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Going beyond tradition: Estimating residential electricity demand using an appliance index and energy services*

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Abstract

In this paper we estimate the long- and short-run price elasticities of residential electricity consumption in Switzerland from a household survey by constructing an index of the stock of household appliances as well as by using energy services. We create the index by aggregating the information on the major household appliances. The index is used to estimate the impact of appliances on residential electricity demand. Furthermore, we also use energy services to estimate the electricity demand. We adopt an instrumental variables approach to obtain consistent estimates of the price elasticity to account for potential endogeneity concerns with the average price as well as the appliance index. Our results suggest that the price elasticity is around -0.6. We conclude that Swiss households are price inelastic in electricity prices. This can be used for policy makers as well as by utility companies to design pricing instruments to modify electricity consumption. We also find that estimates of the electricity demand when we substitute the usual residential characteristics with energy services are quite comparable.

Keywords: Residential electricity, appliance stock index, energy services, instrumental variables.
JEL Classification Codes: D, D1, Q, Q4, Q5.

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1 Introduction

The way forward for Switzerland in terms of its energy and climate policies has been discussed since 2004 when work started on *Energy Perspectives 2035* by the Swiss Federal Office of Energy. The results of this research, published in 2007, led to substantial political debate. It also led to the introduction of the Swiss Electricity Supply Law (StromVG) in 2007 as well as the start of liberalisation in the Swiss electricity market. The Swiss Federal Council and parliament also discussed and worked on new energy policies. The nuclear accident on 11 March, 2011 in Fukushima, Japan led to further debate on the future direction of Swiss energy policies. The Federal Council proposed *Energy Strategy 2050* that includes an initial package of measures with mandatory efficiency goals for utilities and, in a later phase, a possible ecological tax reform. The latter will introduce an energy tax to provide incentives for a more responsible use of resources and to stabilise the consumption of electricity by 2050.

In order to find out the effectiveness of an energy tax on electricity consumption it is important to estimate the responsiveness of electricity demand to its price. Therefore, in this paper, we ask three research questions. Firstly, what is the price elasticity of residential electricity consumption? This will enable the design of appropriate pricing policies by utilities and the regulatory authorities to reduce electricity consumption as well as provide a way to forecast demand and plan for generating capacity in the future. Secondly, how does the stock of electrical appliances affect the consumption of residential electricity? This will enable us obtain a more precise estimate of the price elasticity. Finally, what is the impact of using energy services, such as the number of meals cooked at home and the amount of time spent using personal computers and watching television, on the electricity consumption of a household?

To answer these questions we use data from a survey of Swiss households served by seven electric utility companies and conducted by the Verband der Schweizerischen Elektrizitätsunternehmen (VSE) in 2005 and 2011. The survey contains information on a household's stock of appliances, the usage behaviour, and various socio-demographic characteristics. The survey also reports the electricity consumption of each household in the previous year. We use these information to estimate the residential electricity consumption.

We find that the price elasticity of residential electricity consumption is around -0.6. Our results suggest that Swiss households are price inelastic in electricity prices. However, the estimated values are generally higher than -0.5. These results can be used by policy makers and utility companies to design instruments to reduce and modify electricity consumption.

There are a number of studies which estimate long- and short-run price elasticities for residential electricity demand using aggregated data. However, using data at a more disaggregated level can add great detail to the knowledge of consumer response since residential consumers are very heterogeneous. As noted by Dubin and McFadden (1984), using disaggregated data avoids misspecification error that is caused by aggregation bias from using aggregate electricity consumption and prices. Table 1 gives an overview of some selected estimated price elasticities for electricity using disaggregated data in the literature. For example, Reiss and White (2005) use a sample of about 1,300 Californian households from the Residential Energy Consumption Survey (RECS) in 1993 and 1997 to estimate price and income elasticity using marginal price and a set of appliance variables. They find considerable amount of heterogeneity in the estimated elasticities. Yoo et al. (2007) use survey data from 380 households in Seoul and a bivariate model to account for sample selection. They find significant sample selection bias and also find that a plasma TV or an air conditioner has a significant positive impact in residential consumption in Seoul. However, electricity demand, estimated by using the average price, appears to be price (-0.25) and income inelastic (0.06).

Conversely, Alberini et al. (2011) find much higher price response by residential consumers (-0.86 to -0.67). They use household-level data from over 70,000 households in the 50 largest metropolitan areas in the United States from 1997 to 2007 (a mix of panel data and multi-year cross-section). To correct for a possible mismeasurement problem the average electricity price is instrumented with state-level electricity and gas prices or lagged electricity prices in an alternative model. In contrast to Reiss and White (2005) they find no evidence of significantly different price elasticities for households with electric and gas heating systems. Fell et al. (2012) use monthly data from a consumer expenditure survey collected between 2006 and 2008 to estimate the price elasticity. Using expenditure data and state-level average electricity prices to compute the quantity of electricity consumed they are faced with two possible sources of endogeneity that they solve with a GMM approach. The estimated price elasticity is close to -1 and rather high compared to other cross-sectional studies. They explain this with the fact that they use average price and not marginal price as used in most other studies.

There are only a few previous studies in Switzerland using disaggregated data. Table 1 also provides an overview of disaggregated studies within Switzerland. Among the first studies using disaggregated data were those by Dennerlein and Flaig (1987) and Dennerlein (1990). Dennerlein and Flaig (1987) use pooled cross-section data of almost 6,000 households collected with an expenditure survey from 1975 to 1984. This survey also includes information about the ownership of some appliances. They estimate the electricity demand as well as two separate probit models for the ownership of electric stove and TV. Moreover, they also control for the ownership of electric stove, electric water and space heating and TV and find short-run elasticities between -0.2 and -0.4 and long-run elasticities of between -0.4 and -0.6. Dennerlein (1990) uses the same database but from 1977 to 1986 and finds slightly higher short-run (-0.5) and long-run (-0.7) elasticities using average prices. However, both these studies may suffer from potential simultaneity issues because the choice of appliances may depend on the consumption of electricity.

Zweifel et al. (1997) use data from around 1,300 households from different years (1989-92) and group them in three different pools depending on whether households have a single-tariff structure, a time-of-use structure and a time-of-use structure by choice. These households are customers of utilities that have either both structures or a time-of-use scheme. For the first group, the price elasticity is very small and not significant. But for the second and third groups the elasticities, estimated by OLS, are significant and -0.66 and -0.59 respectively. Excluding the city of Zurich in the third group reduces the elasticity to -0.42. However, the variation of electricity price in this study is based on only three utility companies and is, therefore, low. Since the 1990s there has been no study using disaggregated data in Switzerland to estimate the price elasticity of residential electricity demand and an update is required.

All the studies mentioned above use individual appliance dummy variables to control for the effect of appliances. To the best of our knowledge, Garbacz (1984) and Tiwari (2000) are the only studies that use the concept of an appliance index. Garbacz (1984) develops a three-equation model with an electricity demand equation, an appliance stock equation and an equation for the electricity price. However, his appliance

Table 1: Selected price elasticities using disaggregated data in the literature.

Author		**short-run**	**long-run**
International			
Tiwari (2000)	Mumbai	-0.61 to -0.84	
Halvorsen and Larsen (2001)	Norway	-0.433	-0.442
Reiss and White (2005)	California	-0.39	
Yoo et al. (2007)	Seoul	-0.25	
Alberini et al. (2011)	US	-0.74	-0.81
Fell et al. (2012)	US	-0.98	
Switzerland			
Dennerlein and Flaig (1987)		-0.2 to -0.4	-0.4 to -0.6
Dennerlein (1990)			-0.7
Zweifel et al. (1997)		-0.42 to -0.66	

index is based on typical usage of the individual appliances in kWh and not a measure of typical capacity. Tiwari (2000) calculates the index using the average power requirement of individual appliances. He uses a household survey of the Bombay Metropolitan Regional Development Authority (BMRDA) including more than 6,000 households between 1987 and 1988. He estimates residential electricity demand using average electricity price, income, dwelling characteristics, household characteristics and an appliance index. The appliance index is composed of the average power of television, iron, video, tape recorder, radio and refrigerator owned by the household relative to the maximum power available. He estimates the short-run price and income elasticities to be -0.70 and 0.34, respectively. However, the study ignores the possible endogeneity problem caused by the average electricity price as well as the simultaneity bias caused by the appliance index.

Our analysis contributes to the existing literature in several ways. Firstly, we use a unique survey of households conducted in Switzerland that includes extensive information about the household's stock of appliances. Secondly, we use an instrumental variables approach to account for the possible endogeneity of the average price of electricity. Thirdly, we use an appliance index as an aggregate measure of the household's stock of appliances. This is more precise than using dummy variables and, given that the stock of appliances suffers from a potential endogeneity problem, we do not need to include multiple instruments. As is well-known in the applied econometrics literature, using many instruments for many endogenous variables could, potentially, lead to a problem of weak instruments.[1] Finally, our theoretical model is based on household production theory that posits electricity demand as being a derived demand for energy services. We estimate our model using information collected from the survey that includes, e.g., the number of meals cooked and washing done by a household. Estimating the electricity demand using energy services has, to the best of our knowledge, not been done before and this aspect is a significant contribution to the existing literature.

The rest of the paper is organised as follows. In the next section we provide an overview of a model of electricity demand based on household production theory and a description of our empirical strategy.

[1] We consider 11 appliances and so the problem of weak instruments will be extremely severe.

Section 3 describes the household survey as well as other sources of data. The penultimate section presents the results of our different specifications while the final section has concluding remarks.

2 Model and Empirical Strategy

The residential demand for electricity is considered to be a derived demand since electricity is consumed to provide us with services, e.g. an electric heater providing warmth. It can be modelled using standard household production theory whereby households combine electricity and capital goods to obtain energy services.[2] We can ultimately derive equations for the long- and short-run residential electricity demands by using the following production function for energy services:

$$S = S(E, K) \tag{1}$$

where S is an energy service, E is the amount of electricity consumed and K is the stock of appliances. This equation describes how electricity is combined with appliances to provide an energy service. The energy service then becomes an argument in a household's utility function along with the consumption of other goods and services X and household characteristics Z. This utility function, U, can be written as

$$U = U(S(E, K), X, Z). \tag{2}$$

The objective of a household is to maximise this utility function subject to its budget constraint:

$$M = P_S \cdot S - 1 \cdot X \tag{3}$$

where M is the income and P_S is the price of the energy service, which is a composite good being derived from various energy services. Other goods and services, X, is assumed to be the numeraire and , therefore, its price can be normalised to unity.

Following Deaton and Muellbauer (1980) we model a household's decision as a two-stage optimisation process where, in the first stage, the household minimises the cost of producing a level of energy services S and, in the second stage, maximises its utility function, equation (2), subject to a budget constraint, equation (3). The first stage problem can be written as

$$\min P_E E + P_K K \qquad \text{subject to } S = S(E, K) \tag{4}$$

where P_K is the price of the appliance stock. We obtain a cost function, C, from this optimisation:

$$C = C(P_E, P_K, S) \tag{5}$$

The cost function has the usual properties with respect to being linearly homogeneous in energy services and

[2]See Deaton and Muellbauer (1980) for a description of household production theory and Flaig (1990) and Filippini (1999) for an application to electricity demand analysis.

input prices, increasing in energy services, and concave in input prices. We get the derived input demand functions for energy services and appliance stock by using Shepherd's lemma:

$$E(P_E, P_K, S) = \frac{\partial C(P_E, P_K, S)}{\partial P_E} \tag{6}$$

$$K(P_E, P_K, S) = \frac{\partial C(P_E, P_K, S)}{\partial P_K} \tag{7}$$

The second stage involves maximising the household's utility function:

$$\max U = U(S(E, K), X, Z) \qquad \text{subject to } M = C(P_E, P_K, S) + X \tag{8}$$

We normalise the price of other goods and services to unity. Using the Lagrangian method of optimising this utility function subject to the budget constraint we obtain the demand functions for S and X:

$$S^* = S(P_E, P_K, M, Z) \tag{9}$$

$$X^* = X(P_E, P_K, M, Z). \tag{10}$$

The demand functions for E is obtained by substituting equation (9) in equation (6):

$$E^* = E(P_E, P_K, S^*(P_E, P_K, M, Z)) \tag{11a}$$

$$= E(P_E, P_K, M, Z), \tag{11b}$$

while the demand function for K is obtained by substituting equation (9) in equation (7):

$$K^* = K(P_E, P_K, S^*(P_E, P_K, M, Z)) \tag{12a}$$

$$= K(P_E, P_K, M, Z). \tag{12b}$$

The equations for E^*, K^* and X^* represent the long-run equilibrium consumption amounts for a household. While it is empirically possible to estimate equations (10), (11b) and (12b) simultaneously, researchers limit themselves to estimating equation (11b). Since we are interested in estimating residential electricity demand we will focus our analysis on estimating E^*.[3] Equation (11a) indicates that electricity consumption depends on the electricity price, prices of the stock of appliances and the equilibrium amount of energy services consumed. This implies that, if we can obtain measures of the price variables and the quantity of energy services consumed, we will be able to estimate the electricity demand. We can also use equation (11b) to estimate the electricity demand. This represents electricity consumption as a function of electricity price, price of the stock of appliances and household income. It is also a function of other household characteristics. Typically, the amount of energy services, as in equation (11a), are not measured and are, instead, approximated by including residential and sociodemographic characteristics. Equation (11b) is a static model in the sense that

[3]However, since we use a two-stage instrumental variable procedure to account for the potential endogeneity of the stock of appliances we are, in effect, estimating the demand for capital, as given by equation (12b). The results of this estimation are provided by the estimates in the first stage of the IV regression. The results of the first stages are provided in the appendix since this part is not the focus of our paper.

the adjustment of electricity consumption is instantaneous if there is a change in any of the determinants of electricity consumption. It also reflects the fact that the rate of utilisation and the stock of appliances are adjusted instantaneously when there are changes in prices or income. However, the instantaneous adjustment of the stock of appliances may be a relatively strong assumption. For this reason, it is important to estimate the electricity demand with a short-run perspective in which the stock of appliances cannot be adjusted while it can be in the long run.

With the above discussion in mind, we now present the short- and long-run electricity demand models used in our study. The short-run electricity demand equations, corresponding to (11a) and (11b) respectively, can be written as

$$E^{SR} = E^{SR}(P_E, K, S^*(P_E, K, M, Z)) \tag{13a}$$
$$= E^{SR}(P_E, K, M, Z) \tag{13b}$$

where K denotes a given stock of appliances. In the short-run capital stock is assumed to be fixed. One way to measure a household's stock of appliances is to construct an index by using the capacity of the major appliances owned by the household. Tiwari (2000) uses this method to get an approximate measure of the appliance stock owned by a household.

In the long-run, however, the electricity demand equations, corresponding to (12a) and (12b) respectively, can be written as

$$E^{LR} = E^{LR}(P_E, P_K, S^*(P_E, P_K, M, Z)) \tag{14a}$$
$$= E^{LR}(P_E, P_K, M, Z) \tag{14b}$$

which indicates that the long-run electricity demand changes when the prices of electricity and appliance stock change. Obtaining an estimate of the price of the stock of appliances is key to estimating the long-run equilibrium of electricity consumption and one way is to calculate the price index of the appliance stock by using the capacity of the major appliances owned by the household (the index used in the short-run estimation). This is adjusted with the price of the corresponding appliance to determine the price index of the appliance stock.

Finding an estimate of the price of the stock of appliances is key to estimating the long-run equilibrium of electricity consumption, as denoted by equation (6). We can then estimate the short- and long-run price elasticity of electricity consumption by utilising stock and price information of the appliances, respectively. Using a log-log functional form, as is common in the literature, the long-run electricity demand function for household i can be written as

$$\ln E_i^{LR} = \beta'_0 + \beta'_1 \ln p_i^E + \beta'_2 \ln p_i^K + S_i \delta + \epsilon_i. \tag{15a}$$
$$\ln E_i^{LR} = \beta_0 + \beta_1 \ln p_i^E + \beta_2 \ln p_i^K + \beta_3 \ln M_i + Z_i \gamma + \epsilon'_i. \tag{15b}$$

where δ is a vector of parameters to be estimated for energy services S, γ is a vector of parameters to be estimated for household characteristics Z and ϵ_i and ϵ'_i are the usual error terms, assumed to be independently and identically distributed. An advantage of using a log-log specification is that the coefficient of electricity price, e.g., β_1, is easily interpreted as the price elasticity of electricity demand. This means that a one percent change in electricity price will cause a β_1% change in the electricity consumption, keeping all else the same.

The short-run electricity demand function for household i can be written as

$$\ln E_i^{SR} = \beta_0' + \beta_1' \ln p_i^E + \beta_2' K_i + S_i \delta + v_i. \tag{16a}$$

$$\ln E_i^{SR} = \beta_0 + \beta_1 \ln p_i^E + \beta_2 K_i + \beta_3 \ln M_i + Z_i \gamma + v_i'. \tag{16b}$$

where β_2' and β_2 are vectors of parameters to be estimated for a measure of the stock of major household appliances. In contrast to the long-run equations, the short-run equations include the household's stock of appliances instead of the price of appliances.[4]

The method to calculate the electricity price is crucial to estimate the price elasticity of electricity. While the literature on this is substantial, the main approaches can be divided into two strands. The first approach uses average prices while the second uses marginal prices.

1. Nordin (1976) suggests using the marginal price (and subtract the fixed fee from the income)
2. Shin (1985) uses average price. The average price of electricity is obtained by dividing the electricity bill with the quantity of electricity consumed. In our case, we use the marginal price and fixed fee, if any, to calculate the electricity bill by multiplying the electricity consumption with the marginal price and then adding the fixed fee.

The advantage of using the marginal price over the average price is its exogeneity, i.e. the marginal price of electricity will affect electricity consumption but not the other way round. Since the average price is calculated by dividing spending on electricity with the quantity consumed there exists the problem of simultaneous causality which leads to the average price being an endogenous explanatory variable. However, as mentioned in the literature, the average price is probably more important than the marginal price since households are more concerned about their total electricity bill rather than the price of electricity at the margin (e.g., Shin (1985), Borenstein (2009) and Ito (2012)). We, therefore, use the average price in our analysis.[5] We use instrumental variables in two-stage least squares models to account for the potential endogeneity issues from simultaneity problems with regard to the use of average price.

As mentioned before, the way we utilise a household's stock of appliances will enable us to estimate the long- and short-run price elasticities of demand for electricity. In our analysis, we use an index of the stock of appliances to estimate the short-run price elasticity. The index is calculated by using the estimated capacities (in Watts) of a household's stock of major appliances. A measure of the appliance stock, however, may suffer from simultaneity bias. This may occur because the choice of appliances may depend on the consumption of electricity (Dubin and McFadden, 1984). This leads to the stock of appliances being endogenous in the estimating equation and we use instrumental variables methods to account for this potential bias. An advantage

[4]An alternative approach is to estimate the long- and short-run price elasticities by using a partial adjustment model. Unfortunately, we cannot use this approach since we do not have panel data. See Alberini and Filippini (2011) and Blázquez et al. (2013) for applications.

[5]We do not use marginal prices because of very low variation of these prices across the utilities in our sample.

of using an index of the individual appliances instead of using the individual appliances is the avoidance of using multiple instrumental variables to account for the potential endogeneity of the appliances. It is very difficult to find instruments for multiple endogenous variables due to the possibility of weak instruments that will produce inconsistent estimates. We estimate the long-run price elasticity in two ways. Firstly, by calculating a rental price for each major appliance and secondly, by calculating a price index for the appliances, i.e. the price per estimated installed capacity.

In the rest of our analysis we estimate equations (15b) and (16b) as well as equations (16a) and (15a) where the parameters of interest are the long- and short-run estimates of β_1, i.e. the price elasticities of residential electricity consumption in Switzerland. The goal is to estimate those elasticity parameters by taking into account the possible endogeneity of average price and the appliance index and its possible endogeneity.

3 Data

The primary data comes from a household survey organized by the Verband der Schweizerischen Elektrizitätsunternehmen (VSE) while we use secondary data from the Swiss Federal Electricity Commission (ElCom), the Swiss price supervisor ("Preisüberwacher"), Schweizerische Agentur für Energie Effizienz (SAFE) and comparis, a Swiss price comparison website. The data are described below while table 3 provides the summary statistics of all the variables.

3.1 VSE Survey

We use data from a survey performed by the Verband der Schweizerischen Elektrizitätsunternehmen (VSE). It conducted two surveys on around 2,400 Swiss households served by 7 different utility companies. The first survey was conducted in 2005 and the second survey in 2011, both by telephone interviews. In both surveys data were collected from residential customers of five utilities for a total of 1,200 households. Three out of those five utilities were common to both the 2005 and the 2011 surveys but the households were not necessarily the same. Due to a confidentiality agreement, we are unable to list the names of the utility companies involved. However, these seven utilities account for around 25% of the residential electricity consumption in Switzerland. Variables collected include characteristics of houses (e.g., the number of rooms they live in), demographics of households (e.g., the gender and age group), the stock of appliances, rough characteristics of appliances (e.g. if older than 10 years), the usage of appliances (e.g., the hours switched on) and the annual electricity consumption of the household. We exclude households with a yearly consumption of less than 200 kWh and more than 30,000 kWh. This leaves us with 1,944 observations.

The survey reports the electricity consumption for the previous year. The household electricity consumption was not asked during the interview but was obtained from the last regular meter readings conducted by the respective utility company. Comparing the mean total consumption in kWh per household and per capita in our sample to the Swiss Electricity Statistics (SFOE, 2013) shows that both values in our sample are lower. One possible explanation is that households with an electric heating systems are not part of our sample. Between 2000 and 2008 the share of electric heated homes in Switzerland decreased by 3.8%, but is still at a level of 6% (Prognos, 2008). The distribution of the electricity consumption for the utilities in 2005 and 2011 are provided in the kernel density plots in figures 1 and 2, respectively. The upper graph in each figure is for the total electricity consumption and the lower graph is for its logarithmic transformation. Figure 2 shows that utilities 3 and 7 are quite different compared to utilities 1, 2, and 6. The customers of utilities 3 and 7 are all exclusively located in urban areas while the customers of utilities 1, 2, and 6 are distributed between rural and urban areas, as shown in table 10 in the Appendix.[6] Figure 1 also shows that utility 1 is very different compared to the other utilities. Therefore, we construct a dummy variable to control for a household belonging to utility 1. Table 2 shows the representativeness of our sample, comparing household income, number of rooms, abundance of children and household size to numbers from the Swiss Federal Statistical Office (BFS).[7] In our sample, the distribution of gross household income appears to be a little different from the distribution obtained from BFS. However, since our data has only income groups it is difficult to make an appropriate comparison. The number of rooms, household size and percentage of households with children are comparable to the whole of Switzerland. Therefore, we conclude that our sample is representative.

Table 2: Representativeness

Variable	**BFS**	**VSE**
Gross Household Income in CHF per month†		
1st Quintile	4880	3750
2nd Quintile	7173	5250
3rd Quintile	9702	7500
4th Quintile	13170	12000
Number of rooms		
1-2 rooms	17.96%	11.28%
3-5 rooms	71.06%	72.85%
6 rooms or more	10.97%	15.86%
Household size		
1-2 person	68.91%	66.44%
3-4 person	25.54%	27.77%
5 person or more	5.56%	4.79%
children	32.25%	29.85%

†:VSE incomes are calculated using the mid-point of the income groups

[6] We define urban as an area of agglomeration with more than 10,000 inhabitants.
[7] http://www.bfs.admin.ch/bfs/portal/de/index/themen.html

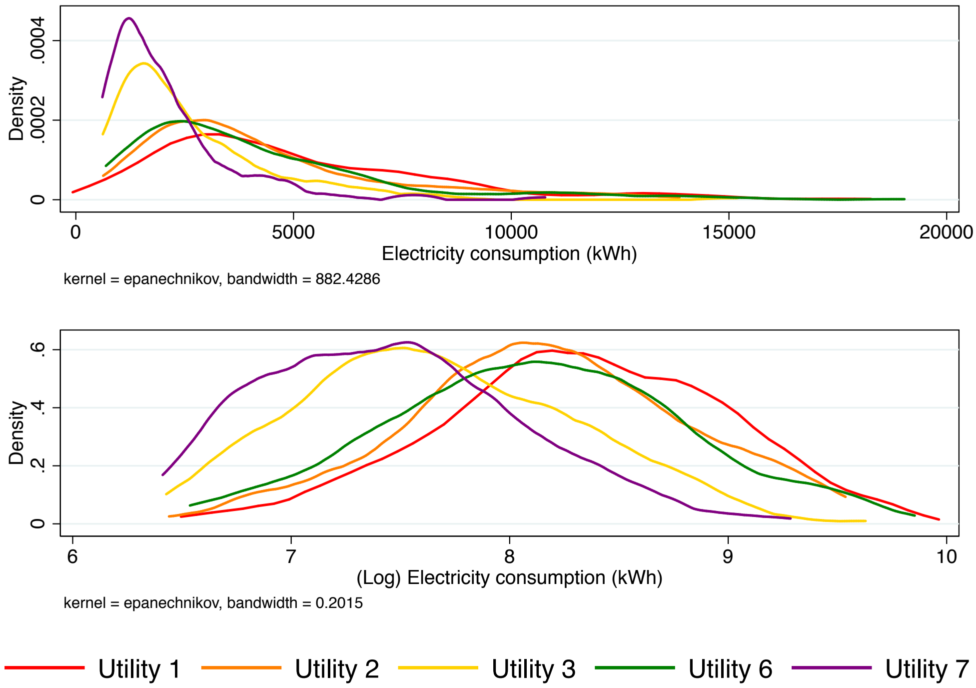

Figure 1: Kernel Density Plot for 2005

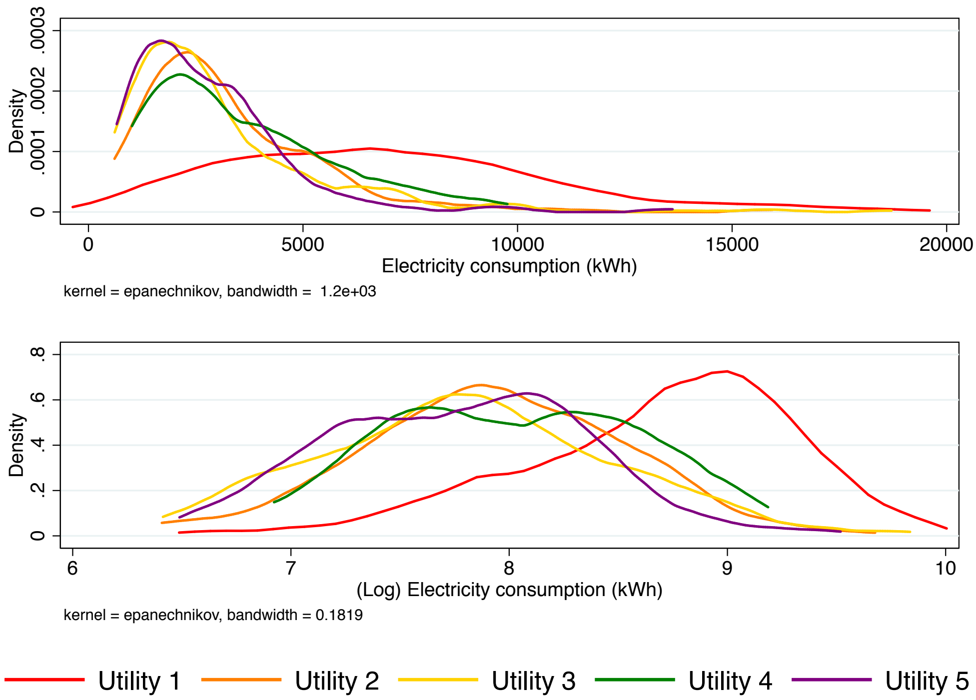

Figure 2: Kernel Density Plot for 2011

Table 3: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Consumption & Price					
Total consumption in kWh	3833.2	3123.27	247	29476	1944
Average Price	17.28	5.73	2.83	62.8	1944
ElCom Price	16.03	4.37	8.02	29.75	1844
Neighbouring ElCom Price	18.91	4.08	9.70	27.42	1844
Income Groups					
Income group 1	0.09	0.29	0	1	1944
Income group 2	0.17	0.37	0	1	1944
Income group 3	0.23	0.42	0	1	1944
Income group 4	0.29	0.46	0	1	1944
Income group 5	0.18	0.38	0	1	1944
Income group 6	0.04	0.20	0	1	1944
Household characteristics					
Number of rooms	4.15	1.49	1	9	1944
Household size	2.38	1.22	1	8	1944
Single family housing dummy	0.34	0.47	0	1	1944
Tenant dummy	0.55	0.5	0	1	1944
Children dummy	0.31	0.46	0	1	1944
Retired dummy	0.32	0.47	0	1	1944
Share female	0.55	0.29	0	1	1944
Time-of-use dummy	0.77	0.42	0	1	1944
Urban dummy	0.6	0.49	0	1	1944
Utility 1 dummy	0.16	0.37	0	1	1944
Year 2011 dummy	0.49	0.5	0	1	1944
Appliances					
Appliance Index (Watt)	5147.48	2049.91	110	11380.1	1944
Freezer	0.55	0.5	0	1	1944
Electric boiler	0.32	0.46	0	1	1944
Washing machine	0.55	0.5	0	1	1944
Dishwasher	0.72	0.45	0	1	1944
Electric stove	0.96	0.2	0	1	1944
Tumble dryer	0.58	0.49	0	1	1944
Micro wave oven	0.52	0.5	0	1	1944
Separate oven	0.37	0.48	0	1	1944
No. of fridge	1.14	0.38	1	3	1944
No. of TV	0.72	0	7	1944	
No. of PC	1.34	1.14	0	9	1944
Appliance User Costs					
Price per watt	0.44	0.4	0.14	7.24	1944
Price of freezer	121.53	17.56	88.55	139.56	1944
Price of electric boiler	81.8	16.61	58.39	156.8	1944
Price of washing machine	348.81	29.98	312.3	382.01	1944
Price of dishwasher	281.01	26.96	238.94	329.6	1944
Price of electric stove	138.18	18.63	109.48	167.22	1944
Price of tumble dryer	178.56	49.85	124.92	231.53	1944
Price of micro wave oven	32.31	7.26	23.93	39.55	1944
Price of oven	133.65	8.12	124.09	142.14	1944
Price of fridge	154.83	45.17	83.28	231.53	1944
Price of TV	307.56	199.15	66.02	1598.12	1944
Price of PC	373.17	143.63	109.49	610.71	1944
Energy Services					
No. of meals per day	2.39	1.03	0.14	13	1944
No. of hot water services per day	1.27	1.41	0	16.14	1944
No. of washing services per week	3.23	4.60	0	54	1944
Hours of entertainment per day	7.34	9.05	1	176	1944

3.2 Electricity Price

Apart from the survey, we also use electricity price data for 2004 from "Preisüberwacher"[8] and for 2010 from the Federal Electricity Commission (ElCom) as well as price data collected from VSE.[9]

We consider the following price variables in our specifications.

1. The first is the **average price** which is calculated by multiplying the electricity consumption of the household with the marginal price faced by the household, adding the fixed fee (if any) and dividing this total cost by the total electricity consumption. This price variable is endogenous since it depends on electricity consumption and therefore, we have to correct for its endogeneity which we do in later specifications. We use an instrumental variables approach that will provide consistent estimates of the price elasticity. The instrument should be correlated with the average price but affect the electricity consumption only through its effect on average price.
2. The second price variable is the **ElCom price** (ElCom, 2013). It is a weighted average price faced by a typical household with certain characteristics. It is calculated according to the consumption profile for each household type by taking into account summer and winter and four blocks during the day (6 a.m.– 12 p.m., 12 p.m.– 6 p.m., 6 p.m.– 10 p.m. and 10 p.m.– 6 a.m.). Since this is an average price faced by a typical household with certain characteristics it does not suffer from a potential endogeneity problem as in the calculated average price above. Therefore, we will use this price as an instrument for the average price. The way we construct the ElCom price for each household is to match a particular household with certain characteristics, as given in table 4, with the ElCom price faced by a typical household with similar characteristics serviced by the respective utility. For example, if a household in our sample lives in a flat and consumes 2000 kWh of electricity per year then it belongs to ElCom household type H2 and is assigned the corresponding ElCom price.
3. The third price we use is the **ElCom price of neighbouring utilities**. This is also used as an instrument for the potentially endogenous average price. The reason for choosing this as an instrument is that it is very likely that the electricity price of a utility will be highly correlated with that of neighbouring utilities but the electricity consumption of a household in that particular utility will not be correlated with the price in a neighbouring utility. We choose utilities that are geographically near to a particular utility and calculate the average ElCom price of those utilities. We then use this average price as our second instrument.

[8] http://www.preisueberwacher.admin.ch/dokumentation/00073/00074/00203/index.html?lang=de

[9] We refer to the 2004 electricity prices as ElCom prices to maintain consistency. ElCom was founded only in 2009 and started collecting data from then onwards. The 2004 prices from the "Preisüberwacher" are collected using the same methodology as the ElCom prices in 2010. Marginal price data were collected with the help of VSE.

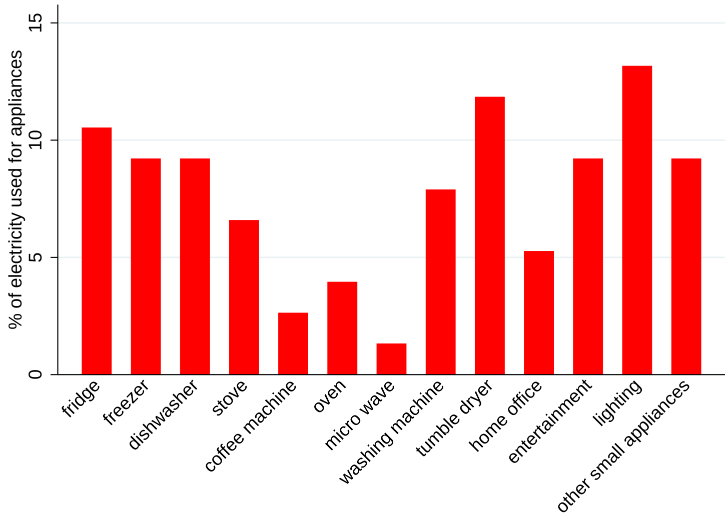

Figure 3: Share of electricity used by major household appliances. (Source: SAFE)

Table 4: ElCom Household Types

Type	Electricity [kWh/year]	Other	Number	%
H1	0-1,600	flat	366	18.83%
H2	1,600 - 2,500	flat	347	17.85%
H3	2,500 - 4,500	flat+boiler	95	4.89%
H4	2,500 - 4,500	flat+no boiler	301	15.48%
H5	0-7,500	sfh	484	24.90%
H6	13,000 - 25,000	sfh	36	1.85%
H7	7,500 - 13,000	sfh	137	7.05%
H8	> 4,500	flat	78	4.01%
Not matched			100	5.14%

3.3 Appliances

The VSE survey contains information on a number of appliances owned by a household. Schleich and Mills (2011) state that the major household appliances use 35% of residential end-use consumption of electricity in the EU 15 states. Figure 3 shows the most abundant home appliances and their share of electricity consumption in Switzerland. Kitchen appliances are a big share with more than 40% of the electricity consumed. In this paper, we do not use the categories "other small appliances", "lighting" and "coffee machine" since the capacities and prices are very diverse within these categories. This will make it challenging to estimate reference values. We use televisions (TVs) and personal computers (PCs) as representative of the categories "home office" and "entertainment". Our analysis is restricted to 11 major appliances, namely, *refrigerators, freezers, electric stoves, electric ovens, microwaves, dishwashers, clothes washers, tumble dryers, electric boilers, television sets* and *personal computers*. We assume that a household possesses a tumble dryer and clothes washer only if their usage is reflected in its own electricity bill.

We construct an appliance index that aggregates the appliances owned by a household into one index that can be compared across the households in our survey. We do this by using estimated reference capacities of the 11 major appliances divided into their vintage (older than 5 or 10 years) and size. The estimated reference capacity of an appliance is the average power used by the appliance while in use. [10] Electric boiler capacities are estimated by using the number of people in a particular household. See table 5 for the detailed appliance characteristics used for the index. The advantage of using an appliance index is the relatively higher precision of the appliance capacity obtained when compared to using an aggregated count variable or individual appliance dummies. Only a few studies have utilised such an appliance index. Garbacz (1984) develops a three-equation model with an electricity demand equation, an appliance stock equation and an equation for the electricity price. However, his appliance index is based on typical usage of the individual appliances in kWh and not a measure of typical capacity. Tiwari (2000), on the other hand, constructs an index based on average power requirement of the appliances.

We define the *appliance index* of household i (AI_i) as the sum of the estimated reference capacities of the 11 appliances (in Watts):

$$AI_i = \sum_{k=1}^{11} \text{Estimated Reference Capacity}_{i,k} \tag{17}$$

where k refers to appliance k. The estimated reference capacity is a function of the vintage, size and household size (only for electric boilers).

Following Diewert (1974) and Thomas (1987) we define P'_k as the *rental price of capital stock*[11] for appliance k:[12]

$$P'_{k,t} = \Big((\delta_{lifetime} \cdot P_{k,t+1}) + (r_{t,canton} \cdot P_{k,t}) + (P_{k,t} - P_{k,t+1})\Big) \cdot \frac{1}{1 + r_{t,canton}} \tag{18}$$

where $P_{k,t}$ is the estimated reference price of each appliance k [13], $(\delta_{lifetime} \cdot P_k)$ is the annual depreciation cost and $(r_{t,canton} \cdot P_{app})$ is the annual opportunity cost of capital. The interest rate $r_{t,canton}$ consists of cantonal mortgage interest rates.[14] Assuming a *one-hoss-shay* type of depreciation (Bruse and Fuhrmann, 1981), $P_{k,t+1}$ is equal to $P_{k,t}$.[15] Therefore, P'_k simplifies to:

$$P'_k = (\delta_{lifetime} + r_{t,canton}) \cdot P_k \cdot \frac{1}{1 + r_{t,canton}} \tag{19}$$

Using the estimated reference capacity and the estimated rental price of the eleven appliance categories we can create, for each household, a *price per installed capacity (in Watts)*. We will use this price per in-

[10] The estimated reference capacities (in terms of Watt) have been provided by Schweizerische Agentur für Energie Effizienz (SAFE).

[11] This is sometimes referred to as the *user cost of capital*

[12] There is also a simplified version of the rental price that assumes that the capital stock is not sold in the next period but is kept till its value depreciates to zero. We have estimated the models using this version and the results remain unchanged.

[13] These estimates were also provided to us by SAFE.

[14] The interest rate figures were provided by comparis, a Swiss price comparison website.

[15] The initial value of the appliance is the same as in the next time period (t+1), as there are no efficiency losses during the lifetime (called one-hoss-shay depreciation). At the end of the appliance's lifetime the value will be zero instantly.

Table 5: Capacity characterisation of appliances

Appliance	Age class	Size class	Other Char.
fridge	10 years	small/large	freezer compartment/combined
freezer	10 years	small/large	upright/deep
dishwasher	10 years		
stove	10 years		
oven	10 years		
microwave	10 years		
washing machine	10 years		
tumble dryer	10 years		
tv	5 years	small/middle/large	flatscreen
pc	5 years	small/middle/large	flatscreen, laptop/desktop
boiler			household size

stalled capacity in two ways, firstly in the long-run estimation and secondly as instrument for the household's stock of appliances. This is defined as:

$$PI_i = \frac{\sum_{k=1}^{11}(\text{Rental Price of Appliance}_{i,k})}{\sum_{k=1}^{11}(\text{Estimated Reference Capacity}_{i,k})} = \frac{\sum_{k=1}^{11} P'_k}{AI_i}. \quad (20)$$

Table 5 shows the appliance characteristics that we were able to incorporate into the appliance index. The fact that we are able to incorporate vintage and size among other characteristics makes our appliance index unique and more precise than a set of appliance dummies. Figure 4 displays the appliance index as a histogram. In the empirical analysis we use the appliance index because it incorporates the stock of appliances used in the production of energy services more precisely.

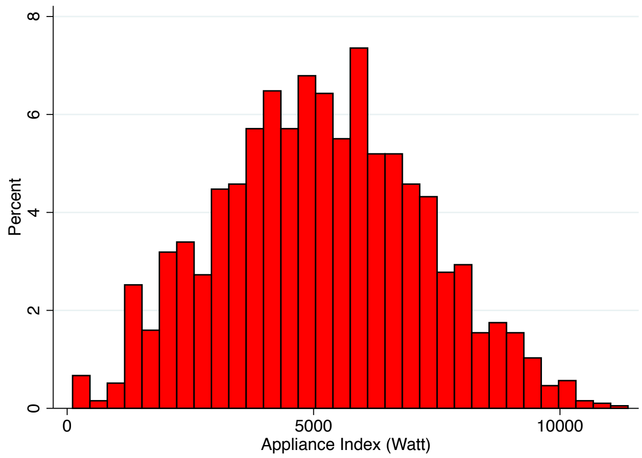

Figure 4: Histogram of Appliance Index

3.4 Energy Services

The VSE survey also contains information on some activities by households with regard to energy usage in the week prior to the survey being undertaken. We combine energy usage into four broad categories, viz. the amount of washing, the amount of meals cooked at home, the number of hours spent on entertainment and the amount of hot water services. We combine the usage of a washing machine, tumbledryer and dehumidifier as representing the amount of washing. The amount of meals cooked at home is defined as the sum of breakfasts, lunches and dinners made at home. We obtain the number of hours spent on entertainment by adding the hours spent on a personal computer and on watching television. Hot water services are calculated by adding the number of showers and baths taken. Table 3 provides a summary of these variables. Lighting is also an important component of energy services. However, since we do not have information on the number of hours a household's lights are switched on we use the number of rooms as an approximation.

4 Estimation Results

We now present the results obtained by estimating models based on equations (15a), (15b), (16a) and (16b). The first set of results estimates short-run models using the appliance index while the second set estimates long-run models using the price index as calculated with equation (20) and then separately with the appliance user costs as estimated in equation (19). We first estimate the models using the set of household and sociodemographics and then estimate the models using energy services.

4.1 Short-Run

The results of the electricity demand estimation in the short run using the appliance index from equation (17) are shown in table 6. In columns (1) and (2) we assume that the average electricity price and appliance stock are exogenous. We test for the potential endogeneity of the average electricity price and the appliance index and find that the null hypothesis of these two regressors being exogenous cannot be accepted.[16] Therefore, we focus on columns (3) and (4) where the average electricity price and the appliance index are assumed to be endogenous. The instruments we use are the ElCom prices, both for the own utility and neighbouring utilities, and the price per installed capacity. The p-value of the Hansen J-statistic for overidentification shows that the null hypothesis of valid instruments cannot be rejected and that the overidentifying restrictions are valid. Since we have two endogenous variables the relevant statistic to test for weak instruments is the Cragg-Donald statistic (Cragg and Donald, 1993). Stock and Yogo (2002) calculate the critical value of the Cragg-Donald statistic for a model with two endogenous variables and three instruments and find it to be 13.43.[17] The values reported in table 6 easily exceed the critical value and we can, therefore, conclude that the instruments are not weak.

The difference between the two columns is that in column (3) we use equation (11b) where the household

[16] We use the `endog()` option in STATA's `ivreg2` (Baum et al., 2010) command.

[17] The first stage results are reported in table 11 in the Appendix. All the instruments are significant and have the expected signs. In the first stages for the endogenous appliance index models we find that the appliance stock is highly dependent on the income dummies, which are all positive and significant. Furthermore, the appliance index depends significantly on the electricity price.

characteristics and sociodemographic variables are used to determine the electricity demand while in column (4) we use equation (11a) where energy services are used instead of sociodemographics. However, we also include certain residential characteristics in column (4), e.g. if the household lives in a single family house, if it resides in an urban area, and if it is a tenant in the residence. These characteristics are not captured by the energy services. We also include the number of rooms as a residential characteristic since our energy services variables do not include the effect of lighting on electricity consumption. We include an indicator for whether a household is a customer of utility 1 since the electricity consumption in that particular utility is quite different to the rest of the utilities in the survey. We also have an indicator for the year in which the survey was carried out as well as an indicator for a household having a time-of-use tariff structure.

The price elasticities are negative, as expected, and statistically significant. Instrumenting for the potential endogeneity bias of the average price, we obtain a price elasticity of between -0.6 and -0.54. The coefficient for appliance stock is positive and significant across the two models and indicates that installing 10% more capacity (in Watts) will lead to a 1.3% to 2% increase in electricity consumption. Unfortunately, we cannot calculate the income elasticity since the VSE survey only reports income ranges for households. While the coefficients for the income dummies are negative in column (1) only two groups are statistically significant. This can be caused by the income effect being captured by certain residential and household characteristics like the number of rooms and household size.[18]

Table 7 shows the expected sign of the coefficients related to the characteristics of households. Most coefficients of household characteristics, as presented in column (3) of table 6, are significant and show the expected sign. Household size, number of rooms, dummy for single family housing and dummy for children increase the electricity demand, as expected. Households residing in an urban area and those with a higher share of females reduce the estimated electricity demand, as expected. Results also indicate that households with a time-of-use (TOU) pricing scheme tend to use less electricity. However, the estimated coefficient is statistically insignificant. The TOU tariff system is designed to shift some of the peak period consumption to the off-peak period. The part of peak period consumption that cannot be shifted to the off-peak period is consumed in the peak price period and therefore less electricity is consumed in the peak period due to the higher price. Share of female may have a negative influence because either there are unobserved wealth effects (Brounen et al., 2012) or because women are more conscious towards environmental and energy related topics (Gaspar and Antunes, 2011). Tenants also tend to use less electricity. The strong statistical significance in household characteristics indicates a large degree of heterogeneity among households which indicates the need to use disaggregated data.

The results of the estimation in column (4) of table 6 indicate the change in electricity demand due to a change in certain energy services. An increase in cooking a meal at home by one per day leads to an increase in electricity consumption by 4% while an hour more of entertainment per day increases electricity consumption by 1%. Using one more hot water service per day increases electricity consumption by 6% while one more washing service per week increases electricity consumption by 2%.

[18]The models have been estimated with only the price of electricity and income groups and the results, not presented here, show that the effect of the income groups is positive and significant. We have also performed a multicollinearity check after estimating the full model and find that the highest variance inflation factor is below 3.5. This indicates that multicollinearity is not an issue in our full model.

Table 6: Short-run electricity demand estimation

	(1)	(2)	(3)	(4)
(Log) Average Price	-0.89[a]	-0.83[a]	-0.59[a]	-0.54[a]
	(0.08)	(0.08)	(0.07)	(0.07)
(Log) Appliance Stock (in Watts)	0.27[a]	0.21[a]	0.19[a]	0.13[a]
	(0.03)	(0.03)	(0.04)	(0.04)
Income group 2	-0.01		-0.02	
	(0.05)		(0.05)	
Income group 3	-0.08		-0.08	
	(0.05)		(0.05)	
Income group 4	-0.14[a]		-0.12[b]	
	(0.05)		(0.05)	
Income group 5	-0.17[a]		-0.13[b]	
	(0.06)		(0.06)	
Income group 6	-0.14[c]		-0.07	
	(0.08)		(0.08)	
(Log) Household size	0.27[a]		0.27[a]	
	(0.04)		(0.04)	
Children dummy	0.10[b]		0.07[c]	
	(0.04)		(0.04)	
Retired dummy	-0.10[a]		-0.09[a]	
	(0.03)		(0.03)	
Share female	-0.16[a]		-0.17[a]	
	(0.05)		(0.04)	
Single family housing	0.23[a]	0.21[a]	0.32[a]	0.30[a]
	(0.04)	(0.04)	(0.04)	(0.04)
Urban	-0.22[a]	-0.23[a]	-0.15[a]	-0.16[a]
	(0.03)	(0.03)	(0.03)	(0.03)
Tenant	-0.15[a]	-0.12[a]	-0.14[a]	-0.11[a]
	(0.03)	(0.03)	(0.03)	(0.03)
(Log) No of rooms	0.24[a]	0.32[a]	0.23[a]	0.31[a]
	(0.05)	(0.04)	(0.05)	(0.04)
No. of meals per day		0.04[a]		0.04[a]
		(0.01)		(0.01)
Hours of entertainment per day		0.01[a]		0.01[a]
		(0.00)		(0.00)
No. of hot water services per day		0.06[a]		0.06[a]
		(0.01)		(0.01)
No. of washing services per week		0.02[a]		0.02[a]
		(0.00)		(0.00)
Utility 1	0.21[a]	0.17[a]	0.25[a]	0.21[a]
	(0.03)	(0.03)	(0.03)	(0.03)
TOU dummy	-0.13[a]	-0.12[a]	-0.02	-0.01
	(0.04)	(0.04)	(0.04)	(0.04)
Year 2011	0.03	0.09[a]	0.07[a]	0.12[a]
	(0.02)	(0.03)	(0.02)	(0.03)
Observations	1,944	1,944	1,844	1,844
Adjusted R^2	0.54	0.53	0.54	0.53
p-value of J-statistic			0.45	0.40
Cragg-Donald F-statistic			878.97	720.14
p-value of Endogeneity test			0.00	0.00

Standard errors in parentheses
[a]: $p < 0.01$, [b]: $p < 0.05$, [c]: $p < 0.10$

Table 7: Household characteristics and their expected sign on electricity demand

Variable	Sign	Reference
Number of rooms	+	Baker et al. (1989)
Household size	+	Baker et al. (1989)
Single Family Housing dummy	+	Brounen et al. (2012)
Tenant dummy	+/−	
Children dummy	+	Baker et al. (1989)
Share female	−	Brounen et al. (2012)
Time of use dummy	+/−	
Urban dummy	−	Leahy and Lyons (2010)
Income groups	+	Economic theory in general

4.2 Long-Run

The long-run estimates of electricity demand are shown in table 8. These models include the rental price of appliances. Columns (1) and (3) use the individual rental prices of the appliances whereas columns (2) and (4) use the price index of the appliances as calculated in equation (20). As in the short-run estimation we use household characteristics and sociodemographic variables in columns (1) and (2) while in columns (3) and (4) we use energy services instead of sociodemographics. The only difference between the long-run and short-run models is that the appliance index in the latter is replaced by either the price of an aggregate measure of appliance stock or by the prices of individual appliances.

The price elasticities of residential electricity demand are negative, as expected, and statistically significant and range from a low of -0.56 to a high of -0.68. Using the rental prices of capital stock, we find that an increase in 10% of the price per watt leads to a decrease in electricity consumption by around 1% to 1.7%.[19] The effect of the income groups is statistically insignificant, except for income group 4 in column (1). The share of females in a household, being located in an urban area and being a tenant have negative and significant effects on the electricity consumption. Increasing the household size, number of rooms and having children have positive and significant effects on the electricity consumption. All the coefficient estimates are very similar across the different models.

As in the case with the short-run estimation we test for the potential endogeneity of the average electricity price and find that the null hypothesis of these two regressors being exogenous cannot be accepted.[20] The p-value of the Hansen J-statistic shows that the overidentifying restrictions are valid at the 5% level. Since we have only one endogenous variable, the relevant statistic to check for weak instruments is the F-statistic of the first stage. The high value of the F-statistic indicates that our instruments are not weak.[21]

The results of the estimation in columns (3) and (4) of table 8 using energy services instead of the usual household characteristics indicate the change in electricity demand due to a change in certain energy services.

[19] We do not report the coefficients of the prices for individual appliances in the table. If we consider the rental prices of individual appliance only those of freezers and electric stoves are negative and significant. The rental price of personal computers is positive and significant in both models.

[20] As before, we use the `endog()` option in STATA's `ivreg2` (Baum et al., 2010) command.

[21] The first stage results are reported in table 12 in the Appendix. Both instruments are significant and have the expected, positive, signs.

The results from the long-run estimation are very similar to the estimates obtained in the short-run electricity demand estimation. An increase in cooking a meal at home by one per day leads to an increase in electricity consumption by around 2-3% while an hour more of entertainment per day increases electricity consumption by 1%. Using one more hot water service per day increases electricity consumption from 4-7% while one more washing service per week increases electricity consumption by 2%.

Table 8: Long-run electricity demand estimation

	(1)	(2)	(3)	(4)
(Log) Average Price	-0.68^a	-0.62^a	-0.60^a	-0.56^a
	(0.07)	(0.07)	(0.07)	(0.07)
Price of Individual Appliances	Yes		Yes	
(Log) Price of Capital Stock		-0.17^a		-0.10^a
		(0.03)		(0.04)
Income group 2	-0.01	0.00		
	(0.05)	(0.05)		
Income group 3	-0.06	-0.04		
	(0.05)	(0.05)		
Income group 4	-0.09^c	-0.07		
	(0.05)	(0.05)		
Income group 5	-0.09	-0.07		
	(0.06)	(0.06)		
Income group 6	-0.03	0.01		
	(0.08)	(0.08)		
(Log) Household size	0.34^b	0.29^a		
	(0.15)	(0.04)		
Children dummy	0.08^c	0.07		
	(0.04)	(0.04)		
Retired dummy	-0.08^b	-0.11^a		
	(0.03)	(0.03)		
Share female	-0.17^a	-0.18^a		
	(0.04)	(0.04)		
Single family housing	0.32^a	0.33^a	0.29^a	0.30^a
	(0.04)	(0.04)	(0.04)	(0.04)
Urban	-0.17^a	-0.16^a	-0.17^a	-0.17^a
	(0.03)	(0.03)	(0.03)	(0.03)
Tenant	-0.15^a	-0.16^a	-0.13^a	-0.13^a
	(0.03)	(0.03)	(0.03)	(0.03)
(Log) No of rooms	0.26^a	0.28^a	0.22^a	0.35^a
	(0.05)	(0.05)	(0.04)	(0.04)
No. of meals per day			0.02	0.03^a
			(0.01)	(0.01)
Hours of entertainment per day			0.01^a	0.01^a
			(0.00)	(0.00)
No. of hot water services per day			0.04^b	0.07^a
			(0.01)	(0.01)
No. of washing services per week			0.02^a	0.02^a
			(0.00)	(0.00)
Utility 1	0.22^a	0.26^a	0.19^a	0.21^a
	(0.03)	(0.03)	(0.03)	(0.03)
TOU dummy	-0.08	-0.03	-0.06	-0.02
	(0.05)	(0.04)	(0.05)	(0.04)
Year 2011	0.59^b	0.05^b	0.55^b	0.12^a
	(0.24)	(0.02)	(0.24)	(0.03)
Observations	1,844	1,844	1,844	1,844
Adjusted R^2	0.53	0.53	0.54	0.53
p-value of J-statistic	0.21	0.38	0.28	0.32
F-statistic of first stage	1092.81	1493.82	1120.17	1515.82
p-value of Endogeneity test	0.00	0.00	0.00	0.00

Standard errors in parentheses

[a]: $p < 0.01$, [b]: $p < 0.05$, [c]: $p < 0.10$

4.3 Discussion

If we compare the models with exogenous and endogenous average price we see that instrumenting for average price reduces the elasticity from around -0.8 to around -0.6. This indicates that not correcting for the endogeneity of average price overestimates the price elasticity.[22] This appears consistent with Vaage (2000) who mentions that ignoring the simultaneity of the appliance choice and usage may lead to a downward bias in the price elasticities of electricity demand.

If we compare the different ways of incorporating appliances into the electricity demand estimation then using an appliance index is a superior approach to using individual appliance dummy variables since it avoids the problem of finding enough instruments in an instrumental variable approach. It is very difficult to find instruments for multiple endogenous variables due to the possibility of weak instruments that will produce inconsistent estimates. We can also distinguish vintage and size among other characteristics of the appliances with the index. This makes our approach using an appliance index unique and more precise than the traditional way of using a set of individual appliance dummies. Our results also indicate that using the appliance index produces very stable results.

A household's appliance stock is not fixed in the long run and therefore we expect the long-run electricity price elasticities to be higher than the short-run price elasticities. While in the short-run only the utilisation rate of the existing capital stock can be chosen, in the long run the level of capital stock can also be optimised. In some studies, elasticity estimates from cross-sectional studies are interpreted as being long-run values (Baltagi and Griffin, 1984). The assumption is that the majority of households in a cross-section are well adapted to their financial circumstances and the cross-section will represent a steady-state. Therefore, the estimated elasticities will represent long-run circumstances (Thomas, 1987). However, the long-run elasticities in this study are only slightly higher than the short-run estimates. This is possibly because the long-term estimates may be considered to be more medium-term due to the cross-sectional nature of the data and we do not directly observe any adjustment decisions. Halvorsen and Larsen (2001) use pooled cross-section data (five years) from the Norwegian Survey of Consumer Expenditure and also find negligible differences between estimated short- and long-run Cournot elasticities. They attribute this result to the fact that there is no substitute for electricity in the use of household appliances in Norway.

5 Conclusion

In this paper we estimate the price elasticity of residential electricity consumption in Switzerland using a unique household survey conducted in 2005 and 2011. The future direction of Swiss climate and energy policies has been the subject of much political debate. It is, therefore, important to obtain a measure of the responsiveness of Swiss households to changes in the price of electricity. This will enable policy makers and electric utility companies to design appropriate pricing policies to modify consumer behaviour. The previous estimate of price elasticity with household data in Switzerland was done in 1998 and our study is a much-needed update of this measure. Moreover, our study improves upon the previous studies by using an

[22] We also correct for the possible endogeneity of the appliance index by using an instrument and find that the price elasticity increases very slightly. The results are not reported in this paper but can be obtained upon request.

Table 9: Estimated price elasticities

Short-Run	
Socio-demographics	−0.59
Energy services	−0.54
Long-Run	
Individual prices & socio-demographics	−0.68
Price of Watt & socio-demographics	−0.62
Individual prices & energy services	−0.60
Price of Watt & energy services	−0.56

instrumental variables approach to correct for potential endogeneity concerns as well as using an aggregate measure of a household's stock of appliances.

We estimate the effect of the stock of household appliances on the consumption of electricity. Previous studies have not always considered household appliances and when they have, not always accounted for the possibility that the choice of appliances may be endogenous. We construct an appliance stock index to capture a household's stock of major appliances. This is a single index that avoids the problem of choosing multiple instruments that may lead to a problem of weak instruments. It also has the advantage of being a more precise measure of the appliance stock than using appliance indicator variables. We also estimate models of electricity demand based on household production theory that use energy services like the number of meals cooked at home and the amount of time spent using personal computers and watching television.

In our analysis we calculate the long- and short-run price elasticities using an instrumental variables approach to account for the fact that the price of electricity and the appliance stock may lead to simultaneous causality and, therefore, be endogenous. The price of electricity is endogenous since we use the average price obtained by multiplying the electricity consumption with the marginal price of electricity and adding the fixed fee component, if applicable. The stock of appliances may be endogenous since the choice of appliances may depend on the amount of electricity consumed.

We find that, after correcting for endogeneity, the long-run price elasticity of residential electricity consumption is generally higher than -0.6 while the short-run estimate is lower than -0.6. Table 9 provides a summary of the estimated price elasticities using the different models. Our observation is in line with existing economic theory that the long-run elasticity should be higher than the short-run because households take into account the decision to adjust their stock of appliances. Therefore, they are more sensitive to price changes in the long-run. The price elasticity estimates for Switzerland fall within the range of other studies made for other countries as well as previous studies for Switzerland that use disaggregated data and show that the response of Swiss households to electricity prices is inelastic.

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Appendix

Tables

Table 10: Rural versus Urban Households

Utility	Rural	Urban	Total
1	252	68	320
2	203	135	338
3	0	468	468
4	88	75	163
5	3	145	148
6	229	114	343
7	0	164	164
Total	775	1,169	1,944

Table 11: First stage - Short-run electricity demand estimation

	(1)		(2)	
	(a)	(b)	(a)	(b)
(Log) Elcom price	0.94^{a}	-0.19^{a}	0.95^{a}	-0.22^{a}
	(0.03)	(0.06)	(0.03)	(0.06)
(Log) Neighbouring Elcom Price	0.05^{b}	0.06	0.05^{b}	0.10
	(0.02)	(0.06)	(0.02)	(0.07)
(Log) Price of Capital Stock	0.01	-0.85^{a}	0.00	-0.79^{a}
	(0.01)	(0.02)	(0.01)	(0.03)
Income group 2	0.00	0.09^{a}		
	(0.01)	(0.03)		
Income group 3	0.01	0.18^{a}		
	(0.01)	(0.03)		
Income group 4	0.00	0.25^{a}		
	(0.01)	(0.03)		
Income group 5	-0.01	0.32^{a}		
	(0.01)	(0.03)		
Income group 6	-0.01	0.41^{a}		
	(0.02)	(0.04)		
(Log) Household size	-0.00	0.13^{a}		
	(0.01)	(0.02)		
Children dummy	0.02	-0.01		
	(0.01)	(0.02)		
Retired dummy	0.01^{b}	-0.12^{a}		
	(0.01)	(0.02)		
Share female	0.01	-0.03		
	(0.01)	(0.03)		
Single family housing	0.16^{a}	-0.00	0.17^{a}	-0.05^{b}
	(0.01)	(0.02)	(0.01)	(0.02)
Urban	-0.02^{b}	-0.03^{b}	-0.02^{b}	-0.03
	(0.01)	(0.02)	(0.01)	(0.02)
Tenant	-0.00	-0.12^{a}	-0.00	-0.12^{a}
	(0.01)	(0.02)	(0.01)	(0.02)
(Log) No of rooms	0.01	0.23^{a}	0.02	0.34^{a}
	(0.01)	(0.03)	(0.01)	(0.03)
No. of meals per day			0.00	-0.00
			(0.00)	(0.01)
Hours of entertainment per day			-0.00	0.01^{a}
			(0.00)	(0.00)
No. of hot water services per day			-0.01^{a}	0.04^{a}
			(0.00)	(0.01)
No. of washing services per week			0.00	0.02^{a}
			(0.00)	(0.00)
Utility 1	-0.03^{a}	0.06^{a}	-0.03^{a}	0.00
	(0.01)	(0.02)	(0.01)	(0.02)
TOU dummy	-0.11^{a}	-0.01	-0.11^{a}	-0.00
	(0.01)	(0.02)	(0.01)	(0.02)
Year 2011	-0.07^{a}	-0.04^{a}	-0.08^{a}	0.00
	(0.01)	(0.02)	(0.01)	(0.02)
Observations	1,844	1,844	1,844	1,844
Adjusted R^2	0.82	0.72	0.82	0.69

Standard errors in parentheses
^{a}: $p < 0.01$, ^{b}: $p < 0.05$, ^{c}: $p < 0.10$

Table 12: First stage - Long-run electricity demand estimation

	(1)	(2)	(3)	(4)
(Log) Elcom price	0.94[a]	0.94[a]	0.94[a]	0.95[a]
	(0.03)	(0.03)	(0.03)	(0.03)
(Log) Neighbouring Elcom Price	0.04[c]	0.05[b]	0.04[c]	0.05[b]
	(0.02)	(0.02)	(0.02)	(0.02)
(Log) Price of Capital Stock		0.01		0.00
		(0.01)		(0.01)
Income group 2	0.00	0.00		
	(0.01)	(0.01)		
Income group 3	0.01	0.01		
	(0.01)	(0.01)		
Income group 4	0.01	0.00		
	(0.01)	(0.01)		
Income group 5	-0.01	-0.01		
	(0.01)	(0.01)		
Income group 6	-0.00	-0.01		
	(0.02)	(0.02)		
(Log) Household size	0.04	-0.00		
	(0.04)	(0.01)		
Children dummy	0.02[c]	0.02		
	(0.01)	(0.01)		
Retired dummy	0.01	0.01[b]		
	(0.01)	(0.01)		
Share female	0.01	0.01		
	(0.01)	(0.01)		
Single family housing	0.16[a]	0.16[a]	0.16[a]	0.17[a]
	(0.01)	(0.01)	(0.01)	(0.01)
Urban	-0.02[b]	-0.02[b]	-0.02[b]	-0.02[b]
	(0.01)	(0.01)	(0.01)	(0.01)
Tenant	-0.00	-0.00	-0.00	-0.00
	(0.01)	(0.01)	(0.01)	(0.01)
(Log) No of rooms	0.01	0.01	0.01	0.02
	(0.01)	(0.01)	(0.01)	(0.01)
No. of meals per day			0.00	0.00
			(0.00)	(0.00)
Hours of entertainment per day			-0.00	-0.00
			(0.00)	(0.00)
No. of hot water services per day			-0.01[a]	-0.01[a]
			(0.00)	(0.00)
No. of washing services per week			-0.00	0.00
			(0.00)	(0.00)
Utility 1	-0.04[a]	-0.03[a]	-0.03[a]	-0.03[a]
	(0.01)	(0.01)	(0.01)	(0.01)
TOU dummy	-0.12[a]	-0.11[a]	-0.12[a]	-0.11[a]
	(0.01)	(0.01)	(0.01)	(0.01)
Year 2011	0.05	-0.07[a]	0.05	-0.08[a]
	(0.07)	(0.01)	(0.07)	(0.01)
Observations	1,844	1,844	1,844	1,844
Adjusted R^2	0.82	0.82	0.82	0.82

Standard errors in parentheses
[a]: $p < 0.01$, [b]: $p < 0.05$, [c]: $p < 0.10$

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