The Effect of Feedback by Text Message (SMS) and email on Household Electricity Consumption: Experimental Evidence

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Abstract:

This paper analyzes the effect of supplying feedback by text messages (SMS) and email about electricity consumption on the level of total household electricity consumption. An experiment was conducted in which 1,452 households were randomly allocated to three experimental groups and two control groups. Feedback was supplied throughout 2007 to members of the experiment groups who accepted the invitation, and data on consumption of electricity for 2006 and 2007 collected for all participants and control group members. 30% of the households invited to receive feedback accepted the invitation. Results suggest that email and SMS messaging that communicated timely information about a household's 'exceptional' consumption periods (e.g. highest week of electricity use in past quarter) produced average reductions in total annual electricity use of about 3%. The feedback technology is cheap to implement and therefore likely to be cost-effective.

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1. Introduction

The purpose of feedback information is to increase the awareness among consumers of their energy consumption. Consumption of electricity is characterized by being indirect in nature, i.e. consumers consume services derived from electricity, for example by using a dishwasher. Understanding the exact marginal costs of using a dishwasher requires reading of the meter before and after the use of the dishwasher while holding constant the use of other appliances, calculating the use of electricity and then its monetary value. This is usually much too complicated compared with the potential gain from understanding the exact marginal costs of consuming a service derived from electricity. Consumers can handle this by applying routine based decision making. Such behavior is sometimes labelled inattentiveness, Reis (2006). Feedback provides consumers with more information, so that consumption decisions can be made at smaller costs. Supplying feedback information about electricity consumption at an increased frequency should enable consumers to make more precise consumption decisions by relying less on routine based decision making. In this sense supplying feedback at an increased frequency could in principle affect the level of consumption both upwards and downwards, since a customer may realize upon having received more information that her level of consumption was actually lower than preferred. Policy makers, however, tend to focus on the ability of such measures to reduce consumption.

There is a long tradition for providing feedback to households about their electricity consumption, for example, by printing last period's consumption level of the energy bill, Wilhite (1999). Such initiatives are typically part of a broader set of initiatives called Demand Side Management (DSM) or Integrated Resource Planning (IRP) aiming at making households reduce consumption of electricity. Historically, utilities have as monopolies been required to initiate such activities by regulators, and electricity utilities in both Europe and the US have been implementing such measures for many years.[1] DSM/IRP activities made by electricity utilities are financed through tariffs. Therefore, it was a concern if the DSM/IRP- activities could survive the introduction of competition. However, in the new reorganized competitive sector, the obligation is delegated to the electricity grid companies that are now the monopoly part of the sector. The DSM/IRP policy in Denmark is a mirror of this international development. Today all grid companies in Denmark have a legal obligation to implement energy savings at their customers.[2]

At the same time as the electricity sector is being liberalized advanced meters with automated meter reading are being implemented in many countries. In Denmark 45% of all Danish customers will be equipped with an advanced meter within a few years. This development takes place without special regulation from the authorities. In Sweden a requirement for monthly meter reading has led to adoption of smart meters, and in other countries like Norway, and the Netherlands a similar development is in progress. The distribution of advanced meters together with the rapid development and proliferation of new information technologies provide new possibilities for giving feedback information.

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[1] See e.g. Joskow (2001) and Goldman (2003) for US-perspectives on the activity. In Europe DSM/IRP has been encouraged by as well the European Union as the member states see Didden et al.(2003).
[2] A general and very recent overview and evaluation can be found in Togeby et al, (2009).

The objective of this paper is to investigate the effect of supplying feedback by text message (SMS) and /or email on the level of total household electricity consumption. Feedback by text message and /or email is being used already in other sectors. In the banking and portable telephone sector, for example, account statements are being supplied to consumers by text messages and emails. For the present purpose this technology is adapted to generate feedback on household electricity consumption, and a randomized field experiment is performed in which a group of customers of a Danish electricity supplier is randomly allocated to two control groups and three experimental groups that are invited to receive feedback. For all the households who accept the invitation and all control households electricity consumption is recorded from 1 January 2006 to 31 December 2007. The experimental groups receive feedback via text messages or emails from 1 January 2007 to 31 December 2007.

The choice of feedback technology is made based on a tradeoff between the type of feedback that is known to have the largest impact and the costs of implementing the technology that supplies it. It is known that feedback information works best if it is given frequently, over a long period and at an appliance specific level; see Fischer (2008). The effect of feedback by text message and email has never previously been explored. As applied in this experiment it meets the first two requirements. It is sent out at a daily frequency, and the experiment runs for an entire year. There is thus plenty of opportunity for participants to adjust and get used to the type of feedback given. The third requirement is not met in our setup. Appliance specific feedback is usually relatively costly as it requires meters to be installed at all the appliances targeted. Unless the savings are very large the benefits are unlikely to be large enough to finance the technology required. Our feedback technology, on the other hand, operates on total household electricity consumption. The majority of the population have access to receiving either email or text messages. This implies that the type of feedback information tested here is cheap to implement, and therefore likely to be cost-effective even if the impact is small. This is important since effects of feedback are likely to be small. For example, Matsukawa (2004) finds that 113 Japanese households, who had feedback provided by a continuous display installed in the residence and giving information about consumption, were observed with a level of electricity consumption that was 1.5 % lower than that of a control group.

The results of the present experiment indicate moderate interest in the type of feedback tested. 30% of the households invited to participate in the experimental groups accepted the invitation. The majority of the participating households preferred to receive feedback by email. In the analysis the growth rate of consumption from 2006 to 2007 is compared for participants and control group members. Results suggest that email and SMS messaging that communicated timely information about a household's 'exceptional' consumption periods (e.g. highest week of electricity use in past quarter) produced average reductions in total annual electricity use of about 3%. This finding is, however, not significant across all econometric specifications investigated, and this is likely due to the fact that the experiment includes a limited number of households, compared with the natural variation in demand. The type of feedback provided in this experiment is very cheap and even small reductions in electricity consumption are therefore likely to make the scheme cost-effective. A rough estimate of the costs of establishing the technology generating the feedback is estimated to be 6 USD (4.4 EUR) if smart meters are already installed. In the experiment the participating households in group 3 reduced consumption by

3% on average corresponding to 135 kWh. The price of 135 kWh to the customer was 37 USD (27 EUR) when valued at Danish electricity retail prices or 6.8 USD (4.9 EUR) when valued at spot market prices.

The paper is organized as follows. In the next section the feedback technology is described. After that, the experimental design is outlined and the data described. Then results are presented and finally the analysis is summarized and conclusions are made.

2. Experiment design

The experiment is conducted by randomly allocating a group of customers of a Danish electricity supplier, SYD ENERGI, to two control groups and three experimental groups that are given different degrees of choice between various types of feedback via text messages or emails. For all the households involved in the experiment electricity consumption is recorded from 1 January 2006 to 31 December 2007.

2.1 Types of feedback

Three types of feedback are given to the experimental groups. Type 1 feedback provides the consumer with information about the development of her consumption level at a regular frequency. Type 2 feedback provides the consumer with feedback when current consumption deviates significantly from the consumption level of the previous period. Type 3 feedback provides feedback when current consumption is extreme relative to the distribution of consumption levels in several earlier periods. The types of feedback are summarized in table 1 below.

Table 1: Types of feedback

Types of feedback	Description
Type 1	The feedback is sent out every day, week or month
Type 2	The feedback is sent out if electricity consumption during this period (day, week or month) deviates with a certain percentage from consumption in the previous period
Type 3	The feedback is sent out if current electricity consumption is among the highest or lowest levels of consumption recorded in previous periods

We select 1,452 households that we include/invite to participate in the experiment. They are allocated randomly to two control groups and three experimental groups. One of the control groups is “blind”, but the members of the second control group are informed that they are part of an experiment testing the effect of feedback information. This second control group is introduced as an attempt to frame any experimental effect that may be present.

The three experimental groups are given different degrees of choice with respect to the type of feedback that they will receive. Group 1 is given no choice of feedback and receives only type 1 feedback at a weekly frequency. Group 2 has more choices. Group 2 members can choose type 1 and/or type 2 feedback at three different frequencies, daily, weekly, or monthly. Experimental group 3 is not restricted in their choice.

This allocation of choices between the three experimental groups reflects a weighting of a design, in which the effect of information on consumption can be measured without complications, group 1, and a design that reflects the available technological possibilities, but where the isolated effect of information on consumption is more difficult to measure, group 2 and 3. This is because the participating households in group 2 and 3 must make choices concerning both consumption and type of information they wish to receive. The types of feedback available to members of the three experimental groups are summarised in table 2.

Table 2: The types of feedback available to the three experiment groups.

Types of feedback	Experiment group 1	Experiment group 2	Experiment group 3
Monthly type 1		X	X
Weekly type 1	X	X	X
Daily type 1			X
Monthly type 2			X
Weekly type 2		X	X
Daily type 2		X	X
Monthly type 3			X
Weekly type 3			X
Daily type 3			X

In connection with the experiment a home page is established in which all households in control group 2 and all three experimental groups can get access to graphical presentations of historical consumption data[3]. All households in the experimental group have to choose whether to receive feedback via text messages and/or email. Text messages contain only text whereas emails also contain a graphical presentation of the consumption data. Generic text messages and emails are shown in the appendix. Participants in group 2 and 3 also have to choose the type of feedback they wish to receive. For these households a default feedback setup was established, but households in group 2 and 3 could adjust the setup, i.e. the type and frequency of the feedback, at the homepage at any point during the experimental period. All types of feedback messages were sent out at 6pm on the relevant day or as soon as possible hereafter.

[3] In this sense control group 2 did get feedback, but it required logging on the home page of SYD ENERGI.

2.2 Implementation

The experiment was conducted among a set of customers of SYD ENERGI. This supplier was targeted because it is the first company in Denmark to install advanced meters enabling automated meter reading at a massive scale to their customers. The meter has a display showing how consumption accumulates. It does not have features generating feedback apart from this, and it is typically located in a utility room, so that its panel is not visible without effort. The pool of participants for the experiment was selected among the customers who had an on-line meter installed and in operation by 1 January 2006. 15,847 customers satisfied this criterion. For these customers we obtained information about dwelling characteristics from the official building registers enabling us to deselect customers that are not likely to benefit from this type of feedback or would not be relevant for the experiment.

From the pool of customers we selected households living in a detached house or terrace/town house that did not use electricity as the main energy source for heating the house. This implies deselecting customers recorded with a metre installed in a summer house, and this constitutes the bulk of the gross sample of 15,847 customers. We deselect that type of customers because consumption is highly irregular. Moreover, we exclude customers using electricity as the main source for heating. Electricity is not the major energy carrier for heating purposes in primary residences in Denmark. This is because a comprehensive collective heating supply system based on natural gas and district heating has been developed, and installation of electric heating as the main heating system has been banned in new houses used as primary residences since 1988.

We also deselect customers that use the house for commercial purposes or use the house as non-permanent residence. Finally, we required the customer to have been living in the house at least since 1 January 2006. Imposing these restrictions left us with 1,452 customers. These households were then randomly allocated to the two control groups and the three experiment groups, approximately 200 to each of the control groups and approximately 350 to each of the experiment groups. More customers were assigned to the experiment groups than to the control groups. This is because households in the experiment groups can choose not to accept the invitation to participate in the experiment, and drop-outs are expected. The control groups, on the other hand, will only suffer from attrition to the extent that some households move during the experiment period.

Invitations were sent out to the experimental groups and information about the experiment sent out to control group 2 in mid-November 2006. Members of control group 1 were not informed that they were part of the experiment. Members of experimental group 1-3 were asked to sign up via the homepage or by returning a reply-form included in the letters. Members of the experimental groups who had not answered by the beginning of December received a second letter reminding to sign up to the experiment. Participants were not told what experimental group they were going to be assigned to until the registration period had ended, and the allocation of households across experimental groups is therefore random (conditional on participation)

For implementing the experiment a technical platform has been developed[4]. The purpose of the platform is to facilitate communication between the electronic on-line meters located at the customers, the billing server located at the energy supplier, and a feedback server that is placed at a third location for the purposes of this experiment. As mentioned previously the feedback technology applied in this experiment is based on an idea known from other sectors. For example, some banks offer feedback to their customers about movements in their account. In that case the bank already has all the necessary information available in their data base. In the present context the consumption data, from which the feedback is to be calculated, is initially collected at the customers. Therefore, consumption data need to be transferred from the customers to the billing server of the electricity supplier and then to the feedback server before feedback is generated and sent back to the customers[5]. Consumption data are transferred from the customers to the billing server by Power Line Communication and from the billing server to the feedback server by an internet connection.

The technical platform also facilitates communication between the feedback server and the customers through a web interface. Here customers can get access to a graphical presentation of their consumption data. The web interface enable customers to update their own profile with e-mail addresses, GSM phone numbers (experimental group 1-3), and choice of feedback (experimental group 2 and 3). Each household can enter more phone numbers and more email addresses. The webpage is secured so that access requires user name and password. The website offers a possibility for the participating households who have forgotten their password to type their address and then via text message or e-mail receive their password.

4. Data and Summary Statistics

The data used in the analysis come from different sources. Consumption was recorded daily for all participants and all control group members for the period 1 January 2006 to 31 December 2007. The number, the timing and type of messages were also recorded. As mentioned earlier we also had access to data from the public building register with information about the type of house, the size and the main heating source. These data are publicly available and were used to select the households entering the sample that we invited to participate or included in the control groups. Next, historical data on annual consumption was obtained from the electricity supplier, SYD ENERGI, for 2004, and 2005. These data were collected for billing purposes by SYD ENERGI before electronic on-line metres were installed. Finally, using the address code of the house we merged background characteristics of the individuals living at the addresses to which electricity was supplied and measured during the experiment. These background characteristics are measured in 2006 and include information about income, education, age, marital/cohabitation status of the adult members, and household size. The background characteristics are obtained from administrative registers. These registers are not publicly available and can only be

[4] The technical platform is designed and developed by ZONITH A/S (http://www.zonith.com/). A detailed description of the platform (in Danish) can be downloaded at http://feedback.noe.dk/Publicering/PDF/FeedbackTeknologiPlatformAfslutningsRapport%20(v12).pdf

[5] The type of online-meter installed at the customers cannot make calculations on location and display results.

used by researchers under strict confidentiality conditions. Because of the confidentiality restrictions this information could only be obtained after the experiment had finished.

Next, we describe the participation rate and summary statistics characterising the participants in the experiment. Also a description of the amount of feedback sent out and the level of electricity consumption across the different groups in the experiment is presented.

In table 3 an overview of the participation rate is given. The first column gives the number of households invited to participate in the experiment. The number of households that has completed the experiment is given in the second column. Not all households who accepted to participate actually completed because they moved during the experiment period. Linking to the administrative register data by matching addresses with the people recorded as inhabitants at the address implies a loss of observations because in some cases the match is not exact. The third column gives the number of households available after we have merged with register data. The final column gives the number of households that have accepted to receive feedback (experimental groups) and for whom we have register data and consumption data for.

The acceptance rate for the experimental groups was 31%. This indicates that the households included in the experiment were only moderately interested in the type of feedback tested. The limited participation also opens for the possibility that households deciding to participate in the experiment are on average different types of consumers than the average consumer in the control groups

Table 3. Participation in the experiment.

	Invited	Completed	Completed and with register data	Accepted, completed and with register data
Control group one	214	205	196	196
Control group two	203	189	183	183
Treatment group one	341	333	325	105
Treatment group two	340	325	319	92
Treatment group three	354	345	336	105
Total	**1,452**	**1,397**	**1,359**	**681**

Source: Register, meter and participation data

Summary statistics for experimental and control households are presented in table 4. The first three columns give summary statistics for participants in the three experimental groups. Colum 4 and 5 give statistics for the two control groups. The experimental groups tend to have a higher level of consumption than the control groups. On average participating families have higher income, are slightly more educated, slightly younger, and are more likely to be living in couples, i.e. married or cohabiting. They also live in larger houses, which is the likely reason for the higher level of consumption.

To assess the degree to which our sample is representative we have obtained a random sample of 1,000 households from the population of households. Column 6 presents summary statistics for this sample. The characteristics of the households in the experimental sample and the random sample are both collected from administrative registers, i.e. the data source is the same. However, for the random population sample we do not have information about electricity consumption. Comparing the random sample with the experimental sample it is seen that households in the experimental sample are on average slightly older, tend to cohabit more often and to live in larger houses. They also tend to have slightly lower incomes than participants but the number of children and the level of education are similar. We therefore conclude that while differences exist between the experimental data and the population, the experimental sample is not decisively different from the random sample.

Table 4. Summary statistics of the characteristics of participants and controls

	Exp. 1 (1)	Exp. 2 (2)	Exp. 3 (3)	Control 1 (4)	Control 2 (5)	Population (6)
kWh, 2005	4823	4911	4617	4404	4517	-
kWh, 2004	4789	4789	4663	4243	4287	-
Income, 1000 DKK	471	508	534	425	430	457
Age of oldest in household	53	55	55	56	56	50.7
Immigrant in household	0.06	0.08	0.09	0.05	0.09	0.10
Highest education in household (years)	10.8	11.0	11.1	10.9	10.3	10.9
Cohabiting	0.74	0.83	0.83	0.63	0.70	0.51
Number of children age 0-2	0.10	0.15	0.07	0.05	0.10	0.09
Number of children age 3-12	0.40	0.33	0.35	0.34	0.37	0.30
Number of children age 13 – 17	0.16	0.21	0.17	0.15	0.19	0.11
m2, size of house	145	150	149	135	138	112
Number of rooms	4.9	4.8	4.9	4.6	4.7	3.903
Number of observations	105	92	105	196	183	1000

Table 5 shows the distribution of feedback media chosen by the households participating in the experimental groups. Most households prefer to use email rather than text messages as the feedback medium.

Table 5. Choice of feedback media

	Number of households			
	Only tesxt message	Only E-mail	Text message and E-mail	Total
Treatment group one	33	59	13	105
Treatment group two	20	60	12	92
Treatment group three	34	58	13	105

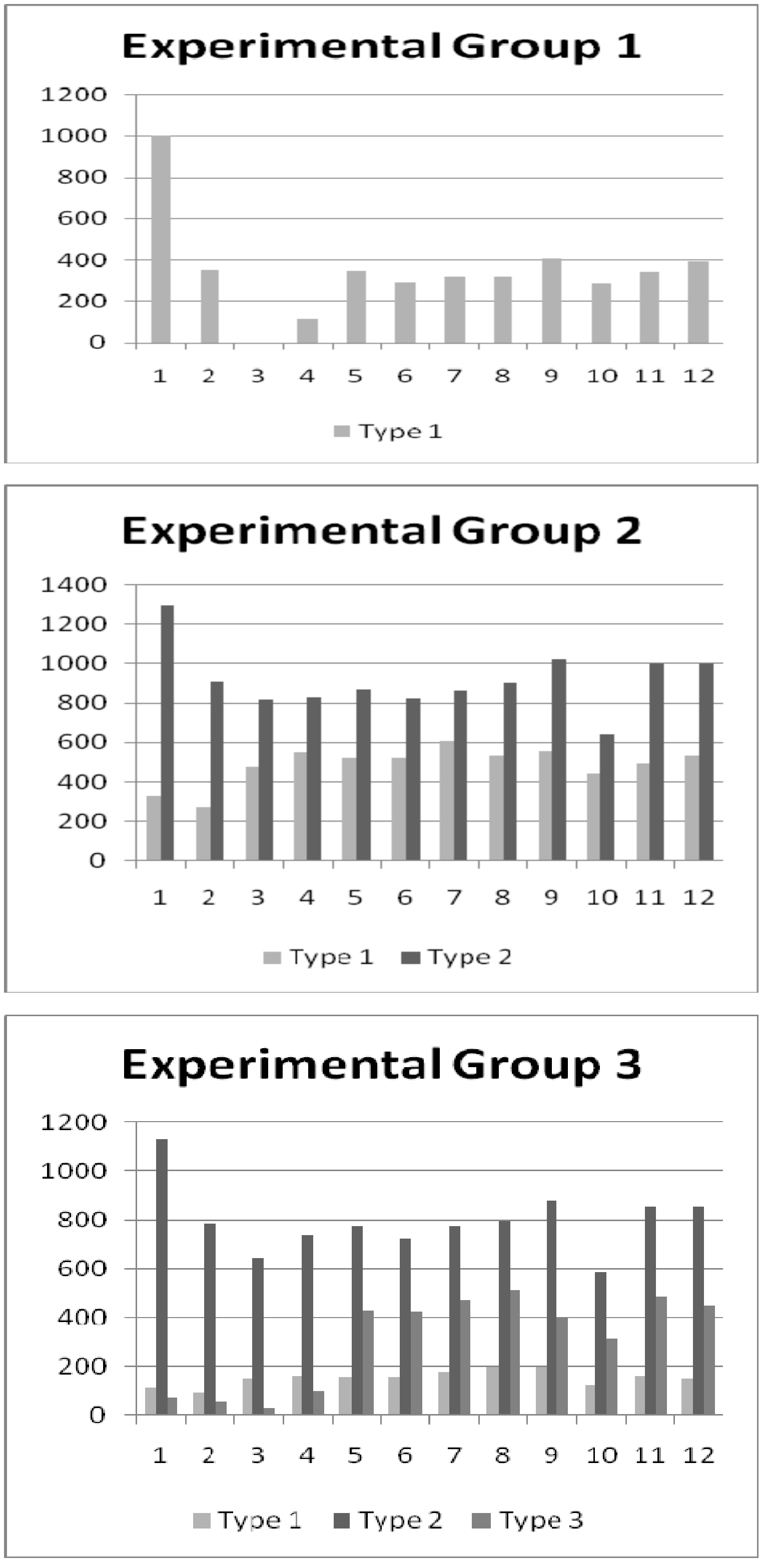
Source: Meter data and own calculations

The total amount of feedback messages sent out to the three experimental groups is summarized in figure 1. Much feedback was sent out during 2007, but unfortunately the feedback server suffered from some technical problems at the beginning of the experimental period. Two problems occurred. Initially, many uninformative messages were sent out. From February this traffic was blocked, so that only informative messages were passed on to the consumers. Also, at the beginning the feedback server was unable to handle missing information on daily electricity consumption. This reduced the number of valid feedback messages that were sent out in the period January to April 2007. This shows very clearly for group 1, the group that did not face any choice and could only receive weekly type 1 feedback. If feedback was sent out according to the plan about 400 messages should have been sent out per month. Figure 1 clearly shows that this is not the case. In January 2007 many messages were sent out, including many uninformative messages, and the number of feedback messages was clearly below the intended level up to and including April.

Experimental group 2, who received both type 1 and type 2 feedback, was not influenced as much by the technical problems. Type 2 feedback was initially low. The number of type 1 feedback messages is much higher than for treatment group one. This is because a fraction of the households in experimental group 2 chose to receive daily type 1 feedback and this type of feedback was not affected by the problems described for experimental group 1.

The distribution of feedback messages sent to experimental group 3 is graphed in the last panel of figure 1. This group was also affected by the technical problems in the period January to April, but this mainly affected type 3 feedback.

Figure 1. Feedback messages sent to experimental group 1, 2 and 3.



5. Results

The primary objective of the study is to analyze the effect of the feedback on consumption of electricity. In order to do this we compare the growth rate of annual electricity consumption from 2006 to 2007 for the participants in the experimental groups with that of the control groups. One important feature of the data is the fact that only 30% of the households invited to take part in the experiment decided to participate. This potentially implies that the effect of the feedback cannot be revealed by simply comparing the level of consumption for participants in the experimental groups with the level of consumption for the control groups. This is because participants in the experimental groups for example could have been recruited from the sub group of invited households with the largest potential for benefitting from the feedback. In order to understand if participation is related to certain characteristics we first analyze the participation decision, and then turn to the analysis of the effect of the feedback on the level of consumption.

5.1 Participation

For analyzing the participation decision we estimate a discrete choice model of participation. For doing this we make use of different data sources. First, we use the experimental data indicating if the customers participate in the experiment. Next, we use historical billing data obtained from the electricity supplier, and finally we make use of the data characterizing the inhabitants of the dwelling that we measure consumption for. This information is, as mentioned previously, obtained from various public administrative registers and merged on to the experimental data by matching address codes. For some address codes we find no match, and the sample that we use for estimation is therefore slightly reduced. 1,035 customers are invited to participate in the experiment, but we only have background information for 980 of them. The number of non-matched households is equally distributed across the three experimental groups.

The participation decision is modeled as a probit model giving the probability of participating as a function of a vector of covariates. In the covariate vector we include the level of log electricity consumption in 2005 and the growth rate of consumption from 2004 to 2005. The lagged level of consumption is intended to control for effects related to the size of the stock of appliances that the household owns, and which we have no direct information about. The idea is that participating households may on average have a stock of electrical appliances that is different from that of all the invited households. The lagged change in log consumption is included because households may have selected into the experiment because they had recently experienced an increase in their electricity consumption and were therefore more interested in gaining additional information about their consumption behavior. Besides historical consumption information we also include the level of income, age of the oldest household member, an indicator of whether the household is an immigrant household, the level of education for the person with the longest education in the household, an indicator of whether the adult members of the household were living together as a couple, indicators for the presence of children in the household, a variable giving the size of the house, and the number of rooms.

Results are presented in table 6. They indicate that the participation decision is significantly related with the level of income and the historical level of consumption. The higher the income level the more likely are households to participate, and the higher the level of consumption in 2005 the larger is the probability that households participate. Note that this is the case even when size of the dwelling and number of household members have been controlled for. Finally, the chance of participation increases with the level of education. The remaining covariates are not significant.

Table 6. Estimates from a probit model of participation on characteristics.

Dependent variable = 1 if Participation = Yes, otherwise 0		
Parameter	Estimate	st. err.
Intercept	-10.9848**	1.7568
Ln(kWh) 2005	0.2658**	0.1213
ΔLn(kWh), 2004-2005	-0.1783	0.1438
Ln(income)	0.4615**	0.1143
Age	0.0052	0.0039
Immigrant	-0.0386	0.1660
Highest education, years	0.0236	0.0146
Cohabiting	0.0906	0.1259
# children age 0-2	-0.0277	0.1409
# children age 3-12	0.0312	0.0719
# children age 13 – 17	0.0238	0.1096
ln(m2), Size of house	0.4108*	0.2389
Number of rooms	-0.0558	0.0448
Number of observations	980	
Log-likelihood	-560.72	
Percent correctly predicted	73	
Note: Reference for number of families in the household is one family.		

5.2. The Effect of Feedback on the Level of Consumption

We now turn to the analysis of the effect of feedback on the level of consumption. Consider a linear demand equation

$$y_{it} = \delta_0 + \beta_0 D2007_t + \beta_1 D_{it} + \mu_i + v_{it} \qquad (1)$$

Where y_{it} is log of kWh of electricity consumption, $D2007_t$ is a dummy variable taking the value 1 if the observation pertains to 2007 as opposed to 2006. This time-dummy capture any “aggregate” effect that is common across participants and controls group members but vary across time. D_{it} is a dummy variable taking the value 1 if the household is observed in 2007 and has accepted the invitation and otherwise takes the value 0. μ_i is an unobserved effect that is assumed to be constant across the entire observation period. We think of this as an unobserved factor governing household *i*’s attitude towards energy savings, but it generally captures that participants are potentially different from nonparticipants. Hence, μ_i may be correlated with D_{it} so as to allow for the case where those accepting to participate are a particular selection of households that are more interested in energy consumption, have a higher level of consumption and therefore more likely to benefit from savings measures, or are otherwise different from the non-participants in a way that is important for consumption and for their decision to participate in the experiment. In the panel data literature μ_i is often called a ”fixed effect”, see for example Wooldridge (2002), and estimating (1) by OLS will give a biased estimate of β_1. v_{it} is an independent error term. δ_0, β_0, β_1 are parameters, and β_1 is the parameter of interest giving the mean effect of feedback among households who have accepted to participate.

Usually, linear demand functions of energy demand include a price term and sometimes a term capturing the impact of weather variations, see for example Reiss and White (2008). In our case all households face the same marginal price of electricity at all levels of consumption. Hence, the marginal price does not vary across the control and treatment groups and therefore does not impact the estimate of β_1 which is the focus in this analysis. In any case the price varies very little over the period 2006-2007 and is therefore not important for describing the development in consumption over the period considered. Similarly, the households included in this analysis all live in a confined geographical area and therefore all face similar weather conditions. Weather conditions should therefore not influence the estimate of the effect of feedback. Because all households in the analysis are exposed to the same weather conditions the effect of weather conditions are captured by the year dummy.

Now, consider a first differenced version of equation (1)

$$\Delta y_{i2007} = \beta_0 + \beta_1 D_{it} + \Delta v_{i2007} \qquad (2)$$

First, note that $D2007_t = 1$ for all observations so that β_0 is now effectively a constant term. Note also that μ_i does not enter equation (2). If this unobserved factor governs selection into accepting the invitation to receive feedback then it does no longer generate bias in the estimate of β_1. The regression effectively compares the growth rate of consumption for the experiment groups with that of the control groups. Having first-differenced the data there is only one record available for each household in the sample, and we can therefore remove the time-subscripts. This type of estimator is known as a differences-in-differences estimator in the economic program evaluation literature; see for example Heckman et al. (1999). In some specifications we add a vector of covariates, X_i, to this regression

$$\Delta y_i = \beta_0 + \beta_1 D_i + \beta_2 X_i + \Delta v_i \qquad (3)$$

Specifically, X_i is the vector of covariates used in the participation analysis, and it is introduced in order to reduce the error variance and thereby to increase the precision of the estimates. β_2 is the associated parameter vector. Note, that X_i is allowed to co-vary with D_i, as the participation analysis suggests it does, and to co-vary with the unobserved term μ_i governing the selection effect. This approach is recommended in the development literature, where experiments are extensively used, cf. Duflo, Glennerster, and Kremer (2008).

Results from estimating equation (2) and (3) by OLS are presented in table 7. In the first two columns no covariates are included and in column (3) and (4) covariates are included. Estimates in Columns (1) and (3) are based on the sample without any selections, and results presented in column (2) and (4) are based on a sample where households observed with a change in consumption of more than 50% from 2006 to 2007 are deselected. These regressions are presented because feedback is likely to generate a small signal (if any) compared to the natural variation in demand, and this may conceal the effect. Moreover, OLS is sensitive to extreme observations, and meter data are well-known to be volatile.

In the estimations all control group households and all experimental group household members who accepted the invitation to receive feedback are included.[6] In all regressions control group 1, the blind control group, is the omitted group. Results from the regressions without covariates, column (1), show that the parameter estimates on the dummy variables indicating control group 2 and experimental group 1-3 are insignificant. Note, however, that the estimated parameters for group 2 and 3 are negative. Group 2 and 3 are the groups that had access to choose which type of feedback they wanted. Also, as mentioned in section 4, the feedback server did not send out feedback regularly in the beginning of the experiment, and group 1 was affected the most by these problems. The pattern of the estimated parameters is consistent with this. When extreme observations are deselected, column (2), then the same qualitative pattern appears, i.e. negative parameter estimates for experimental groups 2 and 3. However, standard errors are now smaller and the parameter estimate for experimental group 3 is significant and suggesting a reduction in consumption of about 3%. Including covariates, column (3) and (4), confirm the picture.

[6] We have also estimated the same regression where all invited households were included in the treatment group. In this regression the estimated effect of feedback was always insignificant.

Table 7. Differences-in-Differences estimates of the average effect of feedback for households who received feedback. Dependent variable = growth in ln(kWh), 2006-2007.

	OLS (1)		OLS, trimmed [(i)] (2)		OLS (3)		OLS, trimmed [(i)] (4)	
Parameter	Estimate	st. err.	Estimate	st. err.	Estimate	st. err.	Estimate	st. err.
Control group two	-0.0130	0.0208	-0.0043	0.0144	-0.0110	0.0207	-0.0029	0.0139
Treatment group one	0.0106	0.0183	-0.0091	0.0162	0.0152	0.0176	-0.0020	0.0155
Treatment group two	-0.0153	0.0202	-0.0227	0.0177	-0.0103	0.0209	-0.0168	0.0173
Treatment group three	-0.0117	0.0184	-0.0330**	0.0158	-0.0138	0.0182	-0.0346**	0.0156
Ln(kWh) 2005	-		-		-0.0610**	0.0230	-0.0847**	0.0162
ΔLn(kWh), 2004-2005	-		-		0.0260	0.0237	0.0457**	0.0193
Ln(income)	-		-		0.0029	0.0181	0.0160	0.0146
Age	-		-		-0.0005	0.0008	-0.0001	0.0005
Immigrant	-		-		0.0116	0.0214	-0.0010	0.0201
Highest educ., years	-		-		0.0007	0.0019	0.0002	0.0014
Cohabiting	-		-		0.0380**	0.0184	0.0404**	0.0153
# children age 0-2	-		-		-0.0421	0.0297	-0.0212	0.0170
# children age 3-12	-		-		0.0131	0.0135	0.0252**	0.0095
# children age 13 – 17	-		-		-0.0178	0.0141	-0.0091	0.0104
ln(m2), Size of house	-		-		0.0209	0.0345	0.0168	0.0289
Number of rooms	-		-		-0.0037	0.0060	-0.0059	0.0055
Intercept	-0.0437**	0.0127	-0.0291**	0.0106	0.3342	0.2525	0.3798*	0.2153
# observations	681		668		681		668	

Note: Standard errors are robust to arbitrary forms of heteroscedasticity. ** indicates significance at 5% level. * indicates significance at 10% level. (i) Dependent variable trimmed: $-0.5 < \Delta \ln kWh_{i2007} < 0.5$

In the analysis presented here we have used annual measurements of consumption. The data have, however, been collected daily and this facilitates analysis of data sampled with higher frequency. Analysis of higher frequency data could potentially be useful if there are higher frequency responses by subjects, for example if responses appear only for a short period following the feedback or if the response is not constant across the experiment period. To address this we tried to run regressions with 12-months consumption differences rather than annual differences, but we found no significant effects using that specification. (These results are not reported but available on request). This is likely because data sampled at this frequency are noisier. Higher frequency data are noisier because the impact of short term weather variations is less likely to average out over a shorter period. Moreover, 12-months differences are susceptible to gaps in data recording, and there is a substantial amount of such gaps in the data. Measurements were transmitted by a GPS phone connection to a central data base, and sometimes the transfer was not successful. If this happened the accumulated consumption was transferred as soon as possible thereafter, but at some later point. At a monthly frequency such cases are more important than at an annual frequency. Finally, the billing period is annual, and so it is not obvious that monthly consumption periods are more relevant than annual differences.

6. Summary and Conclusions

The paper presents an analysis of an experiment designed to test the effect of on-line feedback supplied by text messages and email on total household electricity consumption. 1,452 Danish households were randomly allocated to two control groups and three experiment groups. Households allocated to the experiment group were invited to receive feedback. 30% of the invited households accepted the invitation. Results suggest that email and SMS messaging that communicated timely information about a household's 'exceptional' consumption periods (e.g. highest week of electricity use in past quarter) produced average reductions in total annual electricity use of about 3%. We note that results are not robust across all econometric specifications. Also, experimental evidence generally suffers from the fact that the experiment is temporary. Therefore, participants are potentially less responsive in the longer run and experimental evidence may show the upside of the potential. Danish households, on the other hand, probably face the highest marginal electricity price in the world, and Danish households are therefore likely to be more efficient when it comes to consuming electricity. This suggests that feedback of the type tested in this paper could have a larger effect in other countries.

Lessons from previous studies of feedback have shown that feedback is most likely to have an effect if it is given frequently, over a long period and at an appliance specific level. The type of feedback investigated here satisfies the first two requirements, but compromises the third. This is because appliance specific feedback is likely to be costly to implement and effects are likely to be small. Our feedback technology operates on total household electricity consumption. It is cheap to implement, and even small reductions in consumption are likely to make the feedback cost effective. The company that supplied the technology for this experiment estimates that the costs of the scheme per consumer are 6 USD (4.4 EUR) if smart meters are already installed. Participating household in group 3 on average reduced consumption by up to 3% corresponding to 135 kWh. The price of 135 kWh to the customer was 37 USD (27 EUR) when valued at Danish electricity prices. Danish costumers pay massive taxes and probably face the highest retail price in the world. The value of 135 kWh at 2007 spot market prices was 6.8 USD (4.9 EUR). In any case, the evidence presented does not rule out that the type of feedback tested may be cost-effective when implemented in full scale.

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Appendix: Generic text messages and emails.

This appendix provides generic text messages and emails for the three types of feedback. The fields marked with `$xx$` are replaced with text as indicated in the table below. The text is translated from Danish.

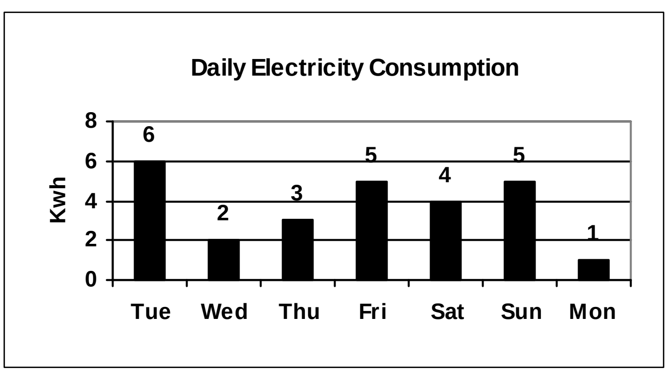
Type 1 and 2: Text message:

> Dear `$Name$`
>
> Your consumption of electricity has in the `$Periode_t$` been |`$Pct$`| % `$Change$` than in `$Periode_t-1$`.
>
> Kind regards SYD ENERGI

Email:

> Dear `$Name$`
>
> Your consumption of electricity has in the `$Periode_t$` been |`$Pct$`|% `$Change$` than in `$Periode_t-1$`.
>
> You can find more information about your electricity consumption at our home page www.???.dk . Here you can also change your personal details and
>
> When visiting the home page please use the following user name and password
>
> UserID: `$ID$`
>
> Password: `$Kode$`
>
> Kind regards SYD ENERGI
>
> `$Graf$`

Example, graph:



Type 3: Text message:

> Dear $Name$
>
> Your consumption of electricity has in the $Periode_t$ been among the $Value$ $Type$ $change$ within the last $Periode_Δ$
>
> Kind regards SYD ENERGI

Email: Similar to type 1 and 2 email except first text section is replaced with text as in text message for type 3.

Variable	Description	Value
$Name$	First name and surname	
$Periode_t$	Depends on the frequency: Daily , weekly, montly	'past day' if daily 'this week' if weekly 'this month' if monthly
Pct	Percentage change in consumption	
$Change$	="positiv" or "negative" depending on the value of Pct.	'higher' if Pct > 0 'lower' hvis Pct < 0
$Periode_t-1$	Depends on the frequency: Daily , weekly, montly	'past day' if daily 'this week' if weekly 'this month' if monthly
ID	Username	
$Kode$	Password	
$Graf$	Graph depending on the frequency: Daily , weekly, montly	
$Value$	Number corresponding to the limit chosen by the customer	
$Type$	Depends if limit is selected as a % or as a number	'%' if percentage ' ' if number
$change$	Depends if number is high or low	'highest' 'lowest'
$Periode_Δ$	Depends on $Periode_t$	'the last month' if $Periode_t$='day' 'the last quarter' if $Periode_t$='this week' 'the last year' if $Periode_t$='this month