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Demand-side management by electric utilities in Switzerland: Analyzing its impact on residential electricity demand [*]

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Abstract

In this paper we use panel data from a survey conducted on 30 utilities in Switzerland to estimate the impact of demand-side management (DSM) activity on residential electricity demand. Using the variation in DSM activity within utilities and across utilities over time we identify the impact of DSM programs and find that their presence reduces per customer residential electricity consumption by around 5%. If we consider monetary spending, the effect of a 10% increase in DSM spending causes a 0.14% reduction in per customer residential electricity consumption. The cost of saving a kilowatt hour is around 0.04 CHF while the average cost of producing and distributing electricity in Switzerland is around 0.18 CHF per kilowatt hour. We conclude that current DSM practices in Switzerland have a statistically significant effect on reducing the demand for residential electricity.

Keywords: Residential electricity; demand-side management; energy efficiency score; difference-in-differences; Switzerland.

JEL Classification Codes: C33, C36, Q41, Q48.

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1 Introduction

Increasing energy efficiency in recent years has become a part of the strategy of many industrialized nations to reduce the emissions of greenhouse gases, the leading cause of climate change. However, policies to increase energy efficiency have been promoted since the oil crises of the 1970s. Energy efficiency policies have also been promoted to reduce air pollution from pollutants such as sulfur dioxide, nitrogen oxides, ozone and particulate matter, to improve energy security and to prevent the need for constructing increasingly expensive new power plants. The World Energy Outlook 2009 (International Energy Agency, 2009) and several other studies (Creyts et al., 2007; Granade et al., 2009; Nauclér and Enkvist, 2009) highlight the huge potential of CO_2 reductions from increased end-use energy efficiency. In view of these advantages of energy efficiency, policy instruments that promote the increase in energy efficiency play an important role. Apart from its impact on greenhouse gas emissions, the literature on energy efficiency argues that promoting energy efficiency costs less than building new power plants. There are also environmental reasons. Utility companies need to follow a number of environmental regulations. There are emissions control strategies in place and saving energy on the margin will allow the more polluting plants to be removed from producing electricity. Reducing electricity demand also reduces the need to upgrade the transmission and distribution network. Lastly, reducing peak demand combined with reducing energy demand can lead to grid reliability.

The discussion on energy efficiency, and energy policy in general, received an added impetus due to the Fukushima Daiichi nuclear accident on 11 March, 2011 that led to worldwide discussions about the security of nuclear power plants and energy policy issues. Germany imposed a three month moratorium on announced extensions for existing nuclear power plants and shut down 7 of its 17 power plants within days after the accident. Afterwards, the government announced that all existing power plants will be phased out by 2022. Italy had already closed down all its nuclear power plants after the Chernobyl accident, the last in 1990. However, the government planned to construct a new nuclear power plant and it was rejected in a referendum that took place in June 2011, just after the Fukushima incident (Jorant, 2011). In Switzerland, the Federal Council decided to suspend the approvals process for new nuclear reactors and, subsequently, to make the ban on new nuclear reactors permanent. Furthermore, it was decided that the country's five existing nuclear reactors would continue producing electricity until they are gradually phased out with no replacements. The implications of a switch in electricity generation from nuclear to other sources are important for countries like Germany and Switzerland that are heavily reliant on nuclear energy.[1]

Following the decision to phase out nuclear energy, the Swiss Federal Office of Energy (SFOE) developed an energy strategy, the *Energy Strategy 2050*. A part of this strategy sees utilities as key players for reducing electricity consumption due to their direct contact with end-customers. With this in mind the Federal Council had proposed, within the initial package of measures, mandatory efficiency goals at a national level

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[1] Almost 40% of Switzerland's electricity in 2011 was produced from nuclear energy. The end-use consumption of electricity was 58.6 TWh of which 30.6% was consumed by households (SFOE, 2013).

for utilities that sell more than 30 GWh as a way to reduce electricity consumption. The World Energy Outlook (International Energy Agency, 2009) emphasizes the huge potential of energy efficiency (EE) measures which are viewed by many as "low-hanging fruit" due to their low marginal cost.

Promoting energy efficiency is a part of demand-side management efforts that are often undertaken by utilities and the government. Demand-side management (DSM) refers to the *"planning, implementing, and monitoring activities of electric utilities that are designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand"* (Energy Information Administration, 1999). Utility DSM programs began in the late 1970s as a response to the energy crises. They were begun primarily by utilities on the west coast of the USA before gradually spreading to other regions of the USA, as well as to British Columbia, Ontario and other provinces in Canada. In recent years DSM has spread to Australia and several countries in Europe, Latin America and Asia, although DSM efforts outside of North America till the 1990s have been limited (Nadel and Geller, 1996).

The original intention of DSM programs was to change the pattern of electricity demand to modify the load faced by a utility. It has been subsequently modified to take into account the programs undertaken by utilities to promote energy efficiency. DSM, therefore, incorporates energy efficiency, energy conservation, and load management (Carley, 2012). There are various ways in which utilities and federal and local governments carry out these objectives. They include, among others, policies like appliance standards, financial incentive programs, information campaigns and voluntary programs (Gillingham et al., 2006).[2]

While there is a substantial literature on the development of DSM in the US and its impact on electricity demand, little is known about DSM efforts in other countries. There is a lack of systematic analysis of DSM efforts in Switzerland given the importance accorded to energy efficiency in *Energy Strategy 2050*. Therefore, we have two research questions. First, do utility DSM programs in Switzerland have an impact on residential electricity consumption? Second, what is the magnitude of this impact, if any? To answer these two questions we designed and carried out a survey on Swiss electric utilities to obtain data on DSM efforts between 2006 and 2012 and use the variation within utilities over time to identify its impact and magnitude. We also use the econometric results to calculate the cost of saving a kilowatt hour given the effectiveness of the DSM programs. We follow previous studies in identifying the impact of DSM programs by correlating differences in the per household residential electricity consumption with the variation in DSM expenditures within utilities over time. Unlike most studies, we also check the robustness of our approach by using an instrumental variables approach to account for any potential endogeneity problems arising out of measurement errors or simultaneity issues. We also try to attenuate any sample selection issues by using a Heckman-type model in the instrumental variables approach.

This paper contributes to the public policy debate about the degree to which DSM programs can reduce

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[2] For a detailed description of the history of utility-sponsored DSM programs in the US please refer to Eto (1996), Nadel and Geller (1996), and Nadel (2000).

the demand for electricity in the residential sector as well as influence the adoption of energy efficiency measures. While we correlate changes in electricity consumption with changes in spending on DSM programs or with the presence of DSM programs, we can only infer that energy efficiency measures are adopted by households through the impact on the household's electricity consumption. A second major contribution of this paper is that, to our knowledge, this is the first econometric estimation of aggregate DSM efforts in a European country. Another contribution is that we construct a scorecard to measure the energy efficiency activities of individual utilities and correlate changes in the scorecard to changes in the residential electricity consumption. Our scorecard is similar to the state energy efficiency scorecard published by the American Council for an Energy-Efficient Economy that measures the commitment of states in the US to promote energy efficiency.

The structure of the paper is as follows. In the next section we provide a brief overview of demand-side management efforts in Switzerland. We then describe the existing literature on evaluating DSM activities in section 3. In section 4 we provide a description of the survey performed on some Swiss utilities, the construction of an energy efficiency score and the utilities in our survey and their DSM activities. The variables used in our model and their sources are described in section 5. Our identification strategy and estimating equation are in section 6 while the results of the econometric estimation are presented in section 7. We perform some robustness checks in section 8. Policy implications are discussed in section 9 while the final section has concluding remarks.

2 DSM in Switzerland

Switzerland is a federal state consisting of 26 cantons and the responsibilities are divided between the federal government, cantonal governments and municipalities. In this institutional context, Swiss energy policy is defined and implemented at all three levels, *viz.* federal, cantonal, and municipal. Moreover, local utilities also play an important role especially for the definition of the implementation of DSM programs. It was only in 1990 that the energy policy was embedded in the Federal constitution. Swiss residents voted for the energy article in September 1990, giving the Federal government a mandate to promote the economical and efficient use of energy and renewable energy (SFOE, 2007). Following that, the Energy Act (EnG) and energy regulation (EnV) came into force in January 1999 (Swiss Confederation, 2014). Their goals were to ensure an economic and sustainable provision of energy and the promotion of local and renewable energy sources. The Federal Councillor Adolf Ogi started a program called "*Energie 2000*" that ran between 1990 and 2000. This program was relaunched in 2001 by Federal Councillor Moritz Leuenberger under "*EnergieSchweiz*". The activities of *EnergieSchweiz* aim at raising awareness, information and education, networking and promotion of projects in renewable energy and energy efficiency. The program works in partnership with the cantons, communities and partners from industry, environmental and consumer organizations, and private sector agencies (SFOE, 2014). Other energy efficiency measures introduced by the national government include appliance standards (SFOE, 2014) and energy labels (Sammer, 2007). The government introduced two measures for the industry: voluntary targets (EnAW, 2010) and competitive tenders (SFOE, 2012).

As previously mentioned, DSM policies are mostly defined and implemented at the local level. In Switzerland, 657 utility companies (as of February 2016) are involved in the production, distribution and supply of electricity.[3] These utilities are of different sizes ranging from small municipal utilities supplying single communities to international operating companies. In contrast to other European countries, there are two DSM measures that Swiss utilities have used for several decades: ripple control and time-of-use (TOU) pricing. Ripple control is a traditional instrument to control load in order to keep the electric network stable. Basically it is a superimposed higher-frequency signal that is put on the standard power signal (50 Hz). Loads can be switched off and on in this way, e.g. for public street lamps, electric boilers and heaters (SFOE, 2009). In addition, ripple control is used to switch from peak to off-peak hours in the traditional metering system. Most Swiss utilities apply TOU pricing to residential customers where prices vary according to the time of the day with higher prices during the day (peak period) as compared to the night (off-peak period). The difference between peak and off-peak prices vary between 50 and 100% (SFOE, 2009). There are also utilities that price differently in winter and summer but this approach has been losing popularity.

Zürich and Basel are two early examples where DSM measures were introduced by utilities in Switzerland. Residents of Zürich voted for a more rational use of energy in 1989. Subsequently, the public utility installed a fund that promoted energy saving measures and green investments (ewz, 2003). The parliament in the canton of Basel-Stadt voted for a new energy law in 1998 that was pioneering. It allowed the canton to impose a tax on electricity with the tax revenue to be redistributed equally among residents and companies (SFOE, 2003). In recent years, several utilities have introduced energy efficiency measures such as the rental of smart meters, awareness campaigns and funding for efficient appliances. However, there has been no policy framework on utility-centered energy efficiency at the national level till now.

3 DSM literature

The empirical literature on the effectiveness of demand side management (DSM) programs in the US is extensive. Table 1 provides an overview of the empirical analyses of DSM, almost exclusively in the US. Early analyses concentrate on estimating its cost-effectiveness measured in terms of the cost of kWh saved compared to the cost of producing it. For example, Joskow and Marron (1992) and Eto et al. (1996) find that these programs are both cost-effective and effective in reducing energy consumption. There are also several other qualitative studies that show that DSM programs are cost-effective (Eto et al., 2000; Nadel,

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[3] `https://www.elcom.admin.ch/elcom/de/home/themen/strompreise/tarif-rohdaten-verteilnetzbetreiber.html`, website accessed 16 July, 2016.

1992; Nadel and Geller, 1996). The early empirical analyses attempt to measure the accuracy of self-reported DSM savings of the utilities and draw conclusions on the effectiveness of DSM programs.

Literature on the evaluation of DMS programs outside of the US and especially the empirical estimation of the effectiveness of DSM measures is scarce. Dulleck and Kaufmann (2004) focus on information programs in Ireland and find that while the short-run demand behavior does not change significantly, the long-run demand changes by a great amount.[4] They conclude that information programs reduce electricity demand by around 7%. Rivers and Jaccard (2011) use a partial adjustment model with bias-corrected estimators and conclude that DSM expenditure has only a marginal effect on electricity consumption in Canada.

To the best of our knowledge, these are the only two empirical studies conducted outside of the US. This leaves a major gap in research on the effectiveness of European energy efficiency measures in the residential electricity sector. Moreover, all of the above-mentioned studies, except for Carley (2012) and Horowitz (2004), treat the policy variable as exogenous. This may bias results since unobserved factors that influence the residential electricity demand may also influence the state's decision on whether or not to introduce a policy leading to a simultaneity problem. We try to overcome this problem by using an instrumental variables (IV) approach. In addition, similar to Carley (2012), we use different versions of policy variables: DSM expenditure per customer, an indicator for positive DSM spending, and a score that measures the DSM effort of a utility. We can then verify the robustness of our estimates.

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[4] While the study by Dulleck and Kaufmann (2004) is also European, our analysis is based on an aggregate DSM measure as opposed to a specific DSM program, *viz.* information programs.

Table 1: Estimated DSM effects in the literature

Source	DSM Policy Variable	Effect	Model
Parfomak and Lave (1996)	Reported conservation (GWh)	99.4% of the reported conservation impacts are statistically observable in system level sales after accounting for economic and weather effects.	Weighted least squares (WLS) estimators
Loughran and Kulick (2004)	1. Indicator of DSM expenditure 2. DSM expenditure	DSM expenditures lowered mean electricity sales by 0.3 to 0.4 percent. Larger effect for a sample of utilities reporting positive DSM expenditures in every year (0.6 to 1.2 percent). Utilities themselves estimated effect between 1.8 and 2.3 percent. Authors think the difference is because utilities generally do not fully control for selection bias.	First difference fixed effects approach
Dulleck and Kaufmann (2004)	Information program value (0-1)	Providing customers with information reduced overall electricity demand by roughly 7%	Monthly time series
Horowitz (2004)	DSM savings per dollar state gross commercial product (which are endogenous) therefore instruments: 1. DSM instrument with non-declining DSM savings by replacing with the latest higher values 2. DSM instrument is estimated with a Tobit model using population and supply costs as explaining variables	Electric utility demand side management programs were responsible for reducing commercial sector electricity intensity in 2001 by 1.9% relative to the 1989 level.	Dynamic GLS-FE model
Horowitz (2007)	Reported accumulated (1992-2003) electricity savings attributable to DSM programs to categorize utilities in four different quartiles of different commitment to EE policies.	Those states that have moderate to strong commitment to energy efficiency programs reduce electricity intensity relative to what it would have been with weak program commitment; in the residential sector by 4.4%	Difference-in-differences approach
Auffhammer et al. (2008)	DSM expenditure	Reported utility DSM savings may be more accurate than Loughran and Kulick (2004) claim. Supports Parfomak and Lave (1996).	Loughran and Kulick (2004) model and data plus better test statistic and nonparametric bootstrap confidence intervals

Continued on next page

Table 1 – continued from previous page

Source	DSM Policy Variable	Effect	Model
Berry (2008)	1. ACEEE efficiency program score 2. Utility efficiency program spending score and 3. Other efficiency program score	The higher the utility efficiency program expenditures per capita and the greater the range of other efficiency programs offered, the greater is the reduction in the growth of electricity sales. A one-point increase in the efficiency program score is associated with about a 3.2% decrease in the growth of electricity sales over the 5-year study period.	OLS regression of difference
Rivers and Jaccard (2011)	DSM expenditure per capita	DSM expenditures by Canadian electric utilities have had only a marginal effect on electricity sales	Partial adjustment model (to correct for the inertia) with bias corrected estimators
Arimura et al. (2012)	DSM spending per customer, lagged DSM spending (as well as their polynomials) as instruments.	They found that DSM expenditures have resulted in an annual average of 0.9 percent electricity savings at an average cost of 5 cents per kWh of electricity savings.	Basic approach of Loughran and Kulick (2004) and address possible endogeneity in spending by using a nonlinear GMM approach
Carley (2012)	1. DSM policy effort (ACEEE score) 2. Public benefit funds spendings 3. Binary variable for a state having an energy efficiency portfolio standard 4. Binary variable for a state offering a performance incentive	State-run DSM efforts contribute to electricity savings across the country. Public benefit funds coupled with performance incentives are found to encourage utility participation in DSM programs. Energy efficiency portfolio standards and performance incentives effectively promote electricity savings, but public benefit funds without the support of other DSM policies are not significant drivers of either DSM program participation or total DSM electricity savings.	Two-step Heckman method

While there is substantial literature on the development of DSM in the US and its impact on electricity demand, little is known about DSM efforts in Switzerland and its effectiveness. There is no policy framework on utility-centred energy efficiency at a national level. In 2011, two environmental organizations, the World Wide Fund for Nature (WWF) and Pro Natura, developed a rating system for the ecological comparison of Swiss utilities. Vettori et al. (2014) assess the extent to which the utilities promote energy efficiency and renewable energy using data on 24 utilities. Blumer et al. (2014) use data on 114 utilities and a two-step cluster analysis to identify three different clusters of Swiss utilities regarding their activity in implementing DSM programs. In addition they use analysis of variance to find that the clusters differ significantly on utility characteristics such as size, share of production, number of large clients, and the level of activity in implementing EE programs.

4 Survey

We conducted a survey to collect data on DSM measures introduced by Swiss electric utilities and use the data to perform an empirical analysis on the impact of DSM on electricity consumption. For this purpose, we sent out questionnaires by e-mail to 105 utilities in Switzerland between April and November 2013. We contacted the 50 largest utilities and a random sample of 55 mid-sized utilities.[5] The objective of the survey was to gather information on the electricity delivered to residential customers as well as to quantify any efforts made by utilities on demand-side measures to reduce electricity consumption. To achieve this objective we split the questionnaire into two parts. The first part covered questions on the consumption of residential customers, number of customers, electricity tariffs and utility characteristics. In the second part of the questionnaire we asked questions on DSM activity.

Table 2 shows the response rates of the survey, differentiating between the three major language areas in Switzerland.[6] The overall response rate of our survey was about 42%. Taking into account sufficiently completed answers resulted in a lower response rate of about 30%. However, these 30 utilities account for almost half of the electricity delivered to households with around 45% of residential electricity sold in 2011. Most of the utilities, around 80%, are located in the German-speaking part of Switzerland while the rest of the utilities are divided almost equally between the French-speaking and Italian-speaking parts, 10% and a little over 10%, respectively.

The utilities surveyed were asked to fill in the respective data for 2006 until 2012. This means that we have panel data. The main advantage of using panel data is that we can control for unobserved heterogeneity in utilities. However, we have an unbalanced panel dataset since some of the utilities were unable to

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[5] There are, as of February 2016, 657 utilities in Switzerland. However, only around 80 utilities serve more than one or two postal codes (a postal code in Switzerland includes, on average, about 2500 persons). The majority (more than 500) are very small utilities that serve only a small municipality and do not have the resources to implement DSM. Moreover, the larger utilities might also have a larger impact with DSM because they can reach more households. Therefore, we targeted primarily the larger utilities in our survey.

[6] For simplicity, we consider utilities located in the Romansh-speaking areas to be part of the German-speaking region.

provide information for the first few years. For our primary variable of interest, electricity consumption, there are 182 observations in total for each of the 30 utilities over 7 years.

Table 2: Survey response rates

Region	Surveys sent	Responses with data	Responses without data	Overall response rate	Useable response rate
German	81	23	9	39.51%	28.40%
French	14	3	5	57.14%	21.43%
Italian	10	4	0	40.00%	40.00%
Total	**105**	**30**	**14**	**41.90%**	**28.57%**

In Switzerland, electric utilities are quite diverse in terms of their organization and ownership, size and field of activity. There are different ways to measure the size of a utility, e.g., the sales revenue, the number of employees or the quantity of electricity delivered. The majority of utilities in our sample supply between 100 and 300 gigawatt hours (GWh).

Another feature of Swiss utilities is the legal form. We distinguish between five legal forms: (1) dependent public institution, (2) independent public institution, (3) publicly owned stock company, (4) stock company with a majority of public ownership and, (5) stock company with a minority of public ownership. A third of the utilities in our sample are independent public institutions. Together with dependent public institutions they constitute about 45% of the utilities in our sample. The other three categories consist of utilities that are stock companies with different degrees of public ownership.

Utilities can be active in production, transmission and distribution of electricity. Since we focus on utilities with residential end-use consumers, the utilities in our sample are mostly distribution companies. Nonetheless, some of the utilities also generate their own electricity. More than 60% of the utilities in our sample produce less than 25% of their electricity sold. This indicates that utilities are more focused on the distribution side. Only a minority, around 20%, generates more than three quarters of the electricity supplied to residential customers.

4.1 Funding activities

A popular method to measure DSM activity of utilities is to use the monetary effort for their programs. We summarize the DSM expenditures between 2006 and 2012 for the 30 surveyed utilities in Table 3. DSM expenditure is measured as the annual expenditure on all energy efficiency measures directed at residential customers. A utility spent annually, on average, 2.86 CHF per residential customer over our survey period. The variation between the utilities is large as shown by the range and standard deviation. There are 14 utilities that have DSM in all the years, from 2006 to 2012. There are 11 further utilities that changed from having no DSM to having some DSM spending over the seven year period. There are 5 utilities that reported zero DSM spending during our study period. The maximum amount spent per customer in a year is almost 31 CHF. Figure 1 provides a graph with the DSM spending of a sample of five utilities. Apart from observing the evolution of an individual utility DSM spending over time, the graph shows that we can exploit the variation in DSM activity within utilities and across utilities over time to make an econometric estimation of the impact of DSM activity on electricity consumption.

In any case, we need to note that DSM expenditure may be measured with measurement error. Because of accounting purposes it is not possible for some utilities to report the exact amount spent on DSM activity. Some utilities have only provided rough estimates of this variable. For this reason, we create two indicator variables that, we think, measure the funding activities more robustly. First, we use a binary variable for positive spending where the cut-off for the switch from zero to one is spending greater than zero. Second, we use a similar indicator with a cut-off at the first quartile of DSM expenditure per customer. Figure 2 shows a box plot of the positive spending binary variable against the consumption per customer from 2006 to 2012. Similar to Figure 1, the graph shows that we can exploit the variation in the binary DSM variable within utilities and across utilities over time.

Table 3: Summary statistics - Funding activities (in CHF)

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Expenditure on all DSM measures	313128.75	1048718.63	0	5900000	210
Expenditure on funding	98089.47	336516.30	0	2951717	210
Expenditure on all DSM measures per customer	2.86	6.13	0	30.83	201
Expenditure on funding per customer	1.28	3.49	0	30.14	185

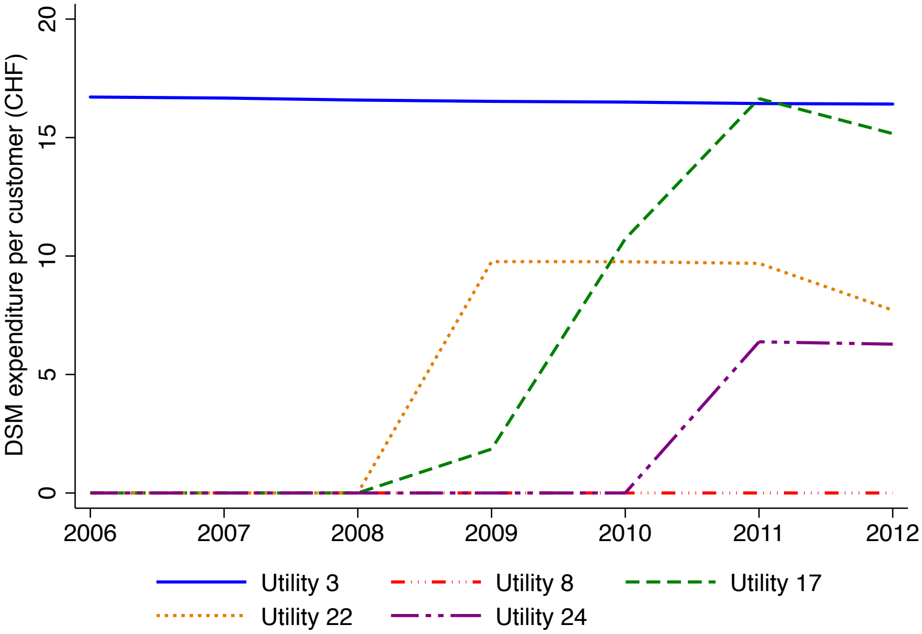


Figure 1: DSM expenditure per customer for some utilities (2006–2012)

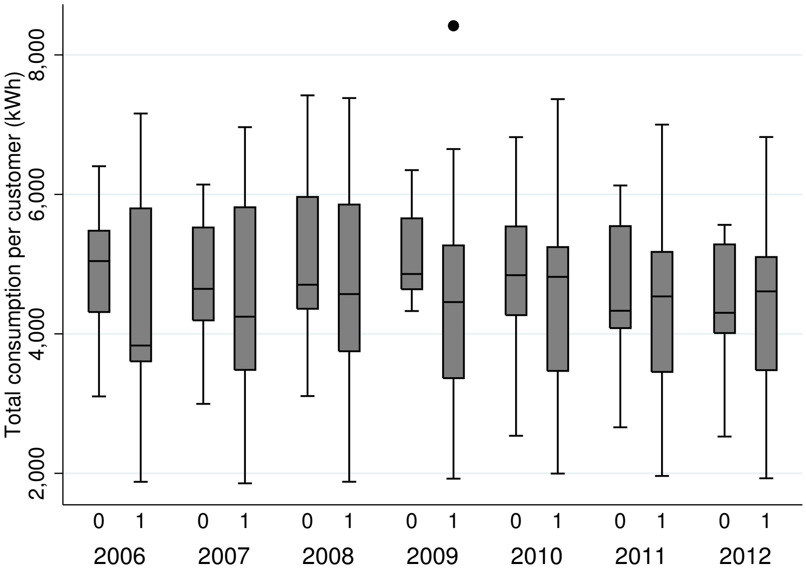
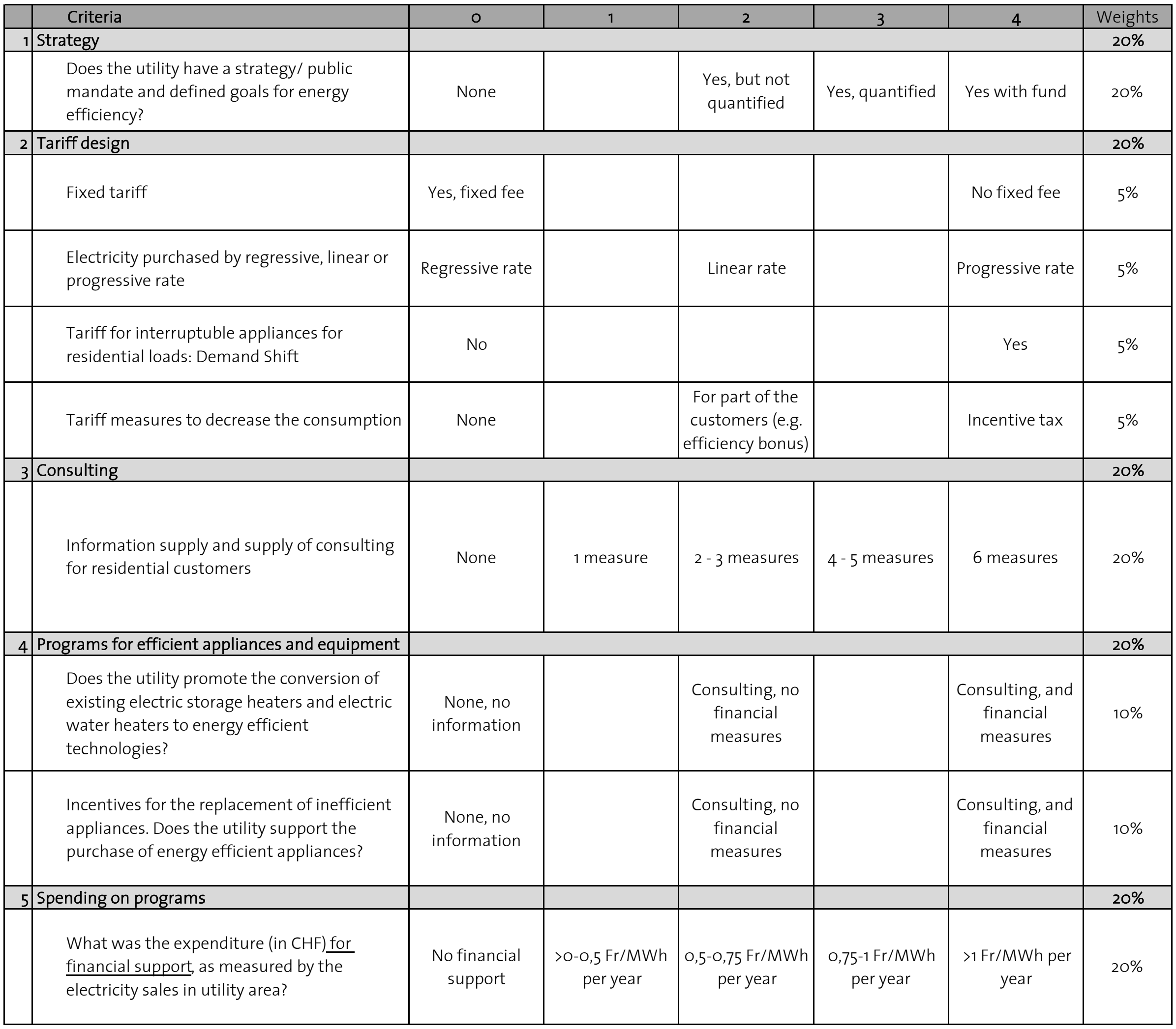


Figure 2: Box plot of electricity consumption per customer by DSM spending indicator (2006–2012)

4.2 Energy efficiency score

In order to aggregate the different DSM activities it may be useful to construct an index. For example, Berry (2008) and Carley (2012) use the ACEEE scorecard to evaluate the effectiveness of DSM in the US. The ACEEE scorecard is an energy efficiency index that the American Council for an Energy-Efficient Economy (ACEEE) calculated for the first time in 2006. It has become an annual benchmark of the progress of US state energy efficiency policies and programs and considers six policy areas, one of which is utility and public benefits programs and policies. Program budget and savings, energy efficiency resource standard and regulation type are considered within this area when calculating the index (ACEEE, 2007).

Using information from the second part of the survey, we develop an energy efficiency score that measures a utility's commitment to promote energy efficiency among their residential customers. For this purpose, we use the reports from Vettori et al. (2011, 2014) as a basis. In contrast to those reports, we consider the energy efficiency policies that are directed only at residential customers and do not consider the commercial and industrial customers. We can calculate the EE score for all years between 2006 and 2012 and also analyze the dynamics of our score. We cover five fields of activity, *viz.*, the utility's strategy, tariff design, consulting offers, replacement of appliances and spending on financial programs. We assign an equal weight of 20% to each of these EE strategies since we do not want to make any assumption on the importance of one EE strategy over another.



	Criteria	0	1	2	3	4	Weights
1	Strategy						20%
	Does the utility have a strategy/ public mandate and defined goals for energy efficiency?	None		Yes, but not quantified	Yes, quantified	Yes with fund	20%
2	Tariff design						20%
	Fixed tariff	Yes, fixed fee				No fixed fee	5%
	Electricity purchased by regressive, linear or progressive rate	Regressive rate		Linear rate		Progressive rate	5%
	Tariff for interruptible appliances for residential loads: Demand Shift	No				Yes	5%
	Tariff measures to decrease the consumption	None		For part of the customers (e.g. efficiency bonus)		Incentive tax	5%
3	Consulting						20%
	Information supply and supply of consulting for residential customers	None	1 measure	2 - 3 measures	4 - 5 measures	6 measures	20%
4	Programs for efficient appliances and equipment						20%
	Does the utility promote the conversion of existing electric storage heaters and electric water heaters to energy efficient technologies?	None, no information		Consulting, no financial measures		Consulting, and financial measures	10%
	Incentives for the replacement of inefficient appliances. Does the utility support the purchase of energy efficient appliances?	None, no information		Consulting, no financial measures		Consulting, and financial measures	10%
5	Spending on programs						20%
	What was the expenditure (in CHF) for financial support, as measured by the electricity sales in utility area?	No financial support	>0-0,5 Fr/MWh per year	0,5-0,75 Fr/MWh per year	0,75-1 Fr/MWh per year	>1 Fr/MWh per year	20%

Figure 3: Energy efficiency score calculation

Table 4: Summary statistics - Energy efficiency score

Variable	Mean	Std. Dev.	Min.	Max.	N
Energy efficiency score	1.21	0.88	0	3.5	210

The calculation of the EE score using the different criteria and their corresponding weights is presented in Figure 3.[7] The overall score ranges from 0 to 4, with 0 being the worst, in terms of energy efficiency efforts, and 4 being the best. Table 4 presents the summary statistics of the score, with utilities obtaining an average score of 1.21 out of a maximum of 4. The maximum EE score reached by one of the surveyed utilities is 3.5. We graphically present the relation between EE score and spending on EE measures in Figure 4 in which the logarithm of positive EE spending is plotted against the EE score. We observe a positive correlation between EE spending and the EE score with higher EE spending being reflected, on average, by a higher EE score.

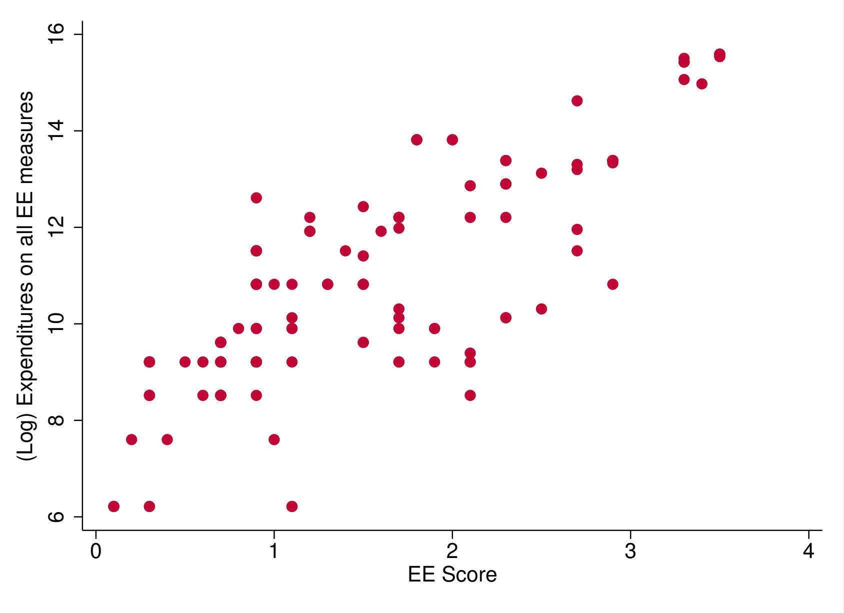


Figure 4: (Log) Expenditure on EE versus EE score

5 Data

We use three main sources of data. The first source is our survey from which we obtain utility characteristics, electricity consumption and price data as well as DSM activity. Demographic data are from the Bundesamt für Statistik (BFS).[8] The final source is MeteoSchweiz that provides information on heating and cooling degree days.

Table 5 shows the summary statistics of all the variables used. Most Swiss utilities have two types of

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[7] We use Cronbach's alpha to estimate the internal consistency of the energy efficiency score (University of Virginia Library, 2016). The estimated value of 0.7913 for the 10 measures falls within 0.7 and 0.8 that is, as a rule of thumb, considered to be good. Therefore, we can conclude that the score is internally consistent.

[8] The Bundesamt für Statistik is Switzerland's Federal Statistical Office.

Table 5: Summary statistics

Variable	Mean	SD	Min.	Max.	N
Total consumption per customer (in kWh)	4547.52	1311.02	1856.77	8418.08	182
Average price (in Rappen/kWh)	20.91	3.75	13.16	28.96	182
Average taxable income per taxpayer (in CHF)	69127.31	9894.18	56006.00	104537.19	210
Household Size: Population/Customers	1.86	0.55	0.76	4.24	185
Heating degree days	3567.52	904.93	2130.16	6452.90	210
Cooling degree days	137.99	90.15	0	442.12	210
Positive DSM expenditure indicator	0.66		0	1	210
DSM expenditure: first quartile indicator	0.51		0	1	210
DSM expenditure per customer (in CHF)	2.86	6.13	0	30.83	201
Energy efficiency score	1.21	0.88	0	3.50	210
Indicator for stock company	0.55		0	1	210
Indicator for share of own production: 0-25%	0.66		0	1	204

Note: 1 CHF (Swiss Franc) = 100 Rappen.

tariffs for customers: a time-of-use scheme and a single tariff scheme. Customers with a time-of-use scheme pay a different price for electricity depending on the time of day with a higher rate during the day and a lower rate at night. Customers with a single tariff scheme pay a single price for electricity regardless of the time of day. To take this into account we weight the average price by using the number of customers in each tariff scheme. Based on the information from residential electricity tariffs, we calculate a weighted average electricity price for each utility and year.[9]

Demographic data are from the BFS. We use the average taxable income as a measure of the income of a household. Electricity demand also depends on the household size and we calculate this by dividing the population of the area served by a utility by the number of customers serviced by that particular utility to get an average size of a household in the area serviced by the utility. We also use heating and cooling degree days, collected from MeteoSchweiz, as a measure of the effect of weather variables on the demand for electricity.

Our primary independent variable of interest is a measure of demand-side management programs. We construct this in several ways. The first two ways are by using indicator variables as described previously in section 4.1. The third measure is a continuous variable of the reported DSM spending by a utility. The last measure is the energy efficiency score as calculated previously in section 4.2.

All these measures have their respective advantages over one another. The advantage of the binary measures over the continuous measures is that, since the DSM spending is self-reported, they do not suffer from measurement error. The advantage of the continuous measures over the binary measures is that they provide a measure of the intensity of DSM activities and not just an indicator of whether a utility engages in DSM or not. The advantage of the EE score is that it captures, in an index, the various DSM activities.

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[9] Details are provided in the Appendix.

However, the disadvantage is that it cannot capture the effectiveness of a particular DSM activity and cannot be expressed in monetary terms.

6 Empirical strategy

Our primary identification strategy to estimate the effectiveness of DSM efforts in Swiss utilities is to use the variation in DSM measures within utilities over time and across utilities. In effect, we use the method of difference-in-differences to obtain this estimate. Difference-in-differences (DD) is a method used to determine causal relationships and its basic idea is to identify a policy intervention or treatment by comparing the difference in the outcomes before and after the intervention for the treated groups with the difference for the untreated groups. It is, therefore, crucial to have observations from the treated and untreated units both before and after the policy intervention. In our analysis, we consider treated utilities to be those that have implemented DSM.

There are two key identification assumptions in the DD approach. The first is that the trend in the outcome variable are similar for both the treatment and control groups in the absence of treatment, referred to as the parallel (or common) trends assumption. The violation of this assumption means that we cannot attribute the effect of the outcome solely to the policy intervention. The second assumption is that the assignment of a unit to the treatment group is exogenous. This may be violated if there is selection based on unobservable characteristics of units or if the policy intervention is affected by the outcome. We perform various robustness checks to ensure that these issues are not a concern.

The simplest formulation in our framework is

$$\ln E_{it} = \beta_0 + \beta_1 DSM_{it} + \lambda_i + \delta_t + \epsilon_{it}, \tag{1}$$

where the subscripts i and t are the indices for an individual utility and time, respectively, E_{it} is the electricity consumption per customer (in kWh), DSM_{it} is the DSM policy variable of utility i in year t, λ_i is the utility fixed effect to control for any unobserved heterogeneity, δ_t is a year fixed effect common to all utilities, and ϵ_{it} is the usual idiosyncratic error term. Our coefficient of interest is β_1 since it captures the effect of the DSM measures on electricity consumption. We can extend this basic model to further include other observable characteristics that can be used to control for any other factors that might influence the electricity consumption per customer. Therefore, we reformulate equation (1) as

$$\ln E_{it} = \beta_0 + \beta_1 DSM_{it} + \beta_2 p^E_{it} + \beta_3 Y_{it} + \beta_4 HS_{it} + \beta_5 HDD_{it} + \beta_6 CDD_{it} + \lambda_i + \delta_t + \epsilon_{it}, \tag{2}$$

where the additional variables p^E_{it}, Y_{it}, HS_{it}, HDD_{it}, and CDD_{it} refer to the electricity price, average taxable income per taxpayer, average household size calculated as the the population divided by the number of customers, heating degree days, and cooling degree days, respectively for the area serviced by utility i in year t.[10] Our specification, equation (2), is in semi-log form since the continuous DSM measure contains zeros and the logarithm of zero is undefined.[11] There exists a variant of equation (2) where the DSM_{it} variable may include DSM effort lagged by one or more time periods. A few studies have explored this possibility, including Loughran and Kulick (2004), Rivers and Jaccard (2011) and Arimura et al. (2012). We considered this extension in our model but obtained a statistically significant effect of the lagged DSM variable on the electricity consumption only in some cases. However, the short time span of our data (7 years) could be an issue and it may be an avenue worth pursuing in the future with richer time-series data.

7 Results and discussion

The results of estimating equation (2) are in Table 6. Columns (1) and (2) are the estimation results with indicator variables for DSM_{it} with spending greater than zero and spending greater than the first quartile, respectively. Column (3) estimates equation (2) with DSM expenditure per customer while column (4) uses the EE score.

Our results from columns (1) and (2) indicate that spending on EE programs has a moderate but statistically significant effect on the electricity consumption per customer. Positive EE spending reduces electricity consumption per customer by around 4.5% in column (1) and by around 6% in column (2).[12] Our estimates from column (3) indicate that using the continuous measure of EE spending confirms the negative and statistically significant impact. Increasing per customer EE spending by 1 CHF leads to a reduction in electricity consumption by around 0.5%. Assuming that a household, on average, consumes 4600 kWh of electricity per year, a reduction in electricity consumption of 0.5% is around 23 kWh per year per Swiss franc of DSM spending. Therefore, the cost of saving one kilowatt hour is around 0.04 CHF.[13] In other words, increasing per customer spending on EE by 10% leads to a reduction in electricity consumption by around 0.14% when evaluated at the mean of DSM spending.[14] The results with the EE score in column (4) also indicate a statistically significant impact of utility DSM activity in reducing per customer electricity demand.

The coefficients of several other explanatory variables in Table 6 are statistically insignificant. The only variables that show consistent statistical significance are electricity price and household size. The price elasticity, evaluated at the mean of the average electricity price, ranges between –0.38 and –0.34 so the results are quite stable. The elasticity for household size is around 0.12 which implies that increasing the household

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[10] Income and heating and cooling degree days are scaled to ensure that the results are easier to read.

[11] We have also performed the regressions by using a linear transformation of the continuous DSM spending variable to ensure that the logarithm is defined and using a log-log model. The results are similar.

[12] The percentage change is calculated by using $100[e^{\beta_1} - 1]$ where β_1 is the coefficient of DSM_{it} in equation (2).

[13] This is obtained by dividing the cost, 1 CHF, with the electricity saved, 23 kWh.

[14] We should note that the estimated impact of the DSM programs obtained in the model with the binary DSM measure and in the model with the continuous DSM measure cannot be directly compared due to the discrete nature of the former measure and the continuous nature of the latter measure.

Table 6: FE Models of (log) residential electricity demand per customer

	(1)	(2)	(3)	(4)
Positive DSM expenditure indicator	-0.047^a			
	(0.017)			
DSM expenditure: first quartile indicator		-0.058^b		
		(0.025)		
DSM expenditure per customer			-0.005^b	
			(0.002)	
Energy efficiency score				-0.030^b
				(0.014)
Average price	-0.018^a	-0.016^a	-0.018^a	-0.018^a
	(0.006)	(0.006)	(0.006)	(0.006)
Taxable income per taxpayer	0.004	0.003	0.005	0.003
	(0.005)	(0.005)	(0.005)	(0.005)
Household size	0.066^c	0.063^c	0.064^c	0.062
	(0.039)	(0.035)	(0.037)	(0.038)
Heating degree days	-0.009	-0.010	-0.008	-0.008
	(0.009)	(0.009)	(0.009)	(0.009)
Cooling degree days	-0.020	-0.038	-0.038	-0.027
	(0.031)	(0.031)	(0.031)	(0.030)
Utility fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	182	182	182	182
Adjusted R^2	0.954	0.955	0.954	0.954

Robust standard errors in parentheses.
^{a}, ^{b}, ^{c}: Significant at the 1%, 5% and 10% levels, respectively.
Income and heating and cooling degree days have been scaled.

size by 1% increases electricity consumption by around 0.12%. The coefficients for the other explanatory variables are statistically insignificant probably due to the fact that there is not much within-variation. Since our panel is relatively short in terms of the number of years we expect the socio-demographic and weather variables to exhibit little variation and be captured by the utility fixed effects. This is not a problem since we are more interested in the coefficient of the policy intervention variable, DSM_{it}.

8 Robustness checks

The advantage of DD estimation is that both group-specific and time-specific effects are accounted for by considering the changes over time in the means of the outcome variable for both the treatment and control groups. However, as with any methodology, we need to be careful in implementing this method. The DD identification, as mentioned previously in section 6, depends on the assumption that the treatment and control groups exhibit parallel trends and we test this below by using placebo tests the results of which are reported in Table 7.

In all the placebo tests we exclude utilities that had EE programs throughout the time period in our survey. First, in Placebo 1, we consider utilities that did not have EE spending in years 1, 2 and 3 but positive spending in years 4, 5, 6 and 7.[15] We assign a value of 1 to the DSM indicator variable to those utilities in year 3. The results from this regression are presented in column (1). We also perform a similar regression for the continuous DSM spending variable.[16] The results are in column (2). Second, in Placebo 2, we again consider utilities that did not have EE spending in years 1, 2 and 3 but positive spending in years 4, 5, 6 and 7. However, this time we assign a value of 1 to the DSM indicator variable to those utilities in years 2 and 3. The results from this regression are presented in column (3). We also carry out a similar regression for the continuous DSM spending variables and the results are in column (4). Third, in Placebo 3, we consider utilities that did not have EE spending in years 1, 2, 3 and 4 but positive spending in years 5, 6 and 7. We assign a value of 1 to the DSM indicator variable to those utilities in year 4. The results from this regression are presented in column (5). We also carry out a similar regression for the continuous DSM spending variables. The results are in column (6). In the fourth, and final, placebo test (Placebo 4) we again consider utilities that did not have EE spending in years 1, 2, 3 and 4 but positive spending in years 5, 6 and 7. This time we assign a value of 1 to the DSM indicator variable to those utilities in years 3 and 4. The results from this regression are presented in column (7). We also estimate a similar regression for the continuous DSM spending variables and the results are in column (8). If the parallel trends assumption were to be violated we would expect our coefficients of interest, the "Pseudo" variables to be significant. However, they are statistically insignificant in all the columns.

Our placebo tests use a low number of observations and we should be careful in interpreting our results. However, the lack of statistical significance for our relevant policy variables in the placebo tests indicates that the parallel trends assumption is not violated. We have, due to the small number of observations in our placebo tests, carried out additional tests to check that the treated and control groups exhibit parallel trends. The tests are based on Angrist and Pischke (2009, pp. 238-239) and increases the number of observations to 60. These tests, while not reported in the paper, also confirm that the treated and control groups have parallel trends.

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[15] We consider here, and in what follows, years 1, 2, 3, 4, 5, 6 and 7 to correspond to our surveyed years 2006, 2007, 2008, 2009, 2010, 2011 and 2012, respectively.

[16] In this regression, as well as in subsequent placebo tests for the continuous variable, we assign a random positive value to those utilities that had positive EE spending in future years.

Table 7: Placebo tests for (log) residential electricity demand per customer

	Placebo 1		Placebo 2		Placebo 3		Placebo 4	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pseudo DSM indicator	-0.135		-0.124		-0.097		-0.122	
	(0.090)		(0.094)		(0.098)		(0.099)	
Pseudo DSM expenditure per customer		-0.005		-0.002		-0.005		-0.007
		(0.004)		(0.003)		(0.005)		(0.007)
Average price	0.063	0.045	0.043	0.024	-0.006	0.003	-0.005	-0.013
	(0.049)	(0.053)	(0.042)	(0.047)	(0.019)	(0.011)	(0.018)	(0.023)
Taxable income per taxpayer	0.004	0.009	0.006	-0.004	-0.002	-0.002	0.004	0.010
	(0.010)	(0.014)	(0.010)	(0.009)	(0.012)	(0.012)	(0.011)	(0.016)
Household size	1.727	1.745	1.144	1.062	-0.008	-0.071	-0.182	-0.211
	(1.349)	(1.357)	(1.085)	(1.168)	(1.101)	(1.043)	(0.975)	(0.927)
Heating degree days	0.045	0.032	0.031	0.010	-0.002	0.001	0.021	0.024
	(0.056)	(0.059)	(0.050)	(0.061)	(0.055)	(0.055)	(0.053)	(0.056)
Cooling degree days	-0.267	-0.224	-0.292	-0.162	-0.145	-0.166	-0.205	-0.206
	(0.169)	(0.184)	(0.195)	(0.171)	(0.169)	(0.181)	(0.168)	(0.179)
Utility fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	27	27	27	27	26	26	26	26
Adjusted R^2	0.905	0.894	0.895	0.872	0.778	0.779	0.810	0.807

Robust standard errors in parentheses.
^{a}, ^{b}, ^{c}: Significant at the 1%, 5% and 10% levels, respectively.
Income and heating and cooling degree days have been scaled.

DD estimation requires that the policy changes are not themselves endogenous as mentioned in section 6. Our placebo tests show that this may not be a concern. However, we use the method of instrumental variables as a further robustness check. An instrument should satisfy the conditions for relevance and exogeneity. It should, therefore, be correlated with the potentially endogenous EE spending variables variable but not with the error term. A weakness of using an instrumental variables procedure is the difficulty of finding valid and convincing instruments. A potential solution is to use utility characteristics that may influence the decision to implement EE programs but will not directly affect the residential electricity consumption.

One of the problems with using instrumental variables in a fixed effects short-panel data framework is the potential low variation of those variables over time. This is especially true for utility characteristics since they exhibit very little variation over time. The instrumental variables we consider are the legal form of a utility and a measure of the share of the total electricity sold by a utility that is produced by itself. These two variables satisfy the condition for instrument relevance since, as we argue below, both firm characteristics are possible determinants of DSM. They also satisfy the exogeneity condition since neither are possible direct determinants of residential electricity demand and the effect will be seen only indirectly through DSM.

The legal form of a utility is obtained from our survey. It is constructed as an indicator variable with a utility being a stock company or not. Since it does not have any within-utility variation over our survey period a traditional fixed effects model with instrumental variables will not work. There is some evidence in the DSM literature that the ownership of a utility may be a factor in the implementation of DSM initiatives. However, there is conflicting evidence on the direction of DSM initiatives taken by utilities based on the ownership. Hopper et al. (2009) shows that the energy-saving goals of investor-owned utilities are higher while Carley (2012) finds that investor-owned and cooperative utilities are more likely to have DSM programs than municipal utilities. On the other hand, Vojdani (2008) states that energy conservation is a low priority for investor-owned utilities in the US. Cabrera et al. (2012) argue that DSM programs are used as tools to obtain certain political goals such as an energy reduction plan and that publicly owned utilities are more active in such a situation.

The share of electricity sold by a utility that is produced by itself may also have an impact on the implementation of DSM programs since utilities that generate only a small share of their own electricity need to purchase electricity at a higher cost to fulfil the demand of their customers. Therefore, these utilities may find it cheaper to engage in DSM activity than in purchasing electricity in the market. On the other hand, Blumer et al. (2014) reason that utilities that generate a substantial fraction of their own electricity may have an incentive to promote DSM since this increases the amount of electricity that they can sell to other utilities.

The presence of a possible endogenous binary policy variable indicates a situation described in Heckman (1978). Therefore, we use a probit model to model the nonlinear binary policy variable. The instrumental variable is used in this probit stage along with the other explanatory variables. We then use the prediction of the policy variable from this stage as an instrument for the endogenous binary policy variable in a fixed effects instrumental variables regression model. This is a consistent estimation method that has been proposed by Amemiya (1978), Heckman (1978) and Lee (1979).[17] The instrumental variable is the excluded instrument in this model. We refer to this Heckman-type selection approach as the "nonlinear" approach.[18] We use the legal form of a utility and a measure of the share of the total electricity sold by a utility that is produced by itself as two instrumental variables in the nonlinear probit first stage.

The results of the selection model, modelled as a probit, are provided in Table 8 where we observe that the probability of DSM decreases when a utility is a stock company while it increases as the own share of electricity production is low. The effects are statistically significant in both columns (1) and (2). The predicted probabilities from this stage are then used as instruments in a two-stage least squares model and the first-stage results of this estimation are provided in Table 9. While the coefficient for the predicted probability is statistically significant in column (1), it is not significant in column (2), which indicates that the instrument is very weak and we expect the second-stage results to be imprecisely estimated.

The final results of these estimation procedures are provided in Table 10. Column (1) corresponds to the instrumental variables estimation for column (1) in Table 6 with the nonlinear approach. The potentially endogenous DSM binary variable is the positive DSM spending. Column (2) corresponds to the first quartile DSM spending binary variable. Our results show that estimates for the effect of DSM spending on per

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[17] Wooldridge (2002, p. 939) provides a description of this method.

[18] We also performed the estimations using the instrumental variables in a standard fixed effects framework but, as expected, we encountered a problem of weak instruments due to the low variability of the instruments that led to problems of identification.

customer residential electricity consumption is very high compared to the normal DD fixed effects results in Table 6. However, it is reassuring to observe that the effects are negative and significant, except in column (2). The estimate of the DSM coefficient in column (2) exhibits a very high standard error and the F-statistic from the first stage also indicates that the nonlinear procedure may have some issues, as we expect from the statistically insignificant coefficient of the predicted probability in Table 9. The F-statistic in column (1) also indicates that our instruments, while valid, may be weak since the value of the F-statistic is less than 10, the generally acceptable cut-off for the strength of instruments.

Table 8: Probit stage of nonlinear estimation

	(1)	(2)
Average price	-0.053	0.006
	(0.034)	(0.033)
Taxable income per taxpayer	0.005	0.011
	(0.012)	(0.011)
Household size	-0.032	0.384^c
	(0.234)	(0.226)
Heating degree days	-0.016	-0.036
	(0.025)	(0.023)
Cooling degree days	-0.552^b	-0.907^a
	(0.228)	(0.251)
Indicator for stock company	-0.971^a	-1.346^a
	(0.256)	(0.249)
Indicator for share of own production: 0-25%	0.839^a	0.480^c
	(0.263)	(0.251)
Intercept	2.289	1.000
	(1.879)	(1.850)
Observations	182	182

Robust standard errors in parentheses.
^{a}, ^{b}, ^{c}: Significant at the 1%, 5% and 10% levels, respectively.
Income and heating and cooling degree days have been scaled.

Table 9: First stage of IV/2SLS estimation

	(1)	(2)
Average price	-0.007	0.015
	(0.021)	(0.018)
Taxable income per taxpayer	-0.022	-0.043^b
	(0.018)	(0.020)
Household size	0.092^c	-0.006
	(0.052)	(0.157)
Heating degree days	-0.001	-0.029
	(0.026)	(0.026)
Cooling degree days	0.250^c	-0.183
	(0.136)	(0.168)
Probability(Positive DSM expenditure)	0.885^b	0.065
	(0.386)	(0.458)
Observations	182	182

Standard errors in parentheses.
^{a}, ^{b}, ^{c}: Significant at the 1%, 5% and 10% levels, respectively.
Income and heating and cooling degree days have been scaled.
^{d} Used in the probit stage.
^{e} Estimated in the probit stage.

Table 10: FE Models of (log) residential electricity demand per customer

	(1)	(2)
Positive DSM expenditure indicator	-0.171^c	
	(0.089)	
DSM expenditure: first quartile indicator		-1.900
		(12.645)
Average price	-0.021^a	0.011
	(0.006)	(0.197)
Taxable income per taxpayer	0.002	-0.076
	(0.005)	(0.547)
Household size	0.074^c	0.064
	(0.040)	(0.257)
Heating degree days	-0.010	-0.063
	(0.009)	(0.365)
Cooling degree days	-0.003	-0.405
	(0.037)	(2.555)
Utility Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Observations	182	182
First stage F-statistic	5.253	0.020

Robust standard errors in parentheses.
^{a}, ^{b}, ^{c}: Significant at the 1%, 5% and 10% levels, respectively.
Income and heating and cooling degree days have been scaled.

The previous part provides a description of a possible way to account for an endogenous binary policy variable. However, we also have continuous dependent variables, DSM expenditure and EE score, that may be endogenous. A way to solve the problem of instruments with low within-variation for the continuous endogenous variables is to use OLS, without individual fixed effects, in the first stage. This will reduce the problem of low within-variation of the instrumental variables. Since this is not a standard procedure available in Stata, we estimate the IV method manually by using the predicted values of the first stage in the second stage. However, this method produces incorrect standard errors (Wooldridge, 2012) and, therefore, we bootstrap the standard errors. The results are reported in Table 11. We also report the F-statistics from the first stages. The F-statistic values of greater than 10 indicate that the instruments are working well in this non-panel setting.

Table 11: Bootstrapped IV, first stage OLS, $N = 10,000$

	Estimate	**Std. Err.**	***t*-statistic**	***p*-value**	**First stage F-statistic**
DSM expenditure per customer	-0.025	0.014	-1.836	0.034	13.65
Energy efficiency score	-0.194	0.100	-1.944	0.027	15.61

Note: The estimate is the mean of the variable of interest from 10000 replications.

The results in Table 11 show that higher DSM spending and a higher EE score reduce residential electricity consumption. While the estimated coefficient is higher when compared to our results in Table 6, the signs of the coefficients are the same. A summary of the results for our variable of interest, the DSM variable in its various forms, is provided in Table 12.

Table 12: Summary of results for DSM variables

Variable	**DD**	**Nonlinear**	**Bootstrapped IV**
Positive DSM expenditure	-0.047	-0.171	
DSM expenditure: First quartile	-0.058	-1.900	
DSM expenditure per customer	-0.005		-0.025
Energy efficiency score	-0.030		-0.194

9 Policy implications

We now perform a simple counterfactual exercise, using the results from our econometric estimation of the impact of DSM initiatives from column (3) in Table 6, to obtain a rough estimate of the cost of such initiatives to a utility.[19] To perform the counterfactual exercise we first estimate the electricity consumed per customer in the absence of any DSM program. Using equation (2), we assign zero to the value of the DSM_{it} variable. Therefore, assuming that $DSM_{it} = 0$ we get

$$\widehat{\ln E_{it}} = \beta_0 + \beta_2 p^E_{it} + \beta_3 Y_{it} + \beta_4 HS_{it} + \beta_5 \cdot HDD_{it} + \beta_6 CDD_{it} + \lambda_i + \delta_t, \tag{3}$$

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[19] A counterfactual exercise is a calculation performed to obtain a scenario of what may have happened in the absence of a policy. This is then compared with the estimated effect of having the policy in place to enable us to make a cost-benefit analysis.

where $\widehat{\ln E_{it}}$ is the (log) electricity consumed per customer in the absence of DSM. We convert the logarithmic value to the level value $\widetilde{E_{it}}$ hereafter.

Since the estimate of the "DSM expenditure per customer" coefficient is negative, an increase in this variable will lead to a reduction in the electricity consumed per customer. Therefore, the estimated electricity consumed in the presence of DSM, $\widetilde{E_{it}}$ will be lower than in the absence of DSM. The reduction in the electricity consumed may be attributed to the effectiveness of the DSM programs. The per customer impact of the DSM programs is, therefore

$$\Delta E_{it} = \widehat{E_{it}} - \widetilde{E_{it}} \tag{4}$$

for utility i in year t. Summing the $\Delta E_{i,t}$ for all utilities over all years and taking into account the number of customers, we obtain the total electicity saving from DSM programs:

$$\text{Total } E \text{ Saved} = \sum_{i,t} (\Delta E_{it} * \text{No. of customers}_{i,t}). \tag{5}$$

The direct cost of the DSM programs is obtained by multiplying the "DSM expenditure per customer" variable with the number of customers for utility i in year t and summing over all these values, i.e.

$$\text{Total } DSM \text{ Cost} = \sum_{i,t} (DSM_{it} * \text{No. of customers}_{it}). \tag{6}$$

Now, the only calculation remaining is to divide the total DSM cost, equation (6), by the total electricity saved due to the DSM programs, equation (5), to get an estimate of the cost to utilities of reducing a unit of electricity by implementing DSM programs:

$$\text{Cost of a kilowatt hour} = \frac{\text{Total } DSM \text{ Cost}}{\text{Total } E \text{ Saved}} \tag{7}$$

We calculate the cost of saving a kilowatt hour by using the estimated coefficient of "DSM expenditure per customer" and find it to be around 0.04 CHF. The average cost of producing and distributing electricity in Switzerland is around 0.18 CHF per kilowatt hour.[20] It should be noted that these costs from the VSE are based on current production and distribution capacities. It is very likely that these costs may be higher in the future with the construction of new capacity. We should recognize, however, that the cost of DSM programs calculated are very rough estimates due to our small sample size and the fact that the DSM figures reported in our survey may suffer from measurement error. The range of estimated cost, based on one standard deviation away from the point estimate, is from a low of 0.03 CHF to a high of 0.09 CHF. Another potential caveat is that we do not consider any possible positive external benefits from not having to produce an

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[20] VSE website, accessed 10 April, 2015.

additional unit of electricity or any possible negative externalities from generating electricity. If there *are* any positive external benefits from not producing electricity or any possible negative externalities from generating electricity, our costs will be overestimated.

10 Conclusion

In this paper we use the results of a survey carried out on 30 Swiss utilities to carry out an econometric analysis of the impact of such practices on the demand for per customer residential electricity demand. We find that while a lot of utilities have some kind of DSM activity in place, the intensity of such programs is somewhat lacking when compared to a country like the US. The average DSM spending per customer in the US is around 9 CHF per customer while it is less than 3 CHF per customer for Switzerland.[21] The difference, in terms of the maximum per customer DSM spending, is also very large with 190 CHF in the US compared to 31 CHF in Switzerland. However, the amount of electricity generated in the US is substantially higher than in Switzerland while the consumption per capita and per household are also much higher. Therefore, if we consider the expenditure on all DSM measures as well as energy efficiency funding per MWh consumed in Switzerland the value is almost 1 CHF for the former and around 0.32 CHF for the latter. This compares to 1.8 CHF on all DSM measures per MWh consumed and 1.2 CHF on energy efficiency spending per MWh consumed in the US. These figures indicate that utility efforts on DSM in the US are substantially higher than similar efforts in Switzerland.[22] We also find significant variation within Swiss utilities with some utilities having a very high spending. Another finding of our analysis is that Swiss utilities tend to focus more on communicating to its consumers about energy efficiency, with many utilities involved in providing information and having public relation campaigns as opposed to financial incentives and energy audits. There are, however, a few utilities that have invested much more in DSM. Using information from our survey, we also calculate an energy efficiency score for each of the surveyed utilities from 2006 to 2012. This has not been performed before for DSM measures on residential customers for Swiss utilities. We find that, while some utilities at the higher end of DSM effort have a relatively high score, we believe that there is a lot of scope to increase DSM activity.

The results of the econometric impact of DSM measures on residential electricity consumption indicate that, while the impact appears to be statistically significant, the size is small. There may be two possible hypotheses for this. The first is that the lack of intensity of DSM efforts may not have a large effect on electricity consumption. It may be effective for utilities to make more intensive efforts in energy efficiency programs due to the low cost of energy efficiency (Goldman et al., 2014). The second explanation is that

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[21] The figure for per customer DSM spending in the US is from Arimura et al. (2012). They report an average DSM spending per customer of US$ 9.41 between 1989 and 2006. We have converted the amount, and subsequent US dollar amounts, to Swiss Francs by using an exchange rate of US$ 1 = 0.97 CHF.

[22] We should note, however, that the figures for the US are for total spending on DSM and energy efficiency. The figures for DSM spending in the residential sector are not available.

there may not be much scope for Swiss households to reduce their electricity consumption. The majority of Swiss households live in multiple family houses. Therefore, we may expect the presence of a principal-agent type of problem with the landlord or the tenant not investing in energy-efficient products because neither reaps the full benefits of that investment. Therefore, it may be more strategic for utilities and policy makers to target owners instead of tenants with energy efficiency programs. However, these are merely hypotheses and it is important to test these possible explanations in future research.

Using the results of the econometric estimation we perform a simple counterfactual exercise to obtain an estimate of the cost of saving a unit of electricity that would have been produced in the absence of DSM programs. We find that, on average, the cost of saving a kilowatt hour is around 0.04 CHF. This is a rough estimate and should be treated with caution due to our relatively small sample size and the possible measurement error of the DSM spending variable. The range of our estimate for this cost using the point estimate and one standard deviation above and below this point estimate is from a low of 0.03 CHF to a high of 0.09 CHF. Compared to this, the current cost of producing and distributing electricity in Switzerland (0.18 CHF/kWh) lies above this range. Our costs may be overestimated since there could be positive external benefits by not having to produce an additional unit of electricity. Given our findings, it appears that DSM programs may be a valuable option for Switzerland to pursue its goals in *Energy Strategy 2050*. Of course, it is possible that other policy options may exist for Switzerland to fulfill its goals. The alternatives include, for example, taxes or standards and, therefore, it is important to evaluate and compare these options.

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Appendix

Electricity price

Based on the information from residential electricity tariffs, we calculate a weighted average electricity price for each utility and year as

$$\begin{aligned} P_{average} = & \frac{customer_{tou}}{customer_{total}} \cdot \frac{E_{peak} \cdot MP_{peak} + E_{off-peak} \cdot MP_{off-peak} + FixedFee_{tou}}{E_{tou}} \\ & + \left(1 - \frac{customer_{tou}}{customer_{total}}\right) \cdot \frac{E_{single} \cdot MP_{single} + FixedFee_{single}}{E_{single}}, \end{aligned} \tag{8}$$

where E_{peak} is the peak period consumption per customer with a TOU tariff, $E_{off-peak}$ is the off-peak period consumption per customer with a TOU tariff, E_{single} is the consumption of a customer with a single tariff, MP_{peak} is the marginal price of electricity in peak periods, $MP_{off-peak}$ is the marginal price of electricity in off-peak periods, MP_{single} is the marginal price of electricity for customers with a single tariff system, $customer_{total}$ is the total number of customers of a particular utility, $customer_{tou}$ is the number of customers of a particular utility that have a TOU scheme, $customer_{single}$ is the number of customers of a particular utility that have a single tariff system, and $FixedFee$ is the fixed fee with subscripts tou and $single$ denoting the tariff scheme to which a customer belongs.

Energy efficiency score calculation

The first field of activity deals with the strategy of the utilities and asks whether the utility has either a public mandate for promoting energy efficiency or a corporate strategy. If it has either of these, we ask whether there are defined efficiency goals or an energy efficiency fund. Some utilities transfer a fixed amount of their revenues or a fixed amount of the electricity price to a fund. From this fund they finance energy efficiency measures, research or renewable projects. The second field of activity, tariff design, covers four criteria: presence of a fixed fee, tariff linearity, interruptible load tariff, and tariff measures. Ito (2014) states that if households respond to average electricity prices rather than to marginal prices the monthly fixed fee removes the incentive to households to save electricity. There is evidence in the literature that shows that residential consumers are more concerned about the average price (e.g., Shin (1985) and Borenstein (2009)). Utilities may also have different tariffs for smaller and larger customers or block tariffs. This results in increasing (progressive), linear or decreasing (regressive) tariff structures. California and Italy introduced progressive tariffs for their residential customers in the 1970s (Dehmel, 2011; Tews, 2011). In Switzerland, on the other hand, many utilities have an interruptible load tariff in order to switch off large users (e.g. the electric boiler) during peak hours. This helps to shift the peak demand to off-peak demand hours. Tariff measures may take the form of an efficiency bonus that rewards customers with rebates for reaching saving goals, or a tax that gets refunded to the households in equal parts.

The third field of activity is consulting offers by a utility. We aggregate the various offers into six categories of measures: information (leaflets, web pages, etc.); public relations (fairs, etc.); rental of smart meters; information on the bill; energy advice centers; and energy audits. Since some utilities in Switzerland help their customers with the replacement of old and inefficient electricity heating systems and home appliances, we analyze this in the fourth field of activity of the score. These programs for efficient appliances can either provide customers with information or financial means. The fifth, and last, field of activity deals with actual spending on such measures. We use spending for financial programs per MWh sold to residential customers as an indicator.