumption tends to be lower because of the fossil fuel based central heaters. Households who lives in a block of flats have lower electricity consumption than households in detached houses, where the need for heating is higher. When the number of degree-days increases (cold weather) electricity consumption increases. The degree-days coefficient is, however, not significantly different from zero. This may be due to various effects neutralizing each other. Cold weather may increase electricity consumption for households using electricity only for heating. However, if the household has supplementary equipment, such as wood-burning stoves, electricity consumption may actually decrease.

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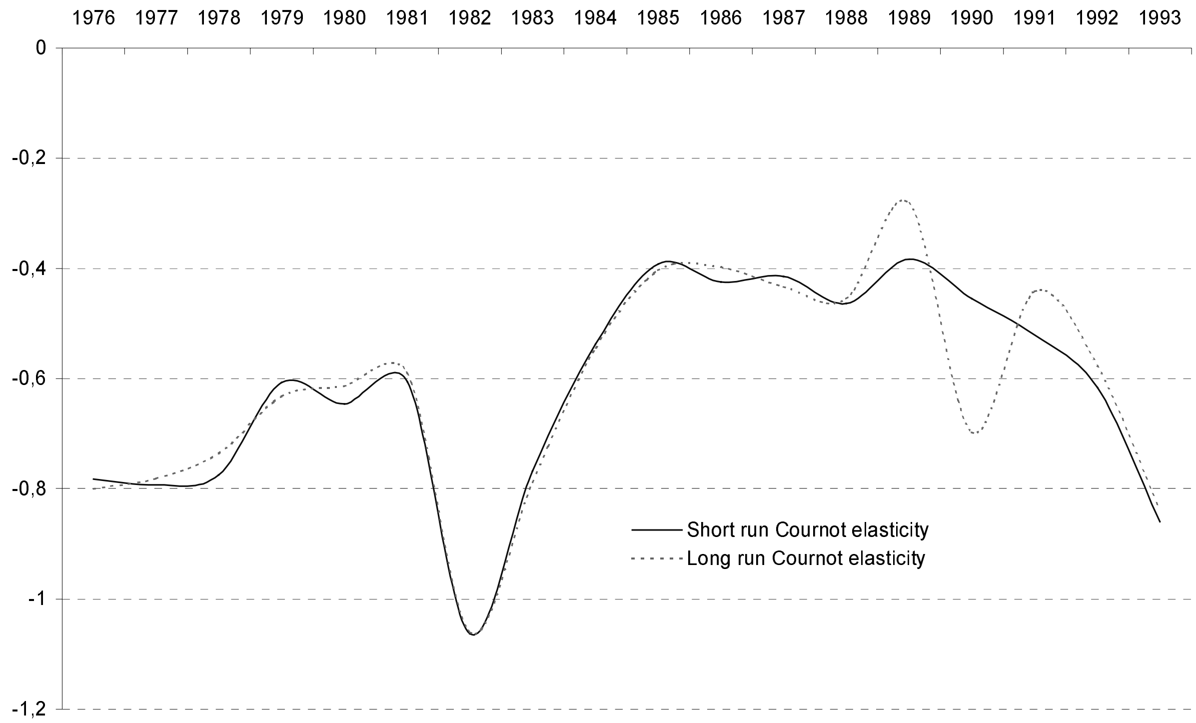
[8] The income effect of these households is the sum of the coefficient for household gross income and the coefficient of newly established household gross income.

4.2. Variation in elasticities over time

The estimated coefficient for the electricity price represents the partial derivative of (short run effects on) the electricity consumption for household appliances with respect to the electricity price. If we multiply this coefficient with the mean electricity price divided by the mean electricity consumption (kWh) we obtain an estimate of the short run direct Cournot elasticity of the Norwegian households' electricity demand. Then, we apply the estimated coefficients from (13) and (14) to calculate the long run elasticity, applying the properties in (12). The yearly short and long run own price elasticities for the period 1976 to 1993 is given in Figure 1.

Figure 1. Short run and long run Cournot elasticities for Norwegian households' electricity consumption, 1976 - 1993



A lower short run than long run elasticity (in absolute terms) may be due to the possibility of adjusting the capital stock with changes in the electricity price. Looking at Figure 1, however, we see that the difference in the estimated short and long run Cournot elasticities are almost negligible, and they do not differ significantly. This is not very surprising, since there is no substitute to electricity for household appliances in Norway. The households can not reduce their use of electricity in the long run by purchasing e.g. gas stoves, only delay or hasten the purchase of new equipment. However, our data do not indicate that households delay or hasten their appliance investments, since the appliance stock is not significantly influenced by the electricity price. The same picture emerge from the estimation on the pooled data, where the estimated short run price elasticity for the whole period is -0.433, and the estimated long run price elasticity is -0.442. We also see that the estimated own price elasticities are stable for most of this period, except the beginning of the 1980's and 1990's.

We have estimated the model with current ownership of appliances instead of the purchase, in order to compare the results from our approach with the more traditional approach. In figure 2, we have plotted the long run own price elasticities from the two approaches for the period 1976 – 1993.

The estimated long run elasticities do not differ significantly between the two approaches. The reason is that the current stock of household appliances is not influenced significantly by the electricity price. Thus, both long run elasticities are dominated by the short-term effect, which do not differ between the two approaches.

In Figure 3, we have plotted the yearly estimated income elasticities, corrected for newly established households and households with a budget share of electricity exceeding 40 percent, for the period 1976 to 1993.

Figure 2. Long run Cournot elasticities for Norwegian households' electricity consumption applying 1) the flow of appliances and 2) the stock of appliances, 1976 – 1993

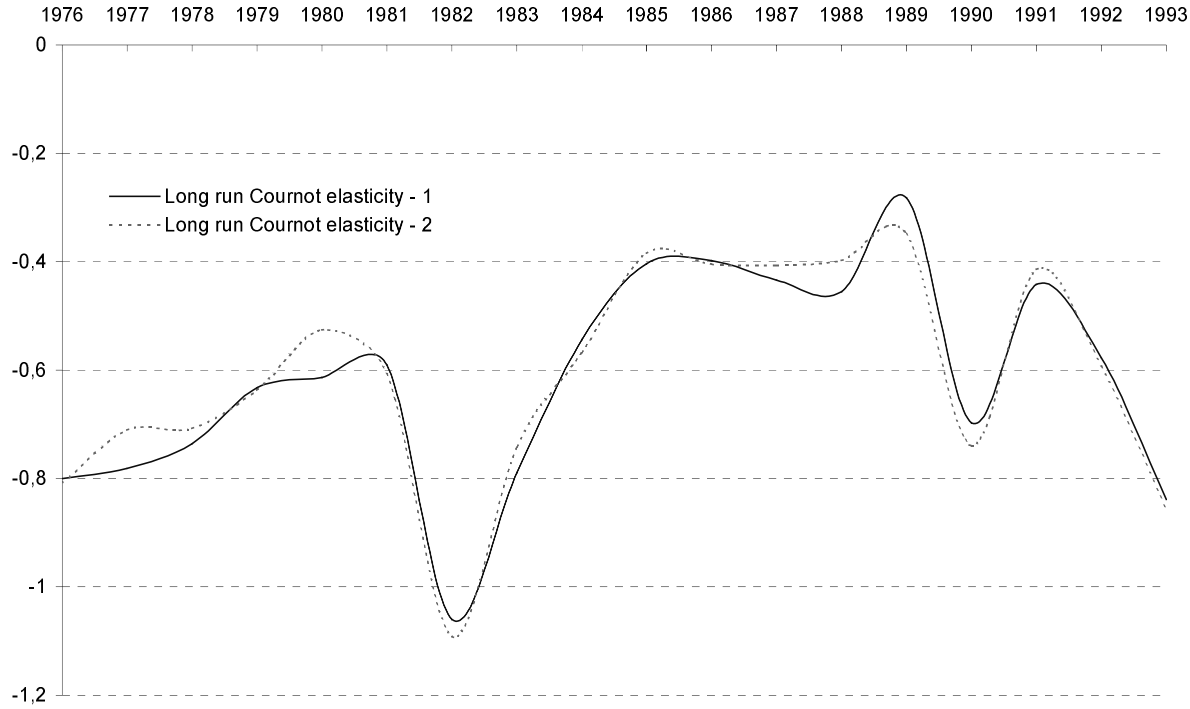
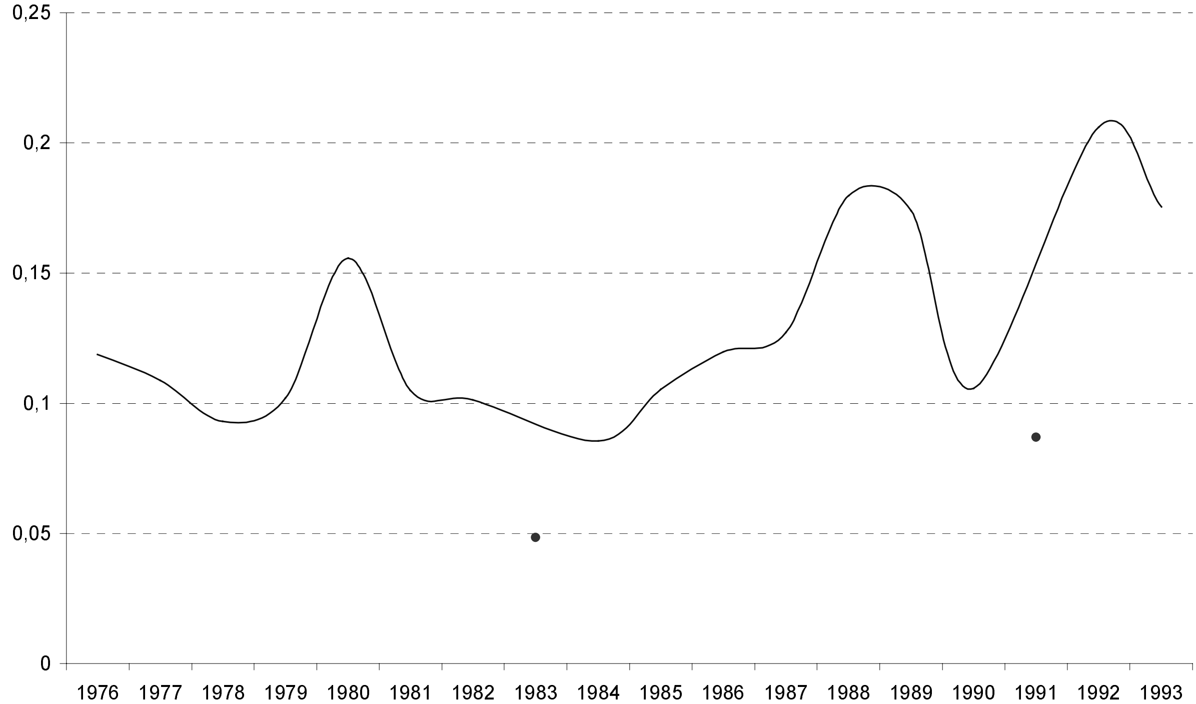


Figure 3. Engel elasticities of the Norwegian households' electricity consumption, 1976 - 1993



In two years, 1983 and 1991, we did not estimate a significant income effect. The two separate points in Figure 2 represent the income elasticities for these years. Norwegian households view electricity as a necessary good, with a low estimated Engel elasticity. Figure 3 also show an increasing trend in the estimated income elasticity in this period.

5. Concluding remarks

In this paper, we have presented an alternative approach to McFadden, Puig and Kirshner (1977), modeling the dynamic properties of residential electricity demand. Our results indicate that Norwegian households view electricity as a necessary good. We also find that the long run Cournot elasticity does not differ significantly from the short run, and that the estimated long run elasticities do not differ significantly between our approach and the approach applied in the previous literature.

Here, we measure the long-term effects through the purchase of electric household appliances only. This may be the reason for the lack of significance between the short and long run elasticities, since there is no alternative source of fuel for these appliances. On the other hand, a large number of alternative fuels are available for space heating equipment. Since the substitution possibilities are larger for space heating, we would expect the electricity price to have an impact on the long-term flexibility of the electricity consumption through the choice of heating system. We then should expect a significant difference in the estimated long run elasticities between the two approaches. Unfortunately, we do not have information about the stock, the purchase of, or price on wood burning, kerosene and fuel oil stoves or central heating systems. Thus, we are not able to measure the total effect of price changes on the long-term consumption of electricity, as we have isolated the long-term effect through the purchase of household appliances only. In future research on the topic, we plan to incorporate the choice of heating system to elicit the total long-term flexibility of Norwegian households' electricity consumption.

We have tested the estimation results with respect to the assumptions made about the distribution of the error term in the purchase decision, and the results are stable. However, we have not discussed the robustness and stability of the estimates with respect to other aspects of the econometric specification. In future research we plan to look into the effects of heterogeneity in revealed preferences between different groups of households, how to model decreasing marginal utility of income econometrically, and the effect of estimating the two-step estimation simultaneously.

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Appendix A

Table A1. List of variables

Variable	
EL	Household's total consumption of electricity (kWh).
F_1	Number of freezers purchased by the household in the last 12 months.
F_2	Number of refrigerators purchased by the household in the last 12 months.
F_3	Number of washing machines purchased by the household in the last 12 months.
F_4	Number of dishwashers purchased by the household in the last 12 months.
F_5	Number of kitchen stoves purchased by the household in the last 12 months.
S_1	Number of freezers owned by the household.
S_2	Number of refrigerators owned by the household.
S_3	Number of washing machines owned by the household.
S_4	Number of dishwashers owned by the household.
S_5	Number of kitchen stoves owned by the household.
P_1	Price of freezers the last 12 months.
P_2	Price of refrigerators the last 12 months.
P_3	Price of washing machines the last 12 months.
P_4	Price of dishwashers the last 12 months.
P_5	Price of kitchen stoves the last 12 months.
LP_1	Price of freezers next 12 months.
LP_2	Price of refrigerators next 12 months.
LP_3	Price of washing machines next 12 months.
LP_4	Price of dishwashers next 12 months.
LP_5	Price of kitchen stoves next 12 months.
FP_1	Mean electricity price for the last two years.
FP_2	Kerosene price.
FP_3	Heating oil price.
GI	The household's annual gross income.
HC_1	Dummy for central heating system.
HC_2	Dummy for households living in a block of flats.
HC_3	Net floor space of the residence.
HC_4	Dummy for one-person households.
HC_5	Dummy for households moving to the current place of residence during the year of the interview.
HC_6	Number of persons living in the household.
HC_7	Year of construction of the residence.
HC_8	Dummy for household with a bathroom in the residence.
HC_9	Dummy for households receiving free electricity (only after 1985).
HC_{10}	Dummy for additional sample of disability benefit recipients.
HC_{11}	Dummy for newly established households.
HC_{12}	Age of the main income-contributing member of the household.
HC_{13}	Number of children below 16 years of age living in the residence.
HC_{14}	Dummy for budget share exceeding 40 present of the household annual gross income.
HDD	Number of heating degree-days over the year.
T	Trend variable.

Table A2. Sample mean and standard deviation (in parentheses) of all variables for selected years and for the pooled data (1975-94). All prices and income are measured in 1994-NOK[1]

Variable	*1976*	*1980*	*1985*	*1990*	*1993*	*Pooled*
Electricity consumption (in 1000 kWh)	14.95	16.17	16.45	17.11	20.10	17.09
	(8.94)	(9.5)	(8.76)	(9.62)	(10.05)	(9.7)
Current stock of household appliances:						
Kitchen stove	0.978	0.984	0.976	0.983	0.975	0.980
	(0.23)	(0.23)	(0.20)	(0.13)	(0.16)	(0.89)
Freezer	0.822	0.877	0.982	1.174	1.207	1.038
	(0.52)	(0.56)	(0.56)	(0.50)	(0.51)	(0.54)
Dishwashing machine	0.074	0.169	0.280	0.432	0.568	0.321
	(0.26)	(0.38)	(0.45)	(0.50)	(0.50)	(0.47)
Washing machine	0.836	0.845	0.907	0.937	0.947	0.899
	(0.4)	(0.39)	(0.32)	(0.24)	(0.22)	(0.32)
Refrigerator	0.842	0.820	0.756	1.058	1.062	0.932
	(0.42)	(0.45)	(0.47)	(0.30)	(0.33)	(0.41)
Prices of household appliances (in NOK):						
Kitchen stove	5701	5724	6474	5887	6218	6109
	(667)	(655)	(841)	(1048)	(1022)	(981)
Freezer	6595	5767	4602	4462	4202	5016
	(506)	(481)	(547)	(649)	(511)	(932)
Dishwashing machine	8644	7055	6678	5288	5012	6547
	(203)	(270)	(647)	(962)	(2380)	(1714)
Washing machine	8017	7449	6226	6851	7086	7087
	(677)	(563)	(542)	(854)	(950)	(937)
Refrigerator	4493	4368	5039	4612	4531	4734
	(429)	(399)	(487)	(477)	(566)	(634)
Price of electricity, 2-year mean (øre/kWh)	21.4	28.1	41.4	43.5	42.8	37
	(4.04)	(2.96)	(5.4)	(3.2)	(3.6)	(8.51)
Price of kerosene (øre/litre)	100	200	314	308	357	252
	(1.77)	(21.3)	(4.7)	(12.8)	(15.2)	(87.6)
Price of heating oil (øre/litre)	87	179	270	250	310	217
	(3.04)	(19.1)	(2.9)	(18.3)	(14.8)	(75.7)
Household gross income (in 1,000 NOK)	237	245	246	300	358	281
	(155)	(159)	(172)	(162)	(215)	(192)
One-person household	0.125	0.16	0.16	0.20	0.11	0.15
	(0.33)	(0.36)	(0.36)	(0.40)	(0.31)	(0.36)
Number of household members	3.22	2.995	2.89	2.72	3.18	2.97
	(1.55)	(1.41)	(1.36)	(1.32)	(1.37)	(1.4)
Central heating	0.13	0.16	0.13	0.13	0.10	0.13
	(0.34)	(0.36)	(0.34)	(0.33)	(0.30)	(0.34)
Block of flats	0.01	0.01	0.01	0.14	0.11	0.07
	(0.095)	(0.1)	(0.09)	(0.34)	(0.32)	(0.25)
Net floorage (in 100 m^2)	1.00	1.01	1.09	1.17	1.27	1.11
	(0.49)	(0.44)	(0.43)	(0.52)	(0.59)	(0.5)
Temperature (in 1000 heating degree-days)	4.35	4.48	4.68	3.61	4.16	4.21
	(0.62)	(0.65)	(0.62)	(0.54)	(0.56)	(0.67)
Year of residence construction	1940	1946	1954	1956	1961	1953
	(37)	(38)	(31)	(36)	(33)	(34)
Bathroom	0.83	0.91	0.97	0.98	0.99	0.95
	(0.38)	(0.29)	(0.18)	(0.13)	(0.10)	(0.23)

[1] One NOK (krone) is approximately 7.5 USD. 100 øre = 1 NOK.

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