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Abstract

A large body of literature shows that the provision of social comparisons can cause households to reduce residential energy and water use. In this paper, we carry out a field experiment that contributes to this literature in two important ways. First, we study a social comparison treatment that is continuous and communicated via pre-installed in-home displays, which are salient and updated in real time. Second, we estimate the effects of provision of social comparisons on two distinguished resources – electricity and water – in the same experimental setting. We find that, on average, our social comparison reduces daily residential energy consumption by 6.7 percent but has no effect on overall residential water use. The electricity savings are impersistent and occur in the evening hours, which only slightly overlap with peak hours. We argue that electricity conservation due to social comparisons is driven by short-run changes in households' electricity saving behavior.

Key words: Consumer economics; Electricity; Field experiment; Real-time displays; Comparison information; Water.

JEL: D12, D83, L94, Q41

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1 Introduction

A large body of literature provides evidence that the use of social comparisons – informing households of their own resource consumption relative to others– can cause households to reduce residential energy and water use. In this paper, we study a field experiment that contributes to this literature in two important ways.

First, we are among the first – to the best of our knowledge – to study a social comparison treatment that is continuous and communicated via pre-installed in-home displays, which are salient and updated in real time. Given the fast development of smart meters and other information-delivering technologies, our research provides an example of whether the demand-side management of resources through the provision of continuous real-time social comparisons can stimulate resource conservation. As our experiment generates frequent data, we are able to study whether the effect of social comparisons varies over the day and we can also estimate the reduction in resource use (if any) during peak and off-peak demand hours.

Second, we are the first, as far as we know, to estimate the effects of provision of social comparisons on two distinguished resources – electricity and water – in the same experimental setting. This enables us to meaningfully examine whether social comparisons affect residential electricity and water use in the same way as it has been shown that households may have a wide range of non-pecuniary motives for conserving these two resources. For instance, according to the latest overview of the large-scale OECD Survey on Environmental Policy and Individual Behavioral Change, information on the environmental impacts of using a resource would be more important factor in encouraging to reduce water use than energy use, better information on the households' own resource consumption would be more important reason to boost energy conservation than water conservation, and information on energy or water consumption of similar households would be equally important in encouraging conservation of both resources (OECD, 2014).

Our one-year field experiment started in March 2016 and took place in Umeå, a city in northern Sweden. The experiment has three key features that make it well-suited for estimating the causal effects of the social comparison treatment. First, we utilized a widely used contiguous block group approach to randomize the control and treatment groups, together comprising 525 households. This allows us to measure unbiased treatment effects on electricity and water use. Second, our experiment was carefully designed to isolate the effects of the social comparison treatment on households' electricity and water from any confounders. Many of the previous field experimental studies combined social comparisons with advice on how to conserve resources, and thus they were not able to disentangle the effect of peer comparisons from that of resource-saving tips. Third, in our study, we aim to control for the "new-gadget effect." For instance, newly installed in-home displays can be perceived as a treatment in itself, which may lead to biased treatment effects. In our experiment, the dwellings of the participating households were already equipped with the real-time displays prior to the experiment started. Thus, we avoid the new-gadget effect and are able to identify the actual causal effect of the social comparison treatment.

Several interesting insights emerge from our study. We find that social comparisons provided through real-time displays affect electricity and water use differently. On average, our social comparison treatment reduces daily residential electricity consumption by 6.7 percent but has no effect on residential water use. We reason that these results might be due to differences in household norms, i.e., in households' motives for conserving these resources. We provide some support for the view that in Sweden, the environmental impacts of water use are less of a concern than those of electricity use, suggesting that social norms might influence water use less than electricity use.

Our results suggest that the electricity savings are impersistent. Furthermore, the analysis of our high-frequency data shows that electricity conservation occurs in the evening hours, which slightly overlap with the Swedish peak hours for electricity demand. The latter finding has concrete policy implications as it suggests that non-pecuniary measures, such as social comparisons communicated through real-time displays, may not be sufficient to encourage continuous electricity savings alone. As Sweden has a high tax on residential electricity use, our findings also suggest that the combination of ordinary economic instruments and social comparisons does not encourage persistent changes in households' electricity consumption behavior. Finally, we argue that electricity conservation caused by social comparisons is driven by minor, short-run changes in households' electricity saving behaviors rather than changes in household habits or changes in the home capital stock.

The rest of the paper is structured as follows. In Section 2, we review several previous field experiments relevant to our study. We describe our experiment in Section 3. The experimental data is described and the results are discussed in Section 4. Section 5 concludes the paper.

2 Brief literature review

Several literature reviews synthesize the earlier studies on the effects of information provision in various forms on residential energy use (see, e.g., Abrahamse et al., 2005; Darby, 2006; Ehrhardt-Martinez et al., 2010; Faruqui et al., 2010; Fischer, 2008). These studies conclude that provision of personalized information, in particular social comparisons, can promote households' energy-saving investments and influence consumption behavior, at least in the short run. Below, we review some of the results from 13 recently published (some peer-reviewed and some not) field experiment studies that resemble ours as they estimate the effects of *social comparisons* on households' energy or water use. Table I summarizes the studies in terms of their object, type of treatment, mode of treatment provision, duration of the treatment, frequency of measurement, average treatment effect (ATE), model used to estimate ATE, persistency of the ATE (addressed during or/and after treatment delivery), geographic location of the experiment, and sample size of the control and treatment groups.

[Insert Table I about here]

Almost all considered studies report positive ATEs (see Column 7 in Table I) of social comparisons on households' electricity, gas or water conservation. These effects range from 26 percent (Schultz et al., 2016) to as little as just over one percent (Ayres et al., 2013). Interestingly, relatively large resource-saving effects of over five percent are found for both residential energy and water use; see, e.g., Brent et al. (2015) for water, Dolan and Metcalfe (April 2015) for gas, and Sudarshan (2017) for electricity. However, since no study analyzes the impacts of social comparisons on both energy and water use in the same experimental setting, it is difficult to say whether these similar effects are due to similar non-pecuniary motives for conserving these resources (e.g., households think that the environmental impacts of using electricity and water are of equal importance) or other factors at play. In this respect, our study differs from the others as by including both electricity and water, we will be able to control for the general context, such as geographical, social, cultural, and institutional factors among many others, and to meaningfully compare the effects of social comparisons on residential electricity and water use.

The key driver of effects of social comparisons on resource use is explained by psychologists who argue that peer comparisons activate social norms – *descriptive* and *injunctive* norms – that have a great influence on behavior (Cialdini et al., 1991; Reno et al., 1993). Descriptive norms specify "what most people do in a particular situation, and they motivate action by informing people of what is generally seen as effective or adaptive behavior there. Injunctive norms (…) specify what people approve and disapprove within the culture and motivate action by promising social sanctions for normative and counternormative conduct" (Reno et al., 1993, p. 104). Psychologists furthermore argue that conformity to descriptive norms may have a symmetric effect on people's behavior (see, e.g., Schultz et al., 2007). For example, households with relatively low water consumption might increase their water use when they realize that they use less than the descriptive norm (e.g., less than their neighbors). This undesirable "boomerang effect," they say, can perhaps be prevented by adding injunctive messages communicating that the desired behavior (e.g., water conservation) is preferred.

The selected field experiment studies allude to both types of norms – descriptive and injunctive – when constructing social comparisons. As is evident from Table I (see Column 3), most studies combine provision of pure peer-comparison information (referring to descriptive norms) either with normative messages (referring to injunctive norms) and/or with other information. To facilitate the discussion here and later in the paper, we will refer to a social comparison that alludes to both descriptive and injunctive norms as a social comparison with *coupled* norms. For instance, several influential studies on the Opower experiments in the U.S. find that the demand for residential electricity, on average, dropped by about two percent in households exposed to the social comparisons with coupled norms and energy-saving tips (Allcott, 2011; Allcott and Rogers, 2014; Ayres et al., 2013; Brandon et al., March 2017; Costa and Kahn, 2013). However, the results of these and other similar studies should be interpreted with caution as they do not isolate the effect of social norms (descriptive and/or injunctive) from the effect of resource-saving tips and, hence, they might have overstated the importance of the norms (Dolan and Metcalfe, April 2015). From the list of our selected studies, Ayres et al. (2013), Dolan and Metcalfe (April 2015), and Bhanot (2017) partially address this problem of confounded effects by isolating the effect of peer comparisons from other effects. Dolan and Metcalfe (April 2015) find an average seven percent reduction in gas use among U.K. households who were provided only the social comparison treatment with coupled norms. However, Ayres et al. (2013) report a much smaller ATE (1.2%) of a similar treatment on electricity and gas conservation among Opower clients in King County, WA, USA. Surprisingly, Bhanot (2017) finds that a social comparison referring to descriptive norms only (a "rank" treatment) had no effect, on average, on water use among households in Castro Walley, California, while a social comparison referring to coupled norms (a "competitive rank" treatment) in fact caused an increase in average water use.

Eleven out 13 studies under consideration explore the persistency of treatment effects over the duration of the treatment (see Table I, Column 9). Three of these studies even estimate treatment effects after treatment removal (Allcott and Rogers, 2014; Brandon et al., March 2017; Dolan and Metcalfe, April 2015). Most of these analyses find immediate treatment effects on resource conservation just after the delivery of treatments. These effects usually decay over the course of the interventions, but remain positive and significant even after removal of treatments in all three studies mentioned above.

Also, we are interested in the modes of information provision. All selected studies used printed letters, emails, websites, or a combination of these to communicate social comparisons to treated households. Furthermore, they relied on discrete treatments, i.e., social comparisons communicated to households through one-time emails or printed letters. The mode and frequency of treatment delivery might affect the salience of the treatment as well as its effectiveness. For example, Dolan and Metcalfe (April 2015) find that social comparisons provided through printed letters had a significant effect on households' gas conservation behavior, but not when the social comparison treatments (even with additional financial incentives) were provided via emails. This result may to some extent be explained by the salience of the information delivery, which is expected to be higher for those receiving social comparisons via a printed letter than by email.

All studies under consideration use daily or monthly data to measure ATEs. More detailed real-time data from smart meters have generated privacy concerns and have therefore been inaccessible for researchers (Allcott and Rogers, 2014). This explains why none of the reviewed studies explore the effects of social comparisons on resource savings during the peak and off-peak demand hours, despite the fact that this is a highly policy-relevant research question for most countries.

Unlike the previous studies summarized above, the present paper aims to expand the existing literature in the field of behavioral environmental and energy economics in the following two unexplored directions. First, our experiment is based on social comparisons communicated via pre-installed in-home displays that are salient and updated in real time; the experiment generates high-frequency data and enables us to measure the effects of the treatment over the day – during both peak and off-peak hours. Second, we estimate the effect of provision of peer-comparison information on the consumption of two resources – electricity and water – in the same experimental setting. This enables us to meaningfully examine whether social comparisons affect residential electricity and water use in the same way.

3 Design of the experiment

3.1 General context

Sweden, in particular the northern part, is abundant with both electricity and fresh water. More than 50 percent of the country's electricity production relies on renewable energy sources and about 40 percent on nuclear power. Even though it may seem like Sweden does not have issues with its electricity consumption, Sweden has implemented several national and EU-wide policies aiming to reduce energy-related pollution and improve energy efficiency in the residential sector and in the economy as a whole. For instance, in 2008, the Swedish Parliament decided on an energy efficiency target aiming for a 20-percent reduction in the energy intensity of the entire economy. This target can be traced back for example to concerns over the environmental impacts of the fossil-fuel based marginal power production in the integrated Nordic-Baltic and continental power markets. Also, in 1980, the results from a referendum on nuclear power generation favored the option to phase out the 12 reactors that existed at the time. The winning option also stipulated that the reactors should be phased out without jeopardizing affordable electricity prices and the security of the power supply. To date, four reactors have been closed and two more will disappear by 2020. The overall view is that improved energy efficiency is a prioritized target of Swedish energy policy. Energy taxation has been used as the primary policy measure in reaching this target. For instance, Swedish households pay a unit tax per kWh of electricity consumed (0.023 €/kWh in the north and 0.034 €/kWh in the south).

The consumption of potable water has not been much of a policy issue in Sweden. The primary issue discussed among policy makers is that water consumption is typically included in the apartment rent, which means that most tenants do not have water meters and therefore do not pay per unit of water consumed. Consequently, tenants are thought to consume unnecessarily large quantities of water. The misaligned incentives of landlords and tenants represent a version of the classical principal-agent problem (Sappington, 1991). However, in our experiment, the treatment and control groups consist of newly built apartments, which are subject to individual metering and billing of cold and hot water. Thus, the households in our experiment are generally not expected to be under social pressure to reduce their water consumption. It should be also added that the hot water supplied to the participating households is produced by district heating plants that use biofuels and solid waste as their main inputs. Thus, we do not expect that tenants in our experiment have strong personal norms regarding their own water consumption.

3.2 Research partner

The field experiment was implemented in collaboration with a municipality-owned rental housing company, AB Bostaden, which is based in Umeå, Sweden. AB Bostaden owns and manages about 15,400 apartments and is in this respect the biggest actor in Umeå's rental housing market with a market share of about 50 percent (60% if including student housing).

The company tracks electricity and water consumption in each newly built rental apartment. Tenants are subject to individual metering and billing of electricity and water, but the costs of heating and some other utilities, such us garbage management and lighting of common areas, are included in the rent. Additionally, information on electricity and water use is provided to tenants on in-home displays, which are salient and updated almost in real time. It is also important to note that AB Bostaden provides all of its tenants with fixed electric appliances, such as fridges, freezers, dishwashers, and kitchen ranges. These appliances are the same or very similar in all new apartments in terms of energy performance and functions.

3.3 Subjects and timeframe of the experiment

The field experiment includes 525 newly built residential rental apartments equipped with real-time displays (RTD). The participating households were observed for 24 months – 12 months before and 12 months after the treatment was delivered on March 1, 2016. The length of the experiment was decided based on the objective to study the persistence of the treatment effect and also the need to control for the seasonal variations in electricity and water consumption.

The experiment was not pre-announced and participation was non-optional to sampled households, and consequently no monetary participation incentives were offered to them. We chose not to pre-notify the affected households about the experiment in order to avoid a so-called social desirability bias, which occurs when treated subjects behave in line with the implicit objectives of an experiment even if these objectives are not explicitly communicated. The participating households had a possibility to contact the rental housing company and express their opinion about the changes in their real-time displays. Not a single household expressed concerns or a wish to have the old design of the RTD back at any point during the experiment period.

3.4 Formation of the treatment and control groups

The sampled households were divided into two treatment groups (one for electricity and one for water, 100 and 110 apartments, respectively) and a control group (315 apartments). The apartments were assigned to the different groups as follows: One “block batch” (a block of eight buildings) was assigned to the two treatment groups and three block batches were assigned to the control group. Each of the eight buildings in the treated block batch was then randomly assigned to one of the two treatments.

The contiguous block group approach was used for two reasons. First, we chose a randomization at the building level instead of at the individual apartment level to minimize the risk of an outcome evaluation problem. That is, when subjects in control and treatment groups get in close proximity to each other, the treatment may affect subjects in both groups and, thus, the outcome for the control group will no longer show the effect of “no treatment” but instead the effect of “possible exposure to the treatment” (Harrison and List, 2004; Heckman and Smith, 1995). We believe that when households are randomized at apartment level, it is more likely that two neighbors, one in the treatment group and the other in the control group, will share information about the changes in their displays.

Second, our research partner AB Bostaden had a strong preference to randomize households at building level, expressing a concern that randomization at apartment level might increase the risk of complaints from tenants about some apartments in a building having the new RTD design and some not.

3.5 RTD designs

The key features of the RTD designs for the three groups (two treatments and one control) are shown and summarized in Figure 1. Before the experiment was introduced, all selected households had been exposed to the control RTD (top RTD in Figure 1), which displays the household's own current electricity and water (cold and hot) consumption in real time ("Actual consumption") and own cumulated 24-hour electricity and water use ("Last 24 hours"). The displays also have some indicators of positive or negative consumption changes over time based on the household's past electricity and water consumption.

[Insert Figure 1 about here]

In our experimental setting, we have two treatment groups – one for electricity use and one for water (cold and hot) use. The decision to have these separate treatment groups was based on our objective to test whether the effects of provision of peer-comparison information on two different resources, with presumably diverse non-pecuniary motives for conserving these resources, differ. The treated households were informed about the changes in their RTDs through printed letters distributed on March 1, 2016. However, the electricity treatment group was not informed about the water treatment group and vice versa.

The middle and bottom RTD displays in Figure 1 show the new information provided by the treated RTDs. As can be seen, three horizontal bars have been added to these displays. The top two bars, labelled *Idag* and *Du*, provide information about the household's consumption of the respective resource in the current 24-hour period (i.e., since midnight) and as a 7-day moving daily average, respectively. The consumption of electricity and water is measured in kWh and liters, respectively. The third, bottom bar, labeled *Andra*, shows the 7-day moving daily average consumption recorded for all other RTD-equipped households in apartments of similar size. This new information allows the treated households to compare their own average consumption of electricity or water with their neighbors' consumption.

For both the control and the treatment groups, the RTDs provide other relevant information as well, including indoor and outdoor temperatures and a 3-day weather forecast. Furthermore, all RTD users can change their RTD settings to view their consumption of electricity or water in monetary terms (in SEK) instead of in kWh or liters.[1] Also, by simply pressing on the electricity or water icons on the RTDs, the users can see their electricity and water consumption on hourly, daily, weekly, or monthly basis.

4 Results of the empirical analysis

4.1 Descriptive statistics

Table II shows the descriptive statistics for the control group and the two treatment groups for electricity and water usage before and after the delivery of the treatment. There are 315 apartments in the control group, 100 apartments in the treatment group for electricity, and 110 apartments in the treatment group for water. We observed these groups for two years – one year before and one year after the delivery of the treatment.

[Insert Table II about here]

Our experiment delivers real-time data. For our research purposes, we aggregate the data on hourly and daily basis. Our main outcome variable is electricity and water use per day over a two-year period. We have 365 daily observations per year for most, but not all, apartments; some of the apartments in the control group were not observed for the entire two-year period as they were built and first occupied later but before the delivery of the treatment.

[1] To view electricity and water use in monetary terms, the households need to manually enter the unit price they pay for the respective resource. However, even after doing this, the displayed cost corresponds only to the *variable* cost of consumption, as the other components of the utility bill, such as taxes and fixed fees, are not displayed on the RTDs.

We removed obviously flawed observations, such as abnormal electricity or water readings (more than 1,000 kWh/hour or 1,000 l/day) from the analysis, along with daily observations with missing data for some hours. We also removed observations of daily electricity consumption when electricity was switched off (reported zero consumption), but not water (reported positive consumption). The dropped observations correspond to less than two percent of the total daily observations. The exact numbers of observations in each group for the pre-treatment and post-treatment periods, as well as other relevant descriptive statistics, are reported in Table II.

Table II shows that the average daily electricity use in the treatment group decreased by 0.23 kWh (from 4.53 kWh to 4.3 kWh), while in the control group the decrease amounted to only 0.11 kWh. The average daily water use in the treatment group increased by 3.4 liters (from 157.4 l to 160.8 l), while the control group displays the opposite development – an average decrease of 4.4 liters per day.

Figure 2 plots the dynamics of the monthly daily average electricity and water consumption before and after the intervention. It is evident that the residential consumption of electricity and water is seasonal, i.e., these resources tend to be used less in the summer. Both the treatment and control groups have very similar pre-treatment trends for both resource use.[2] In the post-treatment phase, the trends for electricity consumption remain similar for both groups, but a continuous drop can be noted for the treatment group. In contrast, when looking at water consumption, it is not clear whether the treatment had any effect at all.

[Insert Figure 2 about here]

4.2 Average treatment effects

To estimate the average treatment effects, we run the following difference-in-difference regression model:

$$y_{it} = \beta_1 TREAT_i + \beta_2 POST_{it} + \beta_3 TREAT_i * POST_{it} + \boldsymbol{\mu} X_t' + \alpha_i + \varepsilon_{it},$$

[2] The formal tests of the similar pre-treatment trends assumption are summarized in Subsection 4.6.1.

where y_{it} is the daily electricity or water use (in kWh or liters) in household *i* at time *t*, $TREAT_i$ is a dummy variable indicating whether household *i* is in the treatment group or the control group, $POST_{it}$ is a dummy variable indicating the pre- and post-treatment periods, X_t' is a set of the time-varying covariates (year-monthly fixed effects and Monday-to-Sunday fixed effects), α_i are household fixed effects, and ε_{it} is an idiosyncratic error term (unobserved household-specific shocks). This model is estimated in OLS using the standard fixed-effects estimator with Huber-White standard errors, which are clustered at the unit of household to account for serial correlation (Bertrand et al., 2004). The estimated coefficient β_3 measures the average treatment effect of provision of peer-comparison information on our outcome variables, i.e., daily consumption of electricity and daily use of water.

Table III reveals a significant treatment effect on electricity use, namely an average daily reduction of 0.304 kWh (or about 6.7 percent). The treatment effect of –0.304 kWh/day means that the average household in the treatment group took electricity saving actions equivalent to turning off one standard 60-watt light bulb for about five hours each day. This relatively large treatment effect on residential electricity consumption is consistent with the results of the similar field-experimental studies summarized in Table I.

[Insert Table III about here]

An ATE on the daily water consumption is not significantly different from zero. This result is not in line with most of the studies discussed in Section 2, of which most find rather large effects of social comparisons (with coupled norms and resource-saving tips) on residential water conservation (e.g., see Ferraro and Price, 2013). Our finding resembles the one of Bhanot (2017), who finds that a neutrally framed peer rank had no impact on water use over the full period of the experiment. Interestingly, one feature that distinguishes our study and Bhanot's from other studies is that our and Bhanot's social comparisons did not communicate an injunctive norm or water-saving tips. This may suggest that allusion to both types of norms – descriptive and injunctive – as well as advice on how to save water may be necessary components to make social comparisons effective, in particular in cases when personal norms are expected to be weak.

4.3 The persistence of the treatment effects

A number of studies find that treatment effects of non-pecuniary incentives tend to decay over time (Allcott and Rogers, 2014). Many of these studies rely on discrete treatments (e.g., treatments delivered through monthly or quarterly printed letters or emails), which may trigger social sentiments initially after a treatment. However, over time, these sentiments may dissipate (Ferraro and Price, 2013; Gneezy and List, 2006).

To examine the persistence of the treatment effects in our study, we plot the ATEs for each month of the experiment for both treatment groups (see Figure 3). The monthly ATEs are generated by estimating a triple difference-in-difference model for each month. In each model, we include an additional triple interaction term of the key treatment variables as described above (see Subsection 4.2) and a dummy variable for a particular month. As before, these models are estimated by using OLS with household fixed effects.

Figure 3 shows that, in the case of electricity use, the treatment effects are negative and statistically significant in the second and third months of the experiment (April–May 2016). After three months, the significant treatment effect disappears for two months and then reappears in August. In the case of water, we do not find any statistically significant monthly ATEs, but from the estimated signs of the ATEs it is evident that households reacted slightly to the treatment only in the first months of the experiment. All in all, these results do not support the idea that continuous and salient treatments in the form of social comparisons encourage persistent resource conservation.

[Insert Figure 3 about here]

4.4 Heterogeneity of treatment effects

Our experimental data allows us to examine not only ATEs but also whether the ATEs vary by time of day (peak vs. off-peak hours), between hot and cold water, or among households (low- vs. high-consumption households and small vs. large apartments). Below we present and discuss the results of estimating models exploring heterogeneity.

4.4.1 Peak vs. off-peak hours

To date, energy-efficiency policies and related analyses have tended to focus on total energy savings without regard to when the savings occur. The high frequency of our experimental data allows us to explore the timing of residential electricity savings induced by our social comparison treatment.

To this end, Figure 4 plots the ATEs on electricity use for each hour over the period of the treatment, for weekdays (Mon–Fri) and weekends (Sat–Sun), respectively. The figure is generated by estimating a triple difference-in-difference model for each hour (48 models in total). In each model, we include an additional triple interaction term of the key treatment variables (as described in Subsection 4.2) and a dummy variable for a particular hour. As before, these models are estimated by using OLS with household fixed effects.

[Insert Figure 4 about here]

Figure 4 shows that the social comparison treatment causes residential electricity savings in the evening hours from 6pm until midnight on weekdays. On weekends, the ATEs are positive in the early afternoon (1pm) and later in the evening (9pm–midnight). Knowing that the typical electricity peak demand hours in Sweden are industry driven and occur between 6am and 6pm,[3] our results concerning electricity savings at 6pm (on Mon–Fri) suggest that social comparisons can be one of the tools in addition to ordinary price instruments to encourage electricity saving in peak hours.

4.4.2 Hot vs. cold water

[3] See a report published by Svensk Energi (April 2016) for a typical daily profile of electricity consumption in Sweden.

Above, we reported the ATE for total water consumption. Here we look at this result closer by examining the ATEs for cold and hot water use separately. From the estimation results reported in Table IV, it is evident that the ATE on daily hot water use is negative and insignificantly different from zero, while the estimated ATE on daily use of cold water is positive and significant, albeit only at the 10-percent level of significance. The signs of these ATEs lead us to suspect that treated households somewhat responded to the intervention by substituting hot water consumption with cold water consumption (e.g., people may reduce the water temperature when taking showers).

[Insert Table IV about here]

4.4.3 Two-room vs. three-room apartments

It is important to recall that, in our experiment, the peer-comparison information on resource use, which is delivered on households' RTDs, is based on all RTD-equipped apartments with an equal number of rooms. For instance, two-room apartments in the electricity treatment group received summative information about the electricity use of all other two-room apartments equipped with an RTD. To see whether the ATEs are similar between smaller and bigger apartments, we divide our sample into two subsamples. The first sample includes only two-room apartments and the second only three-room apartments.[4]

In Table V, the only significant ATEs are found for electricity and hot water consumption in two-room apartments. It could be the case that larger three-room apartments tend to be occupied by larger families with children, who might find it more difficult to conserve electricity and water.

[Insert Table V about here]

4.4.4 Low- vs. high-consumption households

The theoretical models about heterogeneous effects of descriptive norms predict that households that previously consumed less than the norm will increase their consumption after the delivery of the

[4] We focus only on these two subsamples as, in total, there are only one one-room apartment and five four-room apartments in the treatment groups.

descriptive norm. Social psychologists call this phenomenon the *boomerang effect*. To check whether this effect occurred in our field experiment, we compare the ATEs between low- and high-consumption households.

We divide households in two-room (three-room) apartments into a low-consumption and a high-consumption group according to how their pre-treatment resource use compares to the average pre-treatment resource use of all participating households in two-room (three-room) apartments. Households with a below-average consumption level are defined as low-consumption households, and vice versa.

Table VI shows that the electricity-related social comparison treatment induced significant conservation in both types of households in two-room apartments, i.e., both those with low electricity consumption and those with high electricity consumption (by 0.404 kWh/day and 0.437 kWh/day, respectively). No corresponding significant effects were found for three-room apartments. As for overall water use in two-room apartments, we find no significant ATE on either group. However, we do observe a significant ATE on hot water consumption (a drop of 12.90 l/day) for high-consumption households in two-room apartments.

[Insert Table VI about here]

Interestingly, in the case of three-room apartments, the ATEs are positive and significant for total water, hot water, and cold water use; the estimated coefficients of the ATEs are 33.66 l/day, 16.81 l/day and 16.85 l/day, respectively. These results imply that our social comparison, which referred only to descriptive norms, led to a "boomerang effect" in water use by low-water users living in three-room apartments.

4.5 Interpreting the results

Here we aim to answer in depth two questions arising from our results. First, why did our social comparison treatment have a significant effect on electricity savings but not on total water use? Second, what household activities can explain the significant effect on electricity conservation?

4.5.1 Why the effects on electricity but not water use?

To begin with, we argue that the difference in ATEs cannot be explained by monetary incentives to save electricity but not water as the electricity bills and water bills that the studied households pay each month are similar in size.[5] We reason that the lack of social comparison effect on joint water use but large effect on electricity savings might be explained by differences in households' non-pecuniary motives for conserving these resources.

As discussed in Subsection 3.1, water conservation is not much of a policy issue in Sweden, and even households subject to individual metering are not expected to have strong personal norms regarding their water use or be under any significant social pressure to save water. This is contrary to the context of other, similar studies conducted in regions affected by water shortages; see, e.g., Brent et al.'s (2015) California study. Hence, there is reason to believe that people in Sweden are less concerned than people in many other places about the environmental impacts of water use, and that social norms therefore do not provide a very effective tool to reduce residential water use in Sweden.

The same cannot be said about electricity consumption, since Swedes tend to connect it to a number of global and local environmental problems, in particular climate change and the environmental impacts of nuclear power (see Subsection 3.1). The awareness about the negative environmental impacts of energy use is to some degree supported by the results of a recent OECD survey, which shows that when respondents were asked about the seriousness of six specific environmental issues facing the world, Swedish respondents perceived climate change to be the most serious problem (OECD, 2014). The same survey also reports that Swedish respondents were the second most likely to believe that climate change is at least partly caused by human activity, such us the burning of coal or gas for power generation. For

[5] For example, we know from anecdotal evidence that an average monthly water bill and an average electricity bill (not including fixed network charges) for a three-room apartment in the treatment group is about SEK 150 each.

these reasons, we think that social comparisons are likely to be more effective in activating social norms in the case of residential electricity consumption than in the case of residential water use.

4.5.2 What actions underlie electricity conservation?

In previous studies, energy conservation behavior induced by social comparisons is generally explained either by changes in households' habits or by changes in in-home capital stock (see, e.g., Allcott and Rogers, 2014; Brandon et al., March 2017). In our case, we argue that none of these drivers could explain our relatively large but impersistent effect on electricity consumption, i.e., electricity conservation occurred in the first few months, in the evening hours, and more on weekdays than weekends. Also, the households in our study had little motivation to switch to more efficient appliances as the rental housing company provides all of its tenants with nearly identical kitchen appliances, such as fridges, dishwashers, and kitchen ranges. Hence, as our electricity treatment does not refer to injunctive norms and does not provide tips for electricity conservation, we argue that the observed temporary electricity savings induced by the pure social comparison information are due to the short-run changes in "obvious" electricity-saving behaviors, such as turning off lights when leaving a room or the apartment, unplugging electronics and turning on fewer lamps, electricity-saving methods that the treated households were most likely already familiar with. Certainly, this hypothesis requires further investigation and a follow-up survey of the treated households would shed more light on this result.

4.6 Robustness tests

4.6.1 Testing the assumption of parallel trends

Field experiments rely on the important assumption that trends in outcome variables over time should be the same across control and treatment groups. First, we test the assumption of parallel trends in our sample by visually inspecting the dynamics of the monthly daily average and hourly average electricity and water consumption for the control group and the treated groups before and after the delivery of the treatment. Figure 3 shows a similar pattern of resource use in the pre-treatment periods for both groups.

Second, as an additional validation of the parallel-trends assumption, we perform a so-called placebo test by hypothetically assuming another date for the delivery of the treatment. More precisely, we assume the year 2014 as a pre-treatment year and the year 2015 as a treatment year. The results of the placebo test, which are summarized in Table VII, show that there are no statistical differences in the outcome variables between the treatment and control groups for 2014–2015. This suggests that the pre-treatment trends in the outcome variables are the same for the control and treated households in our sample.

4.6.2 Balanced sample

As is evident from the descriptive statistics in Table II, our analysis is based on an unbalanced data sample. To check whether this affects our main results, we rerun the main models by using the balanced data sample. The results of this robustness test show (see Table VIII) that the ATE for the daily electricity use remains negative and significant for the balanced data sample.

4.6.3 Controlling for the new-gadget effect

Over the course of the pre- and post-treatment periods, some apartments changed tenants, which could possibly cause a new-gadget effect in the new tenants. To take this into consideration, we excluded households that moved into an apartment after the delivery of the treatment. The results of OLS estimation using the restricted sample, summarized in Table IX, show that the ATE on the daily electricity use remains significant and of similar size as before.

[Insert Table VII, Table VIII and Table IX about here]

5 Conclusions

Previous literature suggests that informational policies relying on social comparisons may be a useful part of a cost-efficient strategy to reduce households' use of resources such as electricity and water. At present, it has not yet been fully understood when and how social comparisons are effective. In this paper, we present a natural field experiment that contributes to the existing literature in the two following ways. First, we estimate the effect of provision of peer-comparison information on the consumption of two resources – electricity and water – in the same experimental setting. This enables us to meaningfully examine whether social comparisons have the same effect on residential electricity and water use. Second, our social comparisons are communicated via pre-installed in-home displays that are salient and updated in real time. The experiment generates high-frequency data and enables us to measure the effects of the treatment over the course of each day, during peak and off-peak hours. The timing of the electricity savings is relevant from a power systems analysis perspective, where one major concern is to balance the demand and supply under all possible circumstances.

Several interesting insights emerge from our results. We find that social comparisons can influence residential use of electricity but not water use. On average, the treatment effect implies a daily reduction of residential electricity consumption by 6.7 percent. We reason that the differing results for electricity and water consumption may be explained by differences in household norms concerning consumption of the two resources, e.g., that in Sweden, the environmental and social impacts of water use are less of a concern than those of electricity consumption, and hence, households may be more motivated to conserve electricity than water.

Based on our results, we tentatively conclude that the effectiveness of social comparisons depends on the context and that researchers and policy makers should be careful when generalizing results from individual experiments. However, our results concerning residential electricity consumption do contribute to a large body of empirical evidence suggesting that social comparison indeed is an effective means to temporarily stimulate resource conservation. In our experiment, the ATE on electricity use fades after six months after the start of the experiment, which suggests that curtailment activities rather than investments in new capital produced the ATEs. Furthermore, we find that the electricity use foremost was reduced during the evening hours. The system peak in Sweden occurs in the early evening, which suggests that energy conservation following social comparisons have a favorable time-profile.

Our results suggest that social comparisons communicated through salient real-time displays may not encourage persistent resource savings. We argue that the effects of such instruments depend on the context, e.g., whether households have strong norms concerning the resource subject to social comparisons. Furthermore, a persistent effect cannot be taken for granted even if social comparisons are combined with standard pecuniary economic instruments. We see a need for future research that tries to better understand the interactions between economic incentives and social norms in household behavior, e.g., whether economic carrots are better complements to social comparisons than economic sticks.

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List of Tables

Table I. Summary of the selected field experiment studies* on the effects of provision of peer-comparison information on households' energy and water use

Study* (1)	Study object (2)	Type of treatment (3)	Mode of treatment provision (4)	Duration of treatment (5)	Data frequency in measuring ATE (6)	ATE (7)	Model used to estimate ATE (8)	Is ATE persistency addressed? (9)	Location (10)	Sample size (11)
Allcott (2011)	Electricity	Coupled norms[1] with tips[2]	Letters (monthly, bimonthly, quarterly, or mixed)	2 years	Daily	-2.03%	Mean ATE from FE models[3] of 17 experiments	During treatment	U.S. (OPOWER clients in 17 regions)	306,670 (T)[4], 281,776 (C)[5]
Ayres et al. (2013)	Electricity	Coupled norms with tips	Letters (quarterly or monthly)	1 year	Daily	-2.02%	FE models	During treatment	U.S. (OPOWER clients in the Sacramento Municipal Utility District)	34,557 (T), 49,570 (C)
	Electricity & gas	Coupled norms	Letters (quarterly or monthly)	8 months	Daily	-1.2% (electricity); -1.2% (gas); -1.2% (combined)			U.S. (OPOWER clients in Puget Sound Energy, WA)	34,891 (T), 44,121 (C)
Costa and Kahn	Electricity	Coupled norms with	Letters (quarterly or	8–10 months	Daily	-2.1%	FE model	During treatment	U.S. (OPOWER	33,664 (T),

(2013)		tips	monthly)						clients in California)	48,058 (C)
Ferraro and Price (2013)	Water	Tips only	1 letter	4 months	Aggregated water use across 4 months	-1%	OLS models	During treatment	U.S., Georgia	11,676 (T), 71,643 (C)
		Tips with weak descriptive norm				-2.8%				11,676 (T), 71,643 (C)
		Tips with strong descriptive norm				-4.8%				11,676 (T), 71,643 (C)
Allcott and Rogers (2014)	Electricity	Coupled norms with tips	Letters (monthly, bimonthly, quarterly or mixed)	4–5 years	Daily, monthly	-2.5%	FE model (after 4 letters)	During & after treatment	U.S. (OPOWER clients in 3 sites in upper Midwest and on the West Coast)	26,262 (Continued T), 12,368 (Dropped T), 33,524 (C)
Brent et al. (2015)	Water	Coupled norms with tips	Letters and emails (monthly or mixed)	1 year & 3 months (group 1); 1 year & 2 months (group 2); ongoing (group 3)	Daily	-5.11% (group 1); -4.9% (group 2); no effect (group 3)	FE models	During treatment	U.S., California	3 groups: (1) 897 (C) & 992 (T); (2) 1,547 (C) & 1,545 (T); (3) 1,200 (C) & 1,180 (T).
Dolan and	Gas	Coupled norms	Letters (unclear how	1 year & 3	Daily	-7%	FE models	During & after	U.K., London	185 (T), 185 (C)

Metcalfe (April 2015)	Gas	Coupled norms with tips	many)	months		-6%		treatment	U.K., London	191 (T), 185 (C)
	Electricity	Coupled norms with high reward	Email (unclear how many)	2 months	Monthly	No effect			U.K., London	84 (T), 368 (C)
	Electricity	Coupled norms with low reward				No effect			U.K., London	87 (T), 368 (C)
Schultz et al. (2016)	Water	Tips only	1 Letter or website	1 week	Average daily derived from monthly data	No effect	ANOVA	No	U.S., San Diego	46 (T), 43 (C)
		Descriptive norms with tips				-26%				86 (T), 127 (C)
		Coupled norms with tips				-16%				83 (T), 127 (C)
Jaime Torres and Carlsson (April 2016)	Water	Coupled norms with tips	Monthly letters	11 months	Monthly	-5.4%	FE model	During treatment	Columbia, Jericó	656 (T), 655 (C)
Hahn et al. (December 2016)	Water	Descriptive norms with other	Letters	9 months	Monthly	-1.4%	FE model	During treatment	U.S., San Antonio	5,819 (T), 5 821 (9C)
Bhanot (2017)	Water	Descriptive norm ("Rank" treatment)	Letters or emails every two months	5 months	Average daily derived from	No effect	OLS model	During treatment		1,288 (T), 1,308 (C)

		Coupled norms ("Competitive rank" treatment)			monthly data	+8.22 gallons per day			U.S., California	1,300 (T), 1,308 (C)
Sudarshan (2017)	Electricity	Descriptive norms with tips ("Nudge")	Weekly letters	4 months	2–3 day intervals	-7%	FE linear model	No	India, National Capital Region	124 (T), 124 (C)
		Descriptive norms with reward ("Nudge +Incentives")				No effect		No		240 (T), 124 (C)
Brandon et al. (March 2017)	Electricity	Coupled norms with tips	Letters (monthly, bimonthly, quarterly or mixed)	6 years	Monthly	-2.4%	OLS model	During & after treatment	U.S. (OPOWER clients in 21 utilities)	1,685,778 (T), 830,308 (C)

Notes:

- ∗ The studies are listed in chronological order. Priority is given to published peer-reviewed studies.

1. By *coupled norms*, we mean that the author/s study social comparisons with pure peer-comparison information (referring to descriptive norms) *and* with normative messages, such as "smiley faces" or other types of normative encouragement to boost resource conservation (referring to injunctive norms).
2. By *tips*, we mean that the treatment also includes advices on how to conserve resources.
3. *FE model* stands for an OLS difference-in-difference model with households' fixed-effects.
4. *(T)* refers to the number of households in the treatment group.
5. *(C)* stands for the number of households in the control group.

Table II. Descriptive statistics

	Pre treatment			Post treatment		
	No. of daily observations	Average	Std. dev.	No. of daily observations	Average	Std. dev.
Control group						
Electricity, kWh/day	75,301	4.61	3.22	113,127	4.50	3.22
Water, l/day	76,444	175.3	148.2	113,611	170.9	146.8
Hot water, l/day	76,444	71.5	71.8	113,611	72.7	75.5
Cold water, l/day	76,444	103.9	86.7	113,611	98.2	82.3
No. of rooms*	76,517	2.4	0.7	113,820	2.3	0.7
Apartment size, m^2	76,517	60.4	18.7	113,820	59.1	19.0
Electricity treatment group						
Electricity, kWh/day	35,217	4.53	2.69	33,734	4.30	2.5
Water, l/day	36,008	129.6	107.0	36,135	127.5	109.0
Hot water, l/day	36,008	54.6	56.4	36,135	52.8	56.4
Cold water, l/day	36,008	75.0	58.5	36,135	74.7	61.3
No. of rooms	36,009	2.3	0.4	36,136	2.3	0.5
Apartment size, m^2	36,009	59.3	9.6	36,136	59.4	9.7
Water treatment group						
Electricity, kWh/day	39,636	4.89	3.02	39,894	5.00	2.9
Water, l/day	39,768	157.4	128.7	39,753	160.8	130.8
Hot water, l/day	39,768	68.4	67.2	39,753	69.0	66.9
Cold water, l/day	39,768	89.1	71.4	39,753	91.9	74.0
No. of rooms	39,839	2.4	0.6	39,894	2.4	0.6
Apartment size, m^2	39,839	62.3	11.7	39,894	62.3	11.7

Note: *In Sweden, the number of rooms means the number of living space rooms and bedrooms and does not include the kitchen or bathroom. A two-room apartment therefore means an apartment with a living room and a bedroom, a bathroom and a kitchen. In the U.S., this apartment would be called "1 bedroom apartment."

Table III. ATEs on daily electricity (in kWh) and water (in liters) use

	Electricity	Water
Variables	(1)	(2)
TREAT*POST	-0.304**	2.449
	(0.137)	(6.714)
POST	0.158	1.708
	(0.0988)	(3.994)
Constant	5.562***	190.7***
	(0.0621)	(2.373)
Controls	Yes	Yes
No. of observations	257,379	269,576
No. of apartments	415	425

Note: The standard errors clustered at apartment level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table IV. ATEs on daily electricity, cold water, and hot water use

Variables	Water (1)	Cold water (3)	Hot water (2)
TREAT*POST	2.449	6.232*	-3.782
	(6.714)	(3.599)	(3.453)
POST	1.708	-3.059	4.767**
	(3.994)	(2.302)	(1.932)
Constant	190.7***	110.5***	80.20***
	(2.373)	(1.371)	(1.152)
Controls	Yes	Yes	Yes
No. of observations	269,576	269,576	269,576
No. of apartments	425	425	425

Note: Standard errors clustered at apartment level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table V. ATEs on daily electricity (in kWh) and water (in liters) use for two-room and three-room apartments

	Two-room				Three-room			
	Electricity	Water	Cold water	Hot water	Electricity	Water	Cold water	Hot water
Variables	(1)	(2)	(3)	(4)	(3)	(4)	(7)	(8)
TREAT*POST	-0.440***	-8.050	0.343	-8.393**	-0.237	16.14	10.82	5.328
	(0.148)	(8.076)	(4.280)	(4.252)	(0.269)	(12.39)	(6.555)	(6.300)
POST	0.229**	5.788	0.0960	5.692**	0.273	3.177	-2.235	5.411*
	(0.104)	(5.195)	(2.785)	(2.759)	(0.185)	(5.708)	(3.240)	(2.818)
Constant	4.688***	164.6***	93.33***	71.28***	7.020***	228.4***	134.2***	94.23***
	(0.0620)	(2.867)	(1.554)	(1.496)	(0.113)	(4.177)	(2.466)	(2.009)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of observations	138,218	140,090	140,091	140,092	91,795	97,991	97,992	97,993
No. of apartments	219	218	219	220	149	154	155	156

Note: Standard errors clustered at apartment level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table VI. ATE on daily electricity (in kWh) and water (in liters) use for low- and high-consumption households

	Low users				High users			
	Electricity	Water	Cold water	Hot water	Electricity	Water	Cold water	Hot water
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				Two-room apartments				
REAT*POST	-0.404**	-1.269	0.925	-2.194	-0.437*	-12.25	0.649	-12.90**
	(0.174)	(11.41)	(5.848)	(5.974)	(0.230)	(10.45)	(5.741)	(5.529)
POST	0.501***	20.12***	9.309**	10.81**	-0.0937	-6.283	-7.762*	1.478
	(0.126)	(7.407)	(3.644)	(4.132)	(0.167)	(6.949)	(3.937)	(3.577)
Constant	3.507***	102.5***	58.95***	43.52***	5.909***	210.6***	118.9***	91.78***
	(0.0760)	(3.470)	(1.871)	(1.816)	(0.0888)	(4.084)	(2.192)	(2.169)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of observations	70,441	59,161	59,161	59,161	67,777	80,929	80,929	80,929
No. of apartments	107	87	87	87	112	131	131	131
				Three-room apartments				
TREAT*POST	-0.580	33.66**	16.81**	16.85*	-0.260	-9.405	0.0427	-9.448
	(0.368)	(15.56)	(7.868)	(8.415)	(0.384)	(17.59)	(10.20)	(7.842)
POST	0.774***	1.018	-0.688	1.706	-0.0539	5.061	-3.084	8.144*
	(0.271)	(5.908)	(3.652)	(2.865)	(0.251)	(8.536)	(4.791)	(4.193)
Constant	5.464***	146.4***	87.67***	58.73***	8.152***	282.0***	164.8***	117.1***
	(0.169)	(5.427)	(3.176)	(2.542)	(0.146)	(5.695)	(3.352)	(2.804)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of observations	38,538	39,082	39,082	39,082	53,257	58,909	58,909	58,909
No. of apartments	57	55	55	55	92	99	99	99

Note: Standard errors clustered at apartment level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table VII. "Placebo" ATEs on daily electricity and water use

	Electricity	Water
Variables	(1)	(2)
TREAT*POST	-0.101	5.955
	(0.309)	(8.759)
POST	-0.169	-2.516
	(0.274)	(7.138)
Constant	5.643***	178.8***
	(0.139)	(4.003)
Controls	Yes	Yes
No. of observations	64,611	90,340
No. of apartments	109	150

Note: Standard errors clustered at apartment level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table VIII. ATE on daily electricity and water use for the balanced data sample

	Electricity	Water
Variables	(1)	(2)
TREAT*POST	-0.310*	0.128
	(0.184)	(8.291)
POST	0.166	4.037
	(0.156)	(6.141)
Constant	5.961***	196.8***
	(0.0886)	(3.206)
Controls	Yes	Yes
No. of observations	162,061	172,820
No. of apartments	230	240

Note: Standard errors clustered at apartment level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table IX. ATE on daily electricity and water use when excluding new households

	Electricity	Water
Variables	(1)	(2)
TREAT*POST	-0.294**	-3.753
	(0.128)	(5.424)
POST	0.197**	5.197
	(0.0915)	(3.490)
Constant	5.596***	189.0***
	(0.0626)	(2.326)
Controls	Yes	Yes
No. of observations	239,161	249,922
No. of apartments	415	425

Note: Standard errors clustered at apartment level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

List of Figures

Figure 1. RTD designs for the control group and the two treatment groups

	RTD front screen	Key features on the front screen
RTD, control group		*Aktuell förbrukning* (current consumption): The household's current electricity and water (hot and cold) consumption in real time. *Senaste 24 timmarna* (last 24 hours): A household's total electricity and water (hot and cold) consumption in the last 24 hours.
RTD, electricity treatment		Information on current electricity consumption and the electricity consumption in the last 24 hours is replaced with 3 bars: *Idag* (today): the household's total electricity consumption since midnight. *Du* (you): the household's 7-day moving daily average of electricity use. *Andra* (others): the 7-day moving daily average of electricity use of other households in apartments of similar size.
RTD, water treatment		Information on current consumption of hot and cold water and the consumption of hot and cold water in the last 24 hours is replaced with 3 bars: *Idag* (today): the household's total consumption of hot and cold water since midnight. *Du* (you): the household's 7-day moving daily average consumption of hot and cold water. *Andra* (others): the 7-day moving daily average consumption of hot and cold water recorded for other households in apartments of similar size.

Figure 2. Dynamics of the monthly daily average electricity and water use before and after treatment delivery

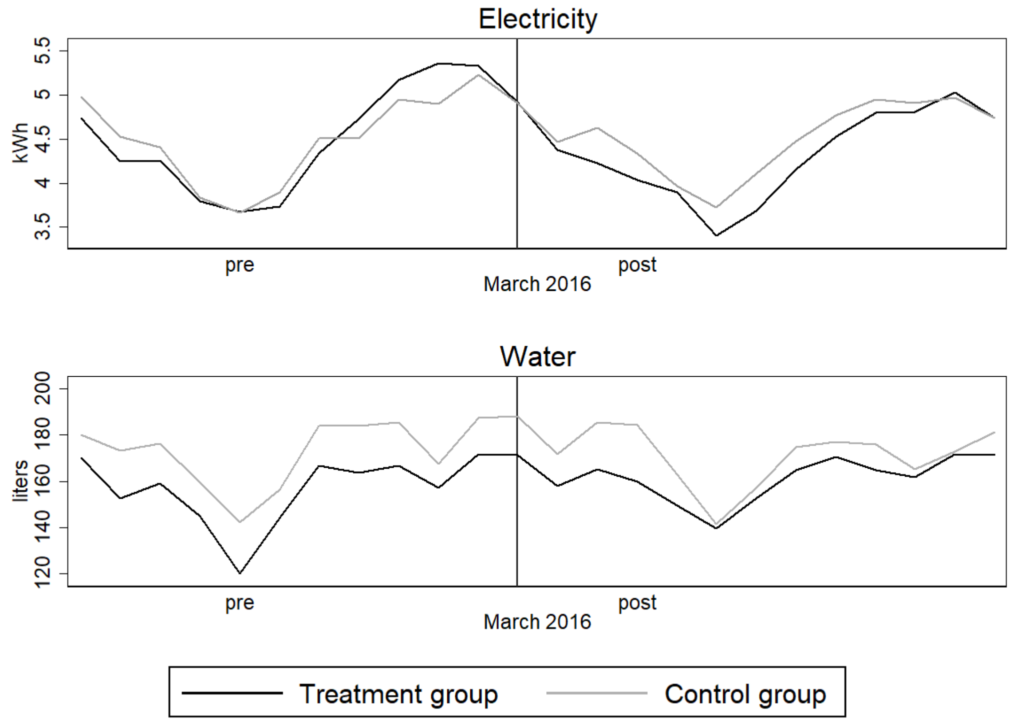

Figure 3. ATEs on electricity and water use for each month over the period of the treatment (CI 95%)

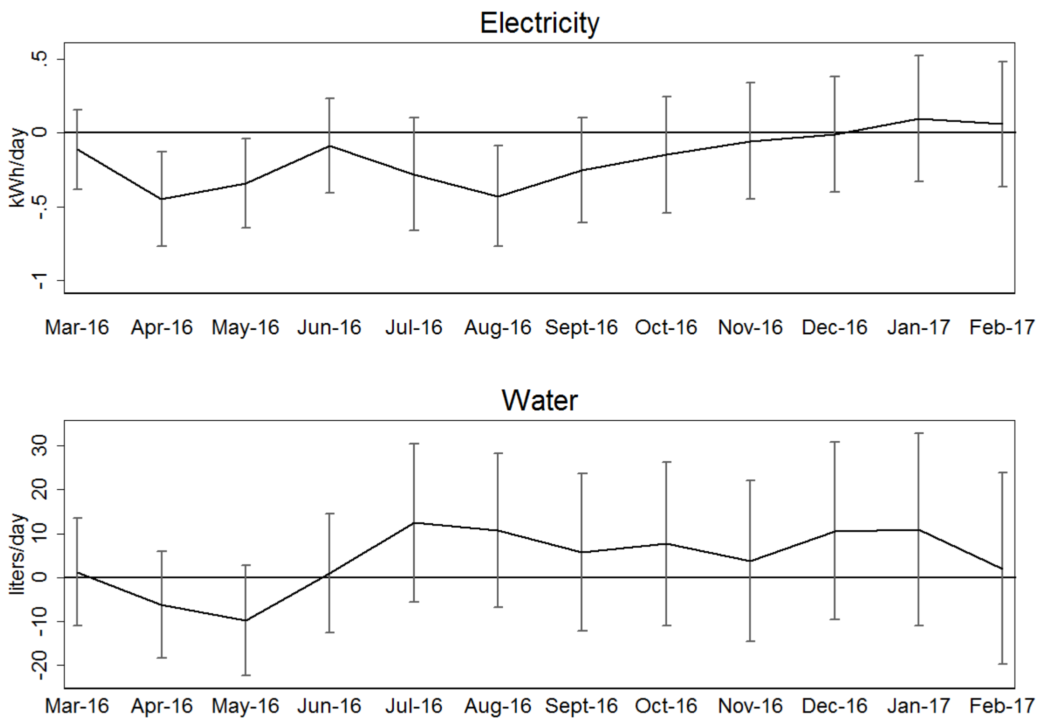

Figure 4. The ATE on electricity consumption by each hour for weekdays and weekends (CI 95%)