Unintended Outcomes of Electricity Smart-metering: trading off consumption and investment behaviour

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Abstract Smart-metering allows electricity utilities to provide consumers with better information on their energy usage and to apply time-of-use pricing. These measures have been shown to reduce electricity consumption and induce time-shifting of demand. Less is known about how they affect residential energy efficiency investment behaviour. We use data from a randomised-controlled trial on a sample of almost 2500 Irish consumers, conducted over a 12 month period to investigate the effect of smart-metering and residential feedback on household investment behaviour. The results show that exposure to time-of-use pricing and information stimuli, while reducing overall and peak usage, can also have the unintended effect of reducing investment in energy efficiency measures within the home. Our findings indicate that households exposed to treatment were less likely to adopt any energy saving measure (23-28% on average); and those households adopted less energy saving features than those in the control group (15-21% on average). This result highlights the potential for behavioural interventions to have unintended consequences on behaviours other than those specifically targeted. Furthermore it underlines the importance of examining a wider range of outcomes and allowing longer time-scales when evaluating this type of experiment.

Keywords Residential electricity smart-metering · Randomised-controlled trial · Energy efficiency investment

1 Introduction

Reducing energy consumption and increasing the adoption of energy saving measures and energy efficient appliances are seen as crucial elements in reducing energy demand. A recent EU directive[1], aims to "remove barriers and overcome market failures that impede efficiency in the supply and use of energy". The reluctance of users to adopt energy efficient appliances that offer them seemingly positive NPV is known as the "Energy Paradox" and has been widely studied (Blumstein et al., 1980; Golove & Eto, 1996; Allcott & Greenstone, 2012).

Any market barrier to energy efficiency that requires a public policy intervention to overcome it could be considered a market failure. Many of these relate to imperfect information, as outlined by Jaffe & Stavins (1994) in a widely cited research paper. The authors discuss three potential information market failures in particular. First, if improved information is a public good, the market might tend to provide less than the socially optimum level. Second, if information is conveyed by the adopter, and the adopter is not compensated by the market for the positive externality they create by adopting. Third, if the party that possesses the information doesn't benefit from the cost savings, i.e. if they are not the bill payer, a principal/agent problem arises as they have no financial incentive to act on the information.

[1] EU Energy Efficiency Directive 2012/27/EU (European Commission, 2012)

Given that a certain proportion of the energy efficiency gap is attributable to a lack of information, it may be possible to remedy this by providing consumers with greater visibility regarding their usage and the associated costs. Allcott & Mullainathan (2010) cite the growing evidence of the effectiveness of behavioural interventions, rather than price-based approaches, in changing consumer choices.

Advanced metering initiatives and feedback programmes give consumers improved information on their usage and have shown they can deliver significant energy reductions, as discussed in the following section. Many countries are rolling-out smart meters as a result[2]. It is hoped that this will encourage a reduction in consumption, or a move of consumption from peak periods when increasing generation is expensive, to periods when generating electricity is cheaper.

Feedback can take many forms, such as as direct feedback from a smart-meter display, available on-demand to the user; indirect feedback provided by a utility in the form of a bill or usage statement; or inadvertent feedback through indirect observations of energy usage and learning by association (Darby, 2001). The type of feedback provided to households can influence both the amount of energy savings achieved (Ehrhardt-Martinez et al., 2010), and the means by which households achieve these savings (Ehrhardt-Martinez, 2012). This could be through curtailing usage of existing appliances - “curtailment behaviour”, or investing in new more energy efficient appliances - “efficiency behaviour”.

In some cases adopting one set of behaviours might catalyse consumers to adopt other behaviours, however, it may also have the opposite effect. Dolan & Galizzi (2015) describe the ripple of behaviour “when a pebble of intervention is thrown in the pond”. A limit of many studies is that they capture the immediate, targeted behaviour and not the ripples that may subsequently emerge.

This study uses data from a randomised-controlled electricity smart-metering trial, based on a nationally representative sample of the Irish population, to provide empirical evidence of an environmental intervention which targets one behaviour, but also induces reduced engagement, or a negative spillover in another behaviour. The trial targeted and achieved a reduction in electricity consumption. Relative to the control group, average overall usage across various treatment groups was reduced by 2.5% and peak usage by 8% (CER, 2011)[3]. However, households across treatment groups were also, on average 23-28% less likely to adopt any energy saving measure during the trial; and for these groups the expected number of energy saving features adopted was, on average 15-21% lower than that of the control group.

As far as we are aware, this trade off between curtailment and efficiency behaviour has not been empirically demonstrated before, however other re-

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[2] EU members are required to proceed with roll-out, covering 80% of consumers in their territory by 2020 (European Commission, 2009).

[3] This was through the use of IHDs, other information stimuli and time of use tariffs.

search has demonstrated perverse side effects between water and electricity usage in energy conservation campaigns (Tiefenbeck et al., 2013).

More generally we demonstrate a case in which a policy targeting one type of behaviour may have unintended consequences on other behaviours within the same domain. This is something that must be considered by policy makers when designing behavioural interventions.

In the following section we discuss other research related to this work, and how our result contributes to this literature. Section 3 outlines the experiment, dataset and methodology used, Section 4 describes the results and finally in Section 5 we explore some potential explanations for our results.

2 Related Research

2.1 The impact of energy related feedback on consumption

There has been considerable research assessing the impact of interventions aimed at reducing household consumption of energy. In a review, Darby (2001) finds that direct feedback has had more promising results than indirect or inadvertent feedback, and can result in energy usage reductions of up to 20%[4]. Generally, direct feedback tends to be most effective when provided in conjunction with other measures, such as pre-pay meters and other information provision.

Abrahamse et al. (2005) provide another review, examining both antecedent strategies (e.g. commitment, goal-setting) and consequence strategies (e.g. feedback, rewards) in an analysis of 38 studies. Various forms of information provision such as workshops, mass-media campaigns and tailored home-energy audits were examined. The findings tend to indicate that improved information results in greater knowledge, but this does not necessarily result in behavioural change[5].

Providing feedback specific to the individual is found to be more successful in reducing consumption, and reductions of just over 20% have been achieved in some instances (Midden et al., 1983; Staats et al., 2004). This intervention was found to be even more effective when combined with goal-setting and when provided on a more continuous basis.

As metering has become more sophisticated, the ability of devices to provide consumers with continuous information on their energy consumption has increased greatly. Faruqui et al. (2010) specifically examines the effect of providing in-house displays (IHD) to consumers in order to encourage reduced consumption. This analysis reviews of a number of North American studies

[4] Similar results were found in Gans et al. (2013)

[5] Similar findings have also recently been demonstrated in an Irish context for gas demand (Diffney et al., 2013). Other research on the particular dataset that we have used in this analysis has shown that feedback can significantly increase knowledge, but that this is not correlated with demand reductions (Carroll et al., 2014). This indicates that feedback may act more as a reminder and motivational tool, rather than providing educational benefits to the consumer.

and indicates that in-house displays can induce consumers to reduce consumption by 7% on average, and up to 18% in some cases.

In a meta-analysis based on 57 studies in various countries, Ehrhardt-Martinez et al. (2010) reported savings of 4-12%, depending on type of feedback households received. The authors found that real-time information combined with feedback provided the most promising avenue in terms of energy savings potential.

A feature of many of the aforementioned studies is the absence of any evidence of their long-term effectiveness. While some have found evidence of long-term effects (Hirst & Grady, 1983; Staats et al., 2004), the vast majority either do not measure, or do not find any evidence of long-term behavioural change, regardless of the type of intervention.

2.2 Energy efficiency versus curtailment behaviour

Reduced consumption could be considered a short-term effect, and as outlined above, little is known about whether feedback can induce long-term behavioural change. Much of the above research examines curtailment behaviour and not efficiency behaviour. As outlined by Gardner & Stern (1996) and Schuitema & Jakobsson Bergstad (2012) amongst others, policies targeting energy reduction have different features; some target efficiency behaviour through the adoption of more energy efficient technologies, others target curtailment behaviour through reducing the usage of existing appliances.

While policies targeting efficiency behaviour are generally more expensive for the consumer as they require a greater up-front investment, some have argued that they tend to be more acceptable as they involve less effort on an on-going basis (Poortinga et al., 2003). However, Ehrhardt-Martinez (2012) suggests that when feedback works it is more likely to be through curtailment behaviour than investment behaviour. In a study comparing three different feedback types, they find that both real-time information provision and enhanced billing are more likely to induce investment behaviour than online feedback.

Gardner & Stern (1996) argue that efficiency behaviours may have greater energy-saving potential, for example, replacing an existing energy-intensive boiler with a more-efficient upgrade may reduce energy usage more than simply curtailing usage of the existing boiler. However others have argued that technology adoption does not occur in isolation, and is linked to behaviour in complex ways (Ehrhardt-Martinez, 2012). Other work has demonstrated that the energy savings actually achieved can be highly context dependent (Peattie, 2010); can depend on the modelling approaches used (Lopes et al., 2012); and cross-country differences can be quite pronounced (Mills & Schleich, 2012).

2.3 Behavioural spillovers

A number of years ago in the UK, the Department for Environment, Food and Rural Affairs (DEFRA) commissioned a report entitled “Exploring Catalyst Behaviours” (Brook-Lyndhurst, 2011). This report reviewed the literature on pro-environmental behaviour, to determine if policies aimed at encouraging certain types of pro-environmental behaviour “spillover” into other domains, for instance, if someone is encouraged to recycle, does this make them more likely to reduce electricity consumption? While the high level findings of this research suggest that anecdotal evidence of various forms of behavioural spillovers exist, a causal link of one behaviour triggering another could not be identified. Other research finds limited evidence of spillovers but again determining causality is elusive (Thogersen & Olander, 2003; Thogersen, 2004; Whitmarsh & O’Neill, 2010).

The idea that people strive to be consistent in their beliefs, attitudes and behaviours comes from a range of social-psychological theories rooted in Festinger’s theory of cognitive dissonance (Festinger, 1962).

This research also examines the potential for negative spillovers. If there are costs associated with increased engagement in one domain, this might reduce engagement in other domains. This could potentially also be due to a “moral licensing” effect and this phenomenon has been observed in many domains of human behaviour, such as political correctness, pro-social behaviour and consumer choice. This theory suggests that individuals who are secure in the knowledge of their past good behaviour, can be more likely to engage in morally questionable actions, freed from the anxiety that normally accompanies these decisions. See Merritt et al. (2010) and Miller & Effron (2010) for a review.

Much of the above research on behavioural spillover tends to be based on lab-based experiments or consumer surveys. Our work is one of the first papers to demonstrate this empirically in a real-world setting. We exploit access to a large smart metering trial[6], and contribute to the literature by examining both curtailment and efficiency behavioural change resulting from a smart-metering and feedback intervention.

3 Methods

3.1 Description of data

We use data from the Irish Commission for Energy Regulation (CER) Smart Metering Customer Behavioural Trial. This is a nationally representative study of households in the Republic of Ireland, containing high frequency energy consumption data along with socioeconomic, attitudinal, behavioural and dwelling data on the participating households. It took place over eighteen months; the benchmark period was from 1st July to 31st December 2009, and the test period was from 1st January to 31st December 2010.

[6] CER Electricity Smart Metering Customer Behavioural Trial data.

The survey was conducted on Electric Ireland customers, who at that time represented 100% of Irish residential electricity demand. It was designed to quantify the effect feedback, better information and time-of-use pricing could have on overall electricity usage and on peak demand, not to examine investments in energy efficiency. However, we can exploit before and after survey questions related to a range of energy efficiency measures adopted within the home both before and during the trial in order to tackle the latter question.

3.2 Experimental design

Households self-selected into the trial and were then randomly assigned to a control group or various treatment groups[7] Treatments included a range of time-of-use tariffs, as per table 1 and information provision. This included providing customers with an electricity usage statement and the use of an in-house display.

The energy usage statement consisted of a first page which was similar to the existing suppliers bill (with additional lines for time of use tariffs). The second page provided additional detail on usage and tips on energy reduction. This included information on typical energy costs of certain appliances at day, night and peak rates; information on the annual cost of certain appliances assuming typical usage patterns, and tips on how to reduce costs; information on usage patterns, whether they have changed over the most recent period and how they compare with other customers on similar tariffs; average daily costs for day of the week[8].

We will refer to the information treatment groups as Treatment 1, 2 and 3 from this point onwards. Treatment 1 received a bi-monthly bill and energy usage statement; Treatment 2 received a monthly bill and energy usage statement; and Treatment 3 received a bi-monthly bill, energy usage statement and in-house display.

Our starting sample consists of $N = 3488$ households. We drop households who received a financial reward for achieving a reduction target. We also drop households who were on a "weekend" tariff as they did not receive an information feedback stimulus. This leaves us with a sample of $N = 2456$ observations, divided into control and treatment groups as per table 2.

Table 3 shows some summary results from the main trial. All groups reduced electricity consumption relative to the control group. Treatment 3 received an in-house-display in addition to other stimuli. This group recorded the biggest reduction in electricity usage, however this effect seems to reduce over time. See Section 7.4 "Impact of DSM Stimuli (in conjunction with ToU Tariffs) over time" of CER (2011) for a detailed discussion of these and other results from the trial.

[7] See (CER, 2011; Di Cosmo et al., 2014; Carroll et al., 2014). for further information on this trial and related research.

[8] See pg 168 of http://www.cer.ie/docs/000340/cer11080(a)(ii).pdf for further information

Table 1 Time-of-Use Tariffs (Cents per kWh) excluding VAT

Group	Night	Day	Peak
Control	14.10	14.10	14.10
Tariff A	12.00	14.00	20.00
Tariff B	11.00	13.50	26.00
Tariff C	10.00	13.00	32.00
Tariff D	9.00	12.50	38.00

Source: CER (2011)

Table 2 Treatment Matrix

Group	Control	Treatment 1	Treatment 2	Treatment 3	Total
Control	693	0	0	0	693
Tariff A	0	199	219	208	626
Tariff B	0	82	89	67	238
Tariff C	0	226	220	205	651
Tariff D	0	81	89	78	248
Total	693	588	617	558	2,456

Source: CER (2011)

Table 3 The change in overall usage in the first and second six month periods of the trial across tested DSM stimuli

Change in electricity usage	Treatment 1	Treatment 2	Treatment 3
Usage pre-trial (kWh)	2097	2091	2074
Reduction in 1st 6 months (percent)	-0.8	-2.6	-4
Reduction in 2nd 6 months (percent)	-1.3	-2.8	-2.4
Reduction in 1st 6 months (kWh)	-16.8	-54.4	-83.0
Reduction in 2nd 6 months (kWh)	-27.3	-58.5	-49.8
Total reduction per household (kWh)	-44.0	-112.9	-132.7

Source: Author's calculations and CER (2011)

3.3 Pre-trial stock of energy saving measures

Given our interest in examining how the trial affected household's investments in energy efficiency, it is important to first examine the pre-trial stock of existing measures installed by households. If systematic differences exist between control and treatment groups, this could lead to post-trial outcomes unrelated to the treatment. From table 4 below we can see that these measures are very evenly distributed amongst control and treatment groups.

Tables A1, A2 and A3 in the Appendix demonstrate there are no systematic differences between control and treatment groups across a whole range of measures that include socioeconomic factors, dwelling characteristics, stock of household appliances and heating type. Di Cosmo et al. (2014) also found no individual or household characteristics to be a significant predictor of being in the control group.

Table 4 Pre-trial stock of energy saving measures

Proportion of households with:	Control	Treatment 1	Treatment 2	Treatment 3	Mean
Energy saving lightbulbs	57%	57%	58%	57%	57%
Double-glazed windows	91%	91%	90%	92%	91%
Lagging jacket on hot-water tank	83%	82%	85%	84%	84%
Attic insulation within the last 5 years	36%	34%	35%	32%	35%
Attic insulation over 5 years ago	54%	56%	55%	57%	55%
External wall insulation	56%	56%	58%	58%	57%
Benchmark period (6 months) electricity usage (kWh)	2048	2097	2091	2074	2077

Source: Author's calculations using data from CER (2011)

Table 5 In-trial adoption of energy efficient measures

Energy saving measures installed	Number of Households	Percentage of Households
Added double glazing to some or all of your windows	199	8%
Installed attic or wall insulation	676	28%
Replaced appliances with A rated ones	396	16%
Fitted a new lagging jacket on your hot water tank	326	13%
Fitted other energy saving devices	206	8%
Added solar panels	35	1%
Added draught-proofing to your doors or windows	241	10%
Replaced a central heating boiler with a more efficient one	164	7%
Added thermostatic controls to radiators	181	7%
None of these	1170	48%

Note: The total does sum to 100% as some households adopted more than one measure
Source: Author's calculations using data from CER (2011)

3.4 In-trial investment in energy efficiency

After the trial was conducted, participants were asked whether they had invested in a range of energy efficiency measures over the previous 12 months. No group received any instructions related to this during the trial. Details are below in table 5. Unfortunately, we do not know the exact timing of these investments, nor their cost.

In total 52% of participants made at least one investment in efficiency, with many adopting a number of measures together. For instance, many of the households who replaced their boilers also added thermostatic controls to their radiators, and lagging jackets to their hot-water tanks.

If the trial had no effect on investment, we should expect no difference between the control group and any treatment group's in-trial investments in efficiency. We test this in a number of different ways.

3.5 Empirical strategy

First, a series of simple t-tests are employed to check for equality in the mean number of in-trial adoptions between the control group and each of the treatment groups. The hypotheses being tested are:

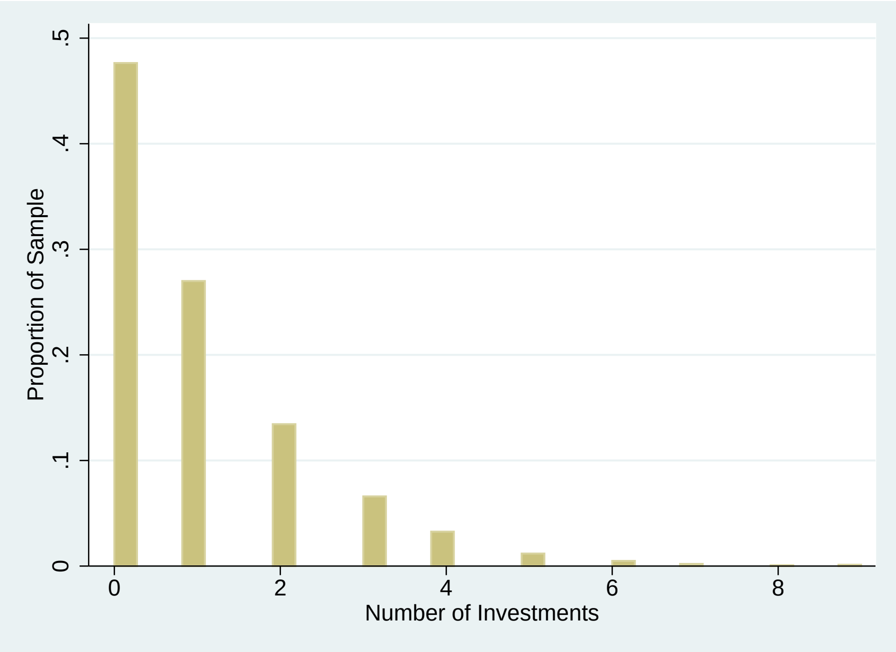

Fig. 1 Investments distribution

$$H_0 : \mu_c = \mu_{t_i} \; vs \; H_A : \mu_c \neq \mu_{t_i} \tag{1}$$

Where μ_c is the mean of the control group and μ_{t_i} is the mean of each treatment group i.

Following this, a binary variable is created which represents adoption of any of the efficiency measures listed in table 5 in the previous section. As stated above 52% of households adopted at least one measure. Using this we estimate a logistic regression model in order to examine if any treatment altered the probability of being an adopter. Formally, the hypothesis tested is:

$$H_0 : \beta_1 = 0 \; vs \; H_A : \beta_1 \neq 0 \tag{2}$$

Where $Prob(Y = 1|x) = p(x)$ and $log\frac{p(x)}{1-p(x)} = \beta_0 + \beta_1 D_i \epsilon_i$. D_i represents the different treatment groups.

Finally, a count variable was created to measure the number of investments each household made. This was used to examine if treatment changed the expected number of energy saving features adopted. We test a similar hypothesis to (2) above.

Fig.1 graphically illustrates the distribution of in-trial investments across the entire sample. If the count of household investments in energy efficiency follows a Poisson process, we can represent the probability of observing an event y_i as:

$$Prob(Y = y_i|x_i) = \frac{e^{-\mu}i\mu_i^{y_i}}{y_i^!} \tag{3}$$

In this case the expected count of new investments can be represented as follows:

$$E(y_i|x_i) = Var(y_i|x_i) = \mu_i = exp(x_i'\beta) \tag{4}$$

The above model assumes equi-dispersion, however, in this case we relax this assumption as $E(y_i|x_i) < Var(y_i|x_i)$. A Negative binomial (NB) model explicitly accounts for unobserved heterogeneity by adding an over-dispersion parameter α. μ_i is replaced by $\mu_i v_i$ and the probability of observing an event can now be expressed as:

$$Prob(Y = y_i|x_i) = \frac{\Gamma(\theta\lambda_i + y_i)}{\Gamma(y_i + 1)\Gamma(\theta\lambda_i)} r^{y_i}(1 - r)^{\theta\lambda_i} \tag{5}$$

The expected mean can be expressed as above, while the variance can now be expressed as:

$$Var(y_i|x_i) = \mu_i(1 + \alpha\mu_i) \tag{6}$$

4 Results and Discussion

This section presents the results of the tests for equality of means, a Logit model examining if treatment altered the probability of adopting any measure, and a Negative binomial model testing if treatment influenced the number energy saving measures installed in the home. Following this we will discuss some possible reasons for our results.

4.1 Equality of means

Exploring the results graphically first, using a box-plot to represent the distribution of in-trial investments for the control and each treatment group, it is immediately obvious that the behaviour of the control group is quite different from any of the treatment groups. The outer edges of the box represent the 25th and 75th percentile of the distribution and the line across the middle of the box is the median, or 50th percentile.

It is clear that the control group have a greater median number of investments, wider inter-quartile range, and the distribution has much greater dispersion. This indicates that households with many investments are more likely to be in the control group rather than any of the treatment groups.

Focusing now on the difference between control and treatment group means, the results reported in table 6, allow us to reject the null hypothesis, that there

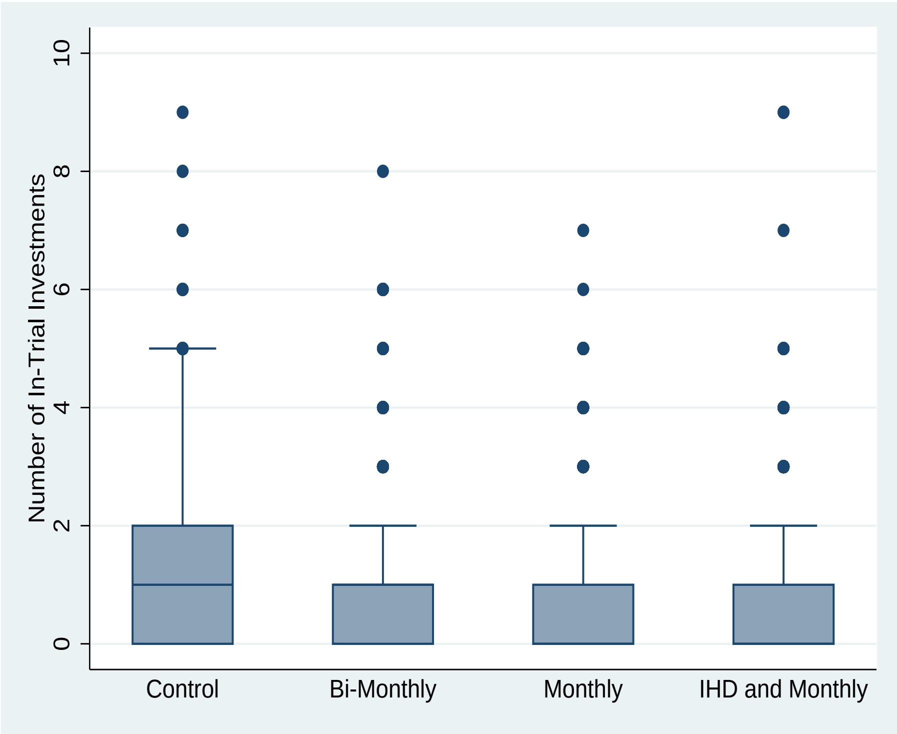

Fig. 2 Investments boxplot

Table 6 Difference in mean in-trial adoption between control and treatment groups

Diff	Mean	Std. Err.	[95% Conf. Interval]	$H_A : diff \neq 0$	$H_A : diff > 0$
(Control) - (Treatment 1)	0.166	0.074	[0.020 - 0.312]	0.026	0.013
(Control) - (Treatment 2)	0.232	0.071	[0.093 - 0.371]	0.001	0.001
(Control) - (Treatment 3)	0.191	0.076	[0.043 - 0.339]	0.012	0.006

is no difference between the mean of the control group and the mean of any treatment group[9]. Furthermore, we can conclude that the mean of the control group is greater than the mean of any treatment group[10]. Welch's t-test is used to allow for samples with unequal variance.

[9] We reject H_0 at a 1% level of significance for treatment 2, and at a 5% level for treatments 1 and 3

[10] We reject H_0 at a 1% level of significance for treatments 2 and 3, and at a 5% level for treatment 1

Table 7 Effect of treatment on investment in energy efficiency

Variable	(1) Binary - OR	(2) Binary - OR	(3) Count-IRR	(4) Count-IRR
Bi-monthly Statement	0.77**	0.76*	0.85**	0.87**
	(0.09)	(0.09)	(0.06)	(0.06)
Monthly Statement	0.71***	0.68***	0.79***	0.79***
	(0.08)	(0.08)	(0.06)	(0.05)
IHD and Bi-monthly Statement	0.72***	0.72***	0.83**	0.83**
	(0.08)	(0.08)	(0.06)	(0.06)
Constant	1.37***	1.21	1.13**	0.73
	(0.11)	(0.78)	(0.05)	(0.26)
lnalpha			-0.34	-0.5
			(0.08)	(0.08)
Household level controls	N	Y	N	Y
Observations	2,456	2,456	2,456	2,456
ll	-1693	-1650	-3368	-3313
dfm	3	43	3	43
chi2	12.42	99.64	11.92	131.24

Notes: Robust tandard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.1
Results are reported relative to the control group

4.2 Regression analysis

The results from the binary regression model further confirm that treatment had a negative effect on investment. We report odds rations (OR) and use the control group as our reference group in each estimation. As can be seen from column 1 of table 7, the treatment groups are less likely to adopt than the control group ($OR < 1$). Interpreting the odds ratios, we can conclude that the treatment groups were 0.72-0.77 as likely, or 23%-28% less likely than the control group to adopt any energy saving measure over the 12 month trial period. Decomposing the dependent variable, we find the result is driven by the adoption of lagging jackets, attic insulation and double-glazing. No other variables are statistically significant.

Treatment not only reduced the likelihood of investment, but also reduced the number of energy saving investments that households made. The results of the negative binomial regression are reported in column 3 of table 7. Reporting the incident rate ratios (IRRs) it is found that being in the treatment group reduced the expected number of energy saving features adopted by 15%-21%.

For robustness we also ran both of the above models including a range of household level control variables that may influence adoption[11]. As can be seen from columns 2 and 4 of table 7 the magnitude of some of the coefficients change slightly but it does not materially alter our results. We tested for

[11] These include socioeconomic characteristics, current stock of appliances, current stock of energy efficient measures, total energy usage for 6 month benchmark period, heating type, house characteristics and use of internet

equality of coefficients in all of the above models and the treatment groups are not statistically different from each other.

4.3 Discussion

These results are certainly a perverse outcome given the overall objective of the trial, and it is unclear why this happened. It could be the result of a moral licensing effect, if someone does "something good" (reduce their energy consumption patterns), they might then feel more justified in doing "something bad" (reduce their investment in efficiency), as they feel they have a moral license to do this. Empirical evidence of behavioural change in energy conservation campaigns has previously been ascribed to this effect (Tiefenbeck et al., 2013). In this case households who received information on their water consumption and reduced their usage, also increased their electricity consumption by 5.6 percent compared to a control group. However the authors caution that while their results are consistent with moral licensing, they are unable to confirm that this is the precise psychological mechanism at play.

Another potential explanation would be a priming effect, whereby improved feedback and information may have focused the treatment group on curtailment behaviour, but distracted them from other means of saving energy, such as investing in efficiency. On the other hand the control group were not primed and therefore focused on a broader range of energy saving options.

One could also argue that these individuals are being economically rational, by taking the least-cost option when faced with a number of alternatives. The treatment groups may have seen the benefits of adaptation and undertook the less costly conservation measure. Rather than investing in a more efficient central-heating boiler, they could achieve similar efficiency gains through adaptation, and at a reduced cost, by time-shifting their demand to less expensive periods.

After the trial concluded, the respondents were asked to rate on a Likert scale of 1-5, how the trial influenced their level of agreement with a number of statements. Broadly speaking these statements can be categorised into respondents' attitudes/interest in electricity reduction; their behaviour over the past 12 months related to electricity reduction; constraints on their ability to reduce electricity even if they wanted to; their understanding of tariffs/information stimuli; their awareness of the cost of their appliance usage; and the effect of the trial on their investment decisions.

We find that the control and treatment groups do not vary much across these categories, but some differences emerge and we will discuss these now in greater detail, and their implications for untangling the various psychological mechanisms that may be driving behaviour.

First, the treatment groups were more likely to agree that they had made changes in order to reduce their electricity consumption (71% Treatment vs 60% Control), and they tended to describe these changes as minor (74%) as opposed to major (30%). Second, the treatment group overwhelmingly felt that both the tariffs and statements helped them to reduce their usage of electricity - the percentage agreement was generally in excess of 80% for a range of statements related to whether the tariff or statement helped households reduce their usage.

This indicates that the treatment group did feel they had made a bigger contribution to electricity reduction than the control group. While this may be considered a necessary condition for evidence of a moral licensing effect, it is by no means sufficient. Particularly as the treatment groups (but not the control) were asked if they felt the trial had any effect on their investments in energy efficiency measures within the home, and a broad consensus did not emerge on this question (46% agreed, 42% disagreed and the remaining 12% neither agreed nor disagreed). Also, we cannot identify those in the treatment group who might have invested, but didn't, nor can we identify those in the treatment group who invested less than they otherwise might have, were it not for the trial.

In terms of potential priming effects, the treatment groups did not seem to have much difficulty understanding tariffs (90% of them reported that they spent less than 1 hour in total over the course of the trial understanding the new tariff structure) or statements. This does not necessarily rule out that a priming effect was at play, however comprehension of the tariff structure does not appear to have overburdened the participants cognitively.

The treatment group felt more in control of their usage than they otherwise would have been, and this may have encouraged some to change their usage through curtailment rather than investment. For example the control group was less likely to agree that they knew what do do in order to reduce their electricity usage (77% Treatment vs 65% Control), and more likely to agree that they did not know enough about the energy usage of individual appliances in order to reduce their consumption (35% Treatment vs 45% Control).

The results are quite possibly a complex combination of the above factors and there is no reason to assume that the psychological mechanisms should be homogeneous across individuals or households.

5 Conclusion

We find that being supplied with better information on electricity usage and exposure to time-of-use tariffs resulted in households reducing their investment in energy efficiency measures. It must be stressed that due to the short timescale of this study, it was only possible to monitor behaviour over a 12 month period. Another interesting element to note is that while this was an electricity smart-metering trial, most of the capital investments related to improving thermal efficiency, not electricity, and only 1% of the sample have electric heating[12].

While we have detailed information on the type of energy efficiency investments made, or not made in the case of the treatment group, it is not possible

[12] See Appendix B.

to quantify whether or not these savings will be offset over a longer period as a result of reduced investment in energy efficient appliances. However, given that the overall electricity reduction relative to the control group was 2.5% (CER, 2011), this result raises the importance of taking a more comprehensive view in the evaluation of energy efficiency interventions.

It also highlights the benefit of allowing a longer time-scale for this type of experiment, as due to the relatively short duration of the study, it is impossible to know the long term behavioural change of households.

Given the widespread implementation of smart-metering trials, this research opens an avenue for others to empirically test whether our results are reproduced in other countries and across different domains.

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6 Appendix

A Characteristics of participants and dwellings

Table A1 Pre-trial distribution of socioeconomic characteristics

Variable	Control	Treatment 1	Treatment 2	Treatment 3	Total
Gender					
male	52%	47%	52%	51%	51%
female	48%	53%	48%	49%	49%
Age					
18 − 25	0%	1%	0%	1%	0%
26 − 35	8%	10%	7%	9%	9%
36 − 45	18%	20%	20%	20%	19%
46 − 55	24%	24%	25%	24%	24%
56 − 65	21%	22%	24%	23%	22%
65+	28%	23%	22%	22%	24%
refused	1%	1%	1%	0%	1%
Employment Status					
employee	43%	49%	47%	47%	46%
self-employed (no employees)	4%	5%	5%	8%	5%
self-employed (with employees)	6%	7%	8%	5%	6%
unemployed (seeking work)	4%	3%	5%	4%	4%
unemployed (not seeking work)	3%	4%	4%	3%	4%
retired	38%	31%	30%	32%	33%
carer	2%	1%	1%	1%	1%
Social Class					
AB	12%	14%	16%	17%	15%
C1	25%	29%	27%	28%	27%
C2	18%	16%	15%	17%	16%
DE	42%	38%	38%	35%	39%
F	3%	2%	3%	2%	2%
refused	1%	1%	1%	1%	1%
Education					
no formal education	1%	1%	2%	1%	1%
primary	15%	10%	11%	11%	11%
secondary to junior cert	15%	19%	17%	16%	17%
secondary to leaving cert	30%	29%	28%	28%	29%
third level	34%	37%	37%	39%	36%
refused	5%	6%	5%	6%	5%

Source: Author's calculations using data from CER (2011)

Table A2 Pre-trial distribution of house characteristics

Variable	Control	Treatment 1	Treatment 2	Treatment 3	Total
House type					
apartment	2%	1%	1%	2%	2%
semi-detached house	30%	33%	29%	29%	30%
detached house	27%	26%	29%	27%	27%
terraced house	14%	15%	14%	14%	14%
bungalow	27%	24%	27%	27%	26%
refused	0%	1%	0%	0%	0%
Tenure type					
rent from a private landlord	2%	1%	1%	1%	1%
rent from a local authority	5%	4%	5%	4%	4%
own outright	58%	56%	56%	55%	56%
own with mortgage	35%	40%	38%	39%	38%
refused	0%	0%	0%	1%	0%
Dwelling Building Energy Rating certified					
yes	1%	1%	1%	1%	1%
no	86%	88%	88%	87%	87%
don't know	13%	11%	11%	12%	12%
Number of people over 15					
1	4%	5%	5%	4%	4%
2	62%	58%	61%	61%	61%
3	20%	20%	17%	16%	18%
4	9%	12%	12%	12%	11%
5	3%	4%	3%	6%	4%
6	1%	1%	1%	0%	1%
7	0%	0%	0%	0%	0%
Number of people under 15					
0	77%	72%	72%	73%	74%
1	10%	11%	12%	13%	11%
2	8%	11%	9%	8%	9%
3	3%	4%	5%	4%	4%
4	2%	1%	1%	1%	1%
5	0%	0%	0%	0%	0%
6	0%	0%	0%	0%	0%
Number of bedrooms					
1	1%	0%	0%	1%	1%
2	11%	9%	6%	10%	9%
3	43%	46%	45%	40%	43%
4	35%	34%	35%	37%	35%
5	10%	11%	13%	12%	11%
6	0%	0%	0%	0%	0%
House age					
1900 − 1940	2%	2%	2%	1%	8%
1941 − 1960	3%	2%	3%	2%	10%
1961 − 1970	3%	3%	3%	2%	10%
1971 − 1980	6%	4%	5%	4%	18%
1981 − 1990	3%	3%	3%	3%	11%
1990 − 1997	2%	2%	2%	2%	8%
after 1997	6%	5%	5%	5%	21%

Source: Author's calculations using data from CER (2011)

Table A3 Pre-trial distribution of appliance stock and heating type

Variable	Control	Treatment 1	Treatment 2	Treatment 3	Total
Appliance					
washing machine	28%	24%	25%	22%	98%
tumble drier	19%	16%	17%	15%	68%
dishwasher	18%	16%	17%	15%	66%
electric shower instant	19%	16%	18%	16%	69%
electric shower pumped	8%	7%	7%	6%	29%
electric cooker	22%	19%	18%	17%	76%
stand alone freezer	14%	13%	13%	12%	51%
water pump	5%	4%	5%	4%	19%
immersion	22%	18%	19%	18%	77%
solar panels to heat water	0%	0%	1%	0%	2%
Heating Type					
electric	2%	1%	1%	1%	1%
electric (plug-in)	1%	0%	0%	0%	0%
gas	25%	29%	30%	28%	28%
oil	42%	44%	43%	45%	43%
solid fuel	29%	24%	23%	26%	26%
renewable	0%	1%	1%	1%	1%
other	1%	1%	0%	0%	1%

Source: Author's calculations using data from CER (2011)

Table A4 Regression results for all investments including household control variables

Variable	(1) Any investment	(2) Double-glazing	(3) Attic-insulation	(4) A-rated appliances	(5) New lagging jacket
Control	[REF]	[REF]	[REF]	[REF]	[REF]
Bi-monthly Statement	0.767**	0.914	0.898	0.808	0.742*
Monthly Statement	0.677***	0.677*	0.667***	0.753*	0.633***
IHD and Bi-monthly Statement	0.720***	0.720	0.803*	0.754*	0.750*
Male	0.961	0.873	1.087	0.971	0.964
Age 18-35	[REF]	[REF]	[REF]	[REF]	[REF]
Age 36-55	1.324*	1.262	0.951	1.077	1.347
Age 55+	1.180	1.057	0.892	0.777	1.103
Age Refused	1.587	2.257	1.716	1.391	1.654
Social Class AB	[REF]	[REF]	[REF]	[REF]	[REF]
Social Class C1	0.828	0.914	0.994	0.959	1.016
Social Class C2	0.944	1.438	1.067	0.927	1.293
Social Class DE	0.879	1.182	0.824	0.786	1.268
Social Class F	0.612	2.350*	0.771	0.482	1.431
Social Class Refused	0.829	0.543	0.870	1.141	1.036
Emp Status Employed	[REF]	[REF]	[REF]	[REF]	[REF]
Emp Status Self employed no employees	0.982	1.696	1.002	0.755	0.738
Emp Status Self employed with employees	1.382*	0.936	1.357	0.874	0.988
Emp Status Unemployed and seeking employment	1.145	2.358**	1.110	0.950	1.986**
Emp Status Unemployed and not seeking employment	0.870	1.288	0.992	1.431	1.105
Emp Status Retired	1.116	1.266	1.482**	1.138	1.223
Emp Status Carer	0.864	1.386	1.314	0.825	2.171
Education Primary	[REF]	[REF]	[REF]	[REF]	[REF]
Education Secondary	0.918	0.641**	1.019	0.768	1.077
Education Tertiary	1.046	0.705	0.980	0.938	1.019
Education Refused	0.881	0.818	0.993	0.757	1.052
Tenure Renting	[REF]	[REF]	[REF]	[REF]	[REF]
Tenure Own outright	1.392*	1.749	1.643**	1.278	1.417
Tenure Own with mortgage	1.374	1.336	1.441	1.166	1.243
House Apartment	[REF]	[REF]	[REF]	[REF]	[REF]
House Attached	1.761	3.235	2.264	1.206	1.361
House Detached	2.046*	3.184	3.171*	1.216	1.290
House age After 1997	[REF]	[REF]	[REF]	[REF]	[REF]
House age After 1941-60	1.376*	2.320**	1.369	0.756	1.623**
House age After 1900-41	1.690***	2.545**	2.086***	1.345	1.569**
House age After 1961-70	1.580***	2.414**	1.594***	1.184	1.946***
House age After 1971-80	1.538***	2.166**	1.912***	1.193	2.223***
House age After 1981-90	1.954***	2.919**	2.206***	1.306	1.876***
House age After 1991-97	1.364*	1.704	1.590**	1.189	1.500
Internet	1.139	1.060	1.024	1.507**	0.686***
Appliances Energy saving lightbulb	1.083***	1.134**	1.062*	1.173**	1.065
Appliances Double glazed windows	0.967	0.827**	1.023	0.938	0.910*
Appliances Lagging jacket	1.163	1.493*	1.074	1.062	1.614**
Appliances Attic insulation more than 5 years ago	1.106	0.582*	1.203	1.054	1.274
Appliances Attic insulation less than 5 years ago	0.874	0.589**	0.775	1.150	1.061
Appliances External wall insulation	0.978	1.044	0.865	1.062	0.967
Constant	0.291***	0.019**	0.056***	0.102**	0.044***
Observations	2456	2456	2456	2456	2456
chi2	0.028	0.069	0.040	0.030	0.047
ll	-1652	-643	-1387	-1053	-917

Table A5 Regression results for all investments including household control variables continued

Variable	(6) Other energy saving measures	(7) Solar panels	(8) Draught proofing	(9) More efficient boiler	(10) Thermostatic controls on radiators
Control	[REF]	[REF]	[REF]	[REF]	[REF]
Bi-monthly Statement	0.869	1.203	0.721*	0.861	0.817
Monthly Statement	0.706*	0.952	0.948	0.894	0.884
IHD and Bi-monthly Statement	0.945	1.018	0.808	0.915	0.825
Male	1.086	1.161	1.067	1.390**	1.342*
Age 18-35	[REF]	[REF]	[REF]	[REF]	[REF]
Age 36-55	1.208	4.179	0.997	1.228	1.044
Age 55+	0.792	3.727	0.845	1.271	0.977
Age Refused	1.841	1.000	1.000	1.000	1.458
Social Class AB	[REF]	[REF]	[REF]	[REF]	[REF]
Social Class C1	0.915	0.816	0.915	0.747	0.844
Social Class C2	0.915	0.295*	0.754	1.002	0.810
Social Class DE	0.773	0.345	0.767	0.794	0.862
Social Class F	0.265*	1.434	0.522	0.247*	0.451
Social Class Refused	0.454	1.000	1.433	1.000	1.000
Emp Status Employed	[REF]	[REF]	[REF]	[REF]	[REF]
Emp Status Self employed no employees	1.261	4.021**	0.752	1.080	0.779
Emp Status Self employed with employees	1.104	0.373	2.344**	2.125**	0.810
Emp Status Unemployed and seeking employment	1.393	1.452	1.703	0.572	0.941
Emp Status Unemployed and not seeking employment	0.653	1.000	1.252	2.396*	1.119
Emp Status Retired	1.005	1.363	1.478	1.051	0.762
Emp Status Carer	2.140	7.061	0.871	4.013**	1.140
Education Primary	[REF]	[REF]	[REF]	[REF]	[REF]
Education Secondary	0.791	0.776	0.933	1.189	0.656
Education Tertiary	0.755	0.642	1.184	1.470	0.773
Education Refused	0.931	1.000	1.015	1.229	0.595
Tenure Renting	[REF]	[REF]	[REF]	[REF]	[REF]
Tenure Own outright	1.115	1.985	0.918	5.309**	1.723
Tenure Own with mortgage	0.853	1.634	1.068	4.696**	1.546
House Apartment	[REF]	[REF]	[REF]	[REF]	[REF]
House Attached	0.546	0.305	0.646	1.687	2.223
House Detached	0.605	0.371	0.527	1.666	1.846
House age After 1997	[REF]	[REF]	[REF]	[REF]	[REF]
House age After 1941-60	1.371	0.386	1.044	2.336**	1.153
House age After 1900-41	1.165	1.584	1.534*	2.558**	2.205***
House age After 1961-70	0.985	1.202	1.147	1.031	1.819**
House age After 1971-80	0.967	0.415	0.898	1.871**	1.480
House age After 1981-90	1.190	0.567	1.471*	1.964**	1.845**
House age After 1991-97	0.961	1.094	0.582	1.943**	0.908
Internet	1.285	0.988	1.024	1.307	1.381
Appliances Energy saving lightbulb	1.120**	1.215	1.033	1.092	1.052
Appliances Double glazed windows	0.970	1.297	0.899*	1.040	1.155
Appliances Lagging jacket	1.440	1.303	1.456*	0.740	1.577*
Appliances Attic insulation more than 5 years ago	1.115	0.537	1.220	0.895	1.084
Appliances Attic insulation less than 5 years ago	1.173	0.626	0.980	0.884	1.076
Appliances External wall insulation	1.273	2.591**	1.071	0.920	1.465**
Constant	0.087**	0.001**	0.189**	0.003**	0.005***
Observations	2456	2218	2442	2422	2435
chi2	0.031	0.121	0.031	0.054	0.041
ll	-686	-158	-762	-568	-618