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Nudging Electricity Consumption Using TOU Pricing and Feedback: Evidence from Irish Households

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Abstract: This paper analyses the electricity usage of 5,000 Irish residential consumers in response to the introduction of TOU tariffs and three different forms of financial feedback: immediate feedback from in-home displays (IHD), monthly billing and bimonthly billing. Half-hourly data on consumption collected during the trial indicated that TOU tariffs reduced consumption at peak, with some reductions lasting beyond the end of the peak period and post-peak spikes in usage were not observed. IHD feedback resulted in the most reliable reductions and bimonthly billing the least. Households with greater education used the information associated to the TOU tariffs slightly better than the average.

Keywords: Demand management, smart meter trials, information, TOU tariffs.

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1 Introduction

Balancing electricity demand and supply is difficult and expensive. Traditionally system operators have used supply-side techniques, such as reserves, to make sure that there is always enough generation to meet a fairly inelastic demand as demand fluctuates.[1] Short-term demand is inelastic in part because retail prices have historically been fixed for long periods of time.

Recently there has been an increasing focus on the use of demand-side tools to improve balancing markets. Encouraging demand to react more to electricity prices has three advantages. First of all, higher prices are typically associated with higher demand.[2] In the short term, limiting peak demand decreases generation at times when it is most costly, thereby decreasing costs more than proportionally to the decrease in demand. In addition, peaking plants tend to run on fossil fuels and be less efficient, causing greater greenhouse gas emissions per unit of electricity generated. Additionally, if peak demand decreases there is need for fewer investments in electricity generation, transmission and distribution in the medium to long term, leading to savings for the system as a whole. Finally, all EU countries must reduce emissions and energy consumption by 2020 to comply with EU energy efficiency targets (2009/28/EC).[3] Reducing peak electricity demand also helps meet this target.

In this paper we examine if changes in the way electricity is priced have an effect on peak consumption, if any decrease in peak consumption is simply shifted to off-peak hours, and if the way electricity prices are communicated is important in achieving changes in consumption. In particular, we use data from a smart metering trial that took place in Ireland. In 2007, the Irish Commission for Energy Regulation (CER) announced a trial smart metering experiment in the Irish residential electricity market in an effort to investigate the benefits of Time-of-Use (TOU) pricing of residential electricity and estimate the role that clear and accessible price charged might play in facilitating consumer behaviour change. This Consumer Behavioural Trial (CBT) employed TOU tariffs in

[1] See for Ireland EIRGRID (2009).

[2] On average, peak load for the Irish system is about 25% greater than the average day demand

[3] Directive 2009/28/EC of the European Parliament and of the Council (2009) on the promotion of the use of energy from renewable sources and amending and subsequently repealing directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union.

combination with other demand side stimuli (bi-monthly and monthly billing and in-home displays which show constantly the electricity consumption installed at home) in an effort to reduce peak demand and overall electricity use in the residential sector. This residential CBT is one of the largest smart metering behavioural trials conducted internationally to date and thus provides a wealth of information on the impact of smart metering on electricity consumers (CER/11/080a).

The Irish smart meter trial follows other similar experiments run in the US (see Faruqui and Sergici (2010)) and in Europe (see Aubin et al. (1995) and Filippini (1995)). These experiments investigate whether consumption reacts more to prices when the cost of electricity follows wholesale costs more closely. In particular, this implies higher electricity prices during peak demand periods. As highlighted by Faruqui et al. (2010), in the US some experiments have been undertaken in order to assess the impact of dynamic pricing on the electricity consumption. The studies confirm that higher prices during congested hours lead to a slight change in the electricity consumption, and that the magnitude of the effect is not constant across the experiments. In some cases, the results show that consumers do not significantly change consumption as prices change. One explanation is that consumers have bounded capacity and do not fully reassess their optimal consumption when the price of electricity increases. Another possible explanation that may be considered is that the opportunity cost of changing behaviour is too high for the consumers (i.e. the time spent monitoring prices constantly is not used for other productive activities).

A wide empirical literature has shown that changes in prices are not sufficient to reduce electricity use significantly Allcott (2011); Jessoe (2013); Di Cosmo et al. (2014). For instance, Gabaix (2006) found that consumers often exhibit uncertainty on the relationship between inputs and outputs, such as how heating a room translates into energy usage or how a use of the washing machine translates into cost. Providing additional information on electricity use and price may help to resolve consumer uncertainty and potentially significantly improve conservation.

Loewenstein and Thaler (1989) suggest that the decision of how much electricity to use is a classic intertemporal choice: electricity and its benefits are immediate, whereas the cost of electricity use is delayed to the time consumers receive their bill. The decision on when and how much electricity to consume is difficult because consumers value future benefits and costs less than current ones, in fact much less. Moreover, Johnson and Bickel (2002) finds that the costs per decision, such as those typical in electricity consumption choices, give rise to more extreme discounting. Consumers are therefore resistant to change their electricity usage patterns.

Another strategy the consumers may adopt is the shift of loads from peak to night hours. TOU electricity pricing reflects the higher cost of supply during peak hours and lower cost off-peak hours. Although TOU pricing does not reflect changes in wholesale prices as accurately as real-time pricing (i.e. following the wholesale price completely) it has possible advantages, because it is easy to understand and predictable, as shown by Faruqui et al. (2010). Mountain and Lawson (1995) analysed Canadian responsiveness to residential TOU rates. Examining the response both in peak and in the boundary hours to the price event, the authors identify the rate structures that give the best response in terms of the reduction of consumption during peak hours. Moreover, the authors look at the hours close to the peak hours and find that there are no potential problems regarding new peak creation. However, many studies have found evidence of load shifting (associated with TOU pricing). Faruqui et al. (2010) provide an example of a TOU tariff in the UK, "Economy 7", where customers take advantage of lower night time tariffs by shifting their electricity usage to night-time storage heaters and water heaters on a timer. Faruqui and Sergici (2010) analyse 15 pricing experiments using TOU pricing and find that customers respond to higher prices during the peak hours by reducing peak hour electricity usage and/or shifting it to less expensive off-peak periods. On average, TOU rates induce a reduction in peak demand from 3-6% in the 15 pricing experiments.

How much consumers value the future versus the present may vary with income and education. Typically, the better educated and higher earners value the future more than less educated and poorer consumers.[4] If, in line with such research, lower socio-economic (SES) groups find it more difficult to change usage in response to TOU pricing, they would end up paying a larger share of electricity costs and effectively subsidising the consumption of higher SES groups. Since individuals with lower income and less education also have fewer financial resources, these higher costs constitute a large relative economic burden and might increase fuel poverty as shown by Scott et al. (2008).

[4] See Green et al. (1996); Reimers et al. (2009)

Our results show that the information on the tariff applied gives consumers incentives to reduce their electricity use. The consumers provided with an in-house display, which clearly communicated changes in electricity price, tend to decrease consumption during peak periods more than other consumers and to keep consumption low for some time after the end of peak pricing.

Our work finds that educated people use the information associated to the TOU tariffs slightly better than the average, reducing their consumption more during high tariffs in the peak hours.

This paper continues by describing our data used from the consumer behavioural trial in Section 2. Section 3 describes the methodology used, section 4 presents the results of our analysis and section 5 concludes.

2 Data

The CBT replaced existing mechanical meter readers with smart meters in approximately 5,000 households. The residential component of the trial involved all these households (customers of Electric Ireland) who were asked to participate in the trial.[5] While participating households self-selected into the trial, and therefore the results cannot be generalised to the overall population, participants were randomly assigned to control and treatment groups. Data were collected over the period 14 July 2009 to 31 December 2010, and as the experiment began on 1 January 2010, six months of pre-trial data are available for both the control and treatment groups. The control group was billed on their normal tariff and saw no changes to their bill. They received none of the information stimuli and were requested to continue using their electricity as normal (Commission for Energy Regulation, 2011a). Benchmark pre-trial data is available for all households (both control and treatment) for the period 14 July 2009-31 December 2009. Treatment groups were exposed to a variety of TOU tariffs and information stimuli (IHD, bi-monthly and monthly billing).[6]More precisely, four TOU tariffs were tested. TOU prices referred to peak (17:00-18:59 Monday-Friday, excluding public holidays), day (08:00-16:59; 19:00-

[5]At the time of recruitment (mid-2008), Electric Ireland customers represented 100 per cent of residential electricity customers in Ireland (CER (2011).

[6]A description of IHD can be found here: `http://www.cer.ie/docs/000117/cer13164-presentation-of-energy-usage-information.pdf`, pg.101.

22:59 Monday-Friday, plus 17:00-18:59 public holidays, Saturday and Sunday) and night (23:00-07:59) periods (based on system demand peaks). A weekend tariff was also tested (whereby the night rate applied all day Saturday and Sunday, with separate peak, day and night tariffs for weekdays). In comparison with the initial flat-rate tariff, the electricity price associated with peak hour consumption rose up to a maximum of 166 per cent of its initial value, while the price of electricity during the day and night was decreased by a maximum of 13 per cent and 37 per cent respectively. The TOU tariffs were designed to be neutral in comparison with the standard flat-rate tariff to ensure that the average participant who did not change their electricity consumption would not be financially penalised.

Table 1: Control and treatment period tariffs (€/cents per kWh, including VAT)

Tariff	Pre-TreatmentPeriod	Post-Treatment Period			*% change*		
	Peak, Day and Night	Peak	Day	Night	*Peak*	*Day*	*Night*
Control	16.24	16	16	16	*-1.5*	*-1.5*	*-1.5*
Tariff A	16.24	22.7	15.89	13.62	*39.8*	*-2.2*	*-16.1*
Tariff B	16.24	29.51	15.32	12.46	*81.7*	*-5.6*	*-23.1*
Tariff C	16.24	36.32	14.76	11.35	*123.7*	*-9.1*	*-30.1*
Tariff D	16.24	43.13	14.19	10.22	*165.6*	*-12.6*	*-37.1*
Tariff W/E	16.24	33.03	14.45	11.35	*103.4*	*-11*	*-30.1*

Data surce: CER (2011)

3 Methodology

Statistics calculated by CER (2011) using the data from the trial, show that smart metering in combination with bimonthly billing and energy usage statement affect electricity consumption with a decrease in peak period consumption of 11.3%. From these initial findings it's not clear if there was new peak formation in energy use as a result of the predicted price change. In general TOU tariffs and two of the Demand-Side Management stimuli (monthly billing and IHD installed) were found to reduce overall electricity usage by 2.5% and peak usage by 8.8%. The statistical analysis, however, don't assess the causal relation between the change in tariff and the electricity consumption. Moreover, it does not take into account the other variables (like weather and appliances installed in the house) that potentially affect the consumer's behaviour. We use half-hourly data to investigate which are the determinants of the behaviour of the consumers both during the peak and the boundary hours, close to the change in the tariff. In order to estimate the changes in electricity consumption before and after the trial we use the difference in difference estimator. As shown by Di Cosmo et al. (2014) and CER (2011), the only difference between the households who populate our sample is the treatment. We divided the sample into three different subsamples, following the three stimuli. Then, for each group, we compare the mean of consumers in the pre-treatment and treatment period and the mean of consumers in the control and treatment group, controlling for everything else that has the potential to affect the behaviour of consumers during time. This can be done by using the random effects estimator for panel data. It's important to highlight that in our sample there are no tariff differences for consumers in the control group. As the CBT trial was set up as a randomized experiment, people in the control group statistically have the same characteristics of the consumers in the other group, but they were not subject to a change in tariff. Moreover, people in the control group were not informed about the change between the "control" and the "treatment" period. As people in the control group were facing the same price during the whole period (control plus trial) for them the diff-in-diff effect of a change in tariff is zero. We include them in our analysis in order to capture symmetric and exogenous shocks that may have happened but that are not under control and are not captured by the regressors included in Eq. 1 below. All models are estimated using STATA 13, and standard errors are adjusted for clustering at the household level.

$$\begin{aligned} q_{its} = \alpha_1 Tar_{A,t} + \alpha_2 Tar_{B,t} + \alpha_3 Tar_{C,t} + \alpha_4 Tar_{D,t} + \alpha_5 Tar_{W,t} \\ + \beta_1 Tar_A * Group_i + \beta_2 Tar_B * Group_i + \beta_3 Tar_C * Group_i + \beta_4 Tar_D * Group_i \\ + \beta_5 Tar_{W,i} * Group_i + Treat_p + Controls \end{aligned} \tag{1}$$

in which q_{its} is the half hourly consumption of electricity by household i under stimulus s observed at the half-hour t. We also include here consumers who were in the control group during the treatment period, to take into account consumers under stimulus s but not subject to tariff's change. $Tar_{z,t}$ is the dummy variable indicating that the household was exposed to tariff z ($z = A, B, C, D$) during the treatment period. $Tar_{W,t}$ is the dummy variable indicating that the household was exposed to the weekend tariff during the treatment period. The coefficients therefore represent our difference-in-difference estimates (i.e., the effect of the various TOU tariffs on household electricity consumption). $Tar_z * Group_i$ is the time-invariant dummy variable indicating that the household is a member of the Tariff z treatment group. These variables should not be significant at the statistical level, as by construction the consumers were distributed randomly across the groups. $Treat_p$ is the dummy variable indicating the treatment period. This variable indicates the differences between the control and the treatment period in terms of electricity consumed. We expect that during the trial the consumers reduce their electricity consumption as they become more aware of their usage, so we expect a negative and significant sign for the $Treat_p$ coefficient.

$Controls$ is an additional variable, which includes a dummy variable for public holidays and a set of dummies for each day of the week. We also include a variable that reflects the heating degree days, sunshine is a variable that reflects sunshine hours (not included in the night specification), a count variable of the number of appliances owned by the household and a dummy variable indicating that the household has an electric heating system. We also include in our specification a variable that interacts the heating degree days with the dummy for electric heating; this variable should control for high electricity consumption during the winter of 2010, in which the temperatures in Ireland were exceptionally low, as well as the differential response to TOU tariffs among households with different heating types.

Finally, on the 20th of July 2010 and on the 6th of December 2010 due to technical problems smart meters stop registering the electricity consumption of a subsample of 80 households. In order to assess the impact of this technical problem we run different robustness checks: first we run the regressions interpolating consumption between the 19th and the 21st of July and the 5th and 7th of December respectively; second we drop those days from our sample and, finally, we drop those days only from the subsample of affected consumers. The results in all of the cases didn't vary significantly from each other.[7]

[7] Complete results are available from the authors upon request.

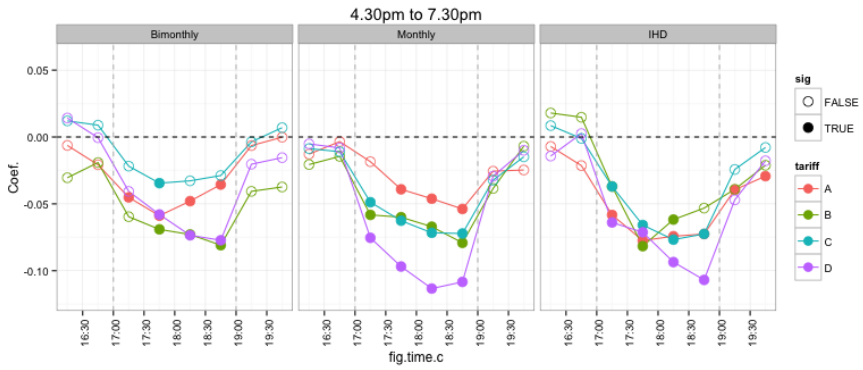
4 Results

4.1 Peak

Table 2 and Figure 1 below show the results of the consumer's reaction to the change in tariffs and stimuli during the trial. As highlighted by Di Cosmo et al. (2014) during the peak hours (from 5PM to 7PM), consumers across all three stimuli (bi-monthly bill, monthly bill and IHD) significantly modify their behaviour during the treatment period, reducing their consumption with respect to the control period. However, Di Cosmo et al. (2014) do not investigate the effects of a tariff change on half-hourly basis. This is particularly important for two reasons. First, to check whether the consumers react constantly during the hours affected by the change in tariff. It's important to assess the consumer's reaction on half-hourly basis in order to establish whether the price signal is perceived correctly in all the four half-hours affected by the tariff change, or if changes in the behaviour occur after the first half-hour. Second, our analysis allows us to assess whether during the boundary half-hours (i.e. the half-hours which immediately precede or follow the change in tariff) there are changes in electricity consumption. This is important because loads may be shifted easily from the peak hours to the period immediately after, generating a new demand peak which potentially undermines the results achieved by the tariff increase during the peak hours.

The following Figure shows the estimated coefficients by stimuli and tariffs applied. The full results are reported in Table 1 in the next page, in which significant coefficients (at 1% level) are reported in bold face. In the Figure below the coefficients which are statistically significant are represented by full dots. The coefficients which are statistically significant measure the difference in the consumer's electricity consumption between the control and the treatment period. For example, the first column of Figure 1 shows the estimated coefficient for consumers with bi-monthly bills. The coefficients related to the tariff dummies reflect the change in electricity consumption for all the people with bi-monthly billing after the increase in the peak tariffs between the control and the treatment periods. The first line represents consumers under tariff A; the fourth line represents consumers under tariff D. By comparing these two lines it is possible to notice that consumers under tariff D reduce their electricity consumption more than consumers facing the same stimulus (i.e. bi-monthly bill) but a lower tariff. The third column of the Figure shows people with IHD installed in their house. Again it is possible to see that all the coefficients estimated for this group of consumers are statistically different from zero and consumers associated with tariff D are reacting more than consumers under tariff A. In particular, comparing the three columns of Figure 1 shows that people with IHD installed in their home are more likely to change their consumption after the introduction of the TOU tariffs than consumers facing other stimuli. [8]

Figure 1: Whole sample results, peak



Looking at the half hourly data allows us to draw some interesting conclusions. Figure 1 above shows that the more responsive people also keep their consumption lower than during the control period at 730PM, which is after the end of the peak tariff. As the peak is defined as the period between 5PM and 7PM, the contraction of consumption at 7.30PM may be seen as an over reaction to the applied tariff. This result is particularly important in order to understand the impact of the tariff change on the boundary hours close to the peak time. After the increase in the peak tariffs, consumers may shift their consumption to the hours immediately before (or after) the hours affected by the price change. In this case, a new peak will be created and the benefit of TOU tariffs will be partially lost. Our results show that people with monthly bill and IHD will still perceive the change of the peak tariff until 7.30PM, which is half-hour later the tariff change. These consumers will be less keen to postpone their consumption immediately after 7PM. At the same time, as examined in the next session, there is no evidence of consumption shift from peak to

[8] Also this result is coherent with the findings by Di Cosmo et al. (2014).

night hours for the participants in the trial. As a result, the application of TOU tariffs associated with either monthly billing or the IHD stimulus may lead the consumers to keep contracting electricity consumption with respect to the control period after the end of the peak tariff. However, our results show that there is no evidence of load shift (with a new peak creation) to hours close to the peak hours.

Analyzing the patterns by the stimuli provided, in the IHD group the relationship between the costs of the TOU tariff and observed reductions was not as strong as for the people in the monthly-bill group. In particular, comparing people facing the highest tariff (tariff D) in these two groups lead to some interesting conclusions. As shown also by Table 2, in all the half-hours people with the highest tariff and monthly-bill reduce their consumption more than people facing the same tariff but with IHD installed. There are two straightforward reasons why this might have occurred. First, IHD feedback (given in €KW/hour) might have reduced behaviour of consumers on the most punitive tariff to such a degree that it reached a floor of electricity reduction, a local minimum due to the limited elasticity of electricity demand. Such a possibility seems the most parsimonious explanation of the observed consumption patterns and is supported by the fact that consumption of consumers on Tariff A who received IHD had reductions similar to the lowest reductions observed in the study. A second possibility concerns the information provided by the IHD when compared to that provided by monthly billing. For a small enough unit of time (e.g., 1 minute), there is very little difference between the cost of electricity across tariffs, so households might not have been sensitive to these small differences as they were observed in small rolling increments. Conversely, with monthly billing, differences in the cost of peak electricity would have been bigger and more clearly observable. Billing at a delay of one month exhibited a clear relationship between cost magnitude and consumption reduction. [9]

[9]Data during control period have been collected from July to December 2009. As a result, the first 7 months of the trial period (January-July 2010) do not have the corresponding control period observations. Therefore, we are not able to check the coefficients for consumers with monthly bills for the first month of the trial and check whether they started to respond immediately or with a monthly lag.

Table 2: Estimation Results - peak hours, (KWh/day)

Hour	**Stimulus**	**A**	**B**	**C**	**D**	**Treat Period**	**Treat Group**	**Weekday Dumm.**	**Bank Holiday**	**Sunsh**	**Appl.**	**Electric Heating**
17-1730	**Bimonthly**	**-0.045**	**-0.060**	-0.022	**-0.041**	S(-)	NS	S	NS	S(-)	S(+)	S(+)
	Monthly	-0.018	**-0.058**	**-0.049**	**-0.075**	S(-)	NS	S	NS	S(-)	S(+)	S(+)
	IHD	**-0.058**	-0.037	**-0.037**	**-0.064**	S(-)	NS	S	NS	S(-)	S(+)	S(+)
1730-18	**Bimonthly**	**-0.059**	**-0.069**	**-0.035**	**-0.058**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
	Monthly	**-0.039**	**-0.06**	**-0.063**	**-0.097**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
	IHD	**-0.077**	**-0.082**	**-0.066**	**-0.071**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
18-1830	**Bimonthly**	**-0.048**	**-0.073**	**-0.033**	**-0.073**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
	Monthly	**-0.046**	**-0.067**	**-0.072**	**-0.113**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
	IHD	**-0.074**	**-0.062**	**-0.077**	**-0.094**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
1830-19	**Bimonthly**	**-0.036**	**-0.081**	**-0.029**	**-0.077**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
	Monthly	**-0.054**	**-0.079**	**-0.072**	**-0.108**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
	IHD	**-0.073**	**-0.053**	**-0.072**	**-0.107**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
19-1930	**Bimonthly**	-0.006	-0.041	-0.004	**-0.02**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
	Monthly	-0.026	**-0.0384**	**-0.032**	-0.029	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)
	IHD	-0.039	-0.039	-0.024	**-0.047**	S(-)	NS	S	S(+)	S(-)	S(+)	S(+)

Significant coefficients are in bold (at 1% and 5% level). NS=not significant (at 5% level), S=significant, S(-) is significant and negative, S(+) is significant and positive

4.2 Day and night

4.2.1 Day

The effects of TOU tariffs and financial feedback were in the main limited to peak hours. During the majority of day time, there were no significant consumption changes. That said, some changes in behaviour were observed the first part of the day, from 10 to 12 AM. Consumers with monthly billing and IHD reduced consumption for certain tariffs relative to baseline (see Table 3).

It is not clear why reductions were observed in the Monthly and IHD groups at this time. One possibility is that home practices in the Monthly group that reduced usage during the peak period were also employed outside of peak times. There is some evidence to support this. First, coefficients throughout the day indicated reduced usage for the Monthly group (though not always significantly so) relative to pre-intervention usage. Second, the dominant strategy for all groups was one of reduced usage rather than displaced usage, and reduction practices may be employed consistently during the day if there was sufficient over-usage during the pre-intervention phase. Finally, as evidenced in the night-time hours, there was some evidence of displacement of usage in all three groups - that is, consumers used more electricity during low cost night-time hours than during the pre-intervention phase. This might have facilitated an all-day reduction strategy by consumers in the Monthly group. That is, by shifting much of the high consumption activities to the night-time period, consumers could more easily engage in a straightforward reduction strategy during daytime hours.

Table 3: Average of significant coefficients, 10AM-12AM

	Bimonthly	Monthly	IHD
A	NS	-0.02872	-0.04043
B	NS	-0.04527	NS
C	NS	-0.03257	NS
D	NS	-0.04456	NS

Complete results based on the half-hourly analysis are available upon request from the Authors. NS=not significant at 5% level

During the other times of the day, however, people under all the three stimuli do not react to change in tariffs. This result is aligned with the findings of Di Cosmo et al. (2014)

which highlight that the tariffs applied during the day in the trial period are almost the same as the tariffs applied during the control period as shown by Table 1.

4.2.2 Night

Night results are also aligned with the results by Di Cosmo et al. (2014), as consumers did not consistently change their behaviour during night time. Sporadic significant increases in usage were identified however in all three groups. As mentioned previously, it is possible that some displacement of usage into low-cost night-time hours occurred. Displacement can be difficult to capture however, since it is not synchronised across users. If displaced usage was spread across the night-time intervals then this would be reflected in small non-significant increases. In fact, the coefficients for the vast majority of intervals were positive for all tariffs and feedback groups, indicating higher usage than during the pre-intervention period. However, small increase in electricity consumption are significantly different from zero before 1AM and after 7AM in the morning for some of the consumers in the trial, which is consistent with the reduction of the tariff during night hours. However, there is not a clear pattern through these results, as shown by Table 4.

Table 4: Estimated coefficients, night selected hours

	Bimonthly	Monthly	IHD
1130PM			
A	NS	NS	NS
B	NS	NS	NS
C	0.040	NS	0.031
D	NS	NS	NS
12PM			
A	NS	NS	NS
B	NS	NS	NS
C	0.046	NS	0.033
D	NS	0.064	NS
1230PM			
A	NS	NS	NS
B	NS	NS	NS
C	0.045	NS	NS
D	NS	0.063	NS
1AM			
A	NS	NS	NS
B	NS	NS	NS
C	0.038	NS	NS
D	NS	NS	NS

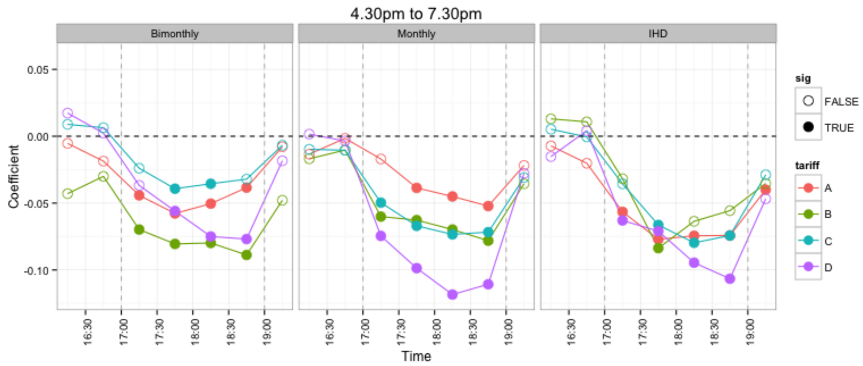
NS=not significant at the 5% level

4.3 Education

In order to check the robustness of our results we ran the same regression described in the previous chapter controlling by education level achieved by the head of household, as other variables such as income or occupational status were not available.[10] Results are shown by Table 6 below and summarized by the following Figure.

[10]See Di Cosmo et al. (2014).

Figure 2: Higher Education sample results, peak



Results for day and night do not change significantly including the education dummy, and are not reported here.[11] However, peak results indicated that highly educated people tend to react slightly stronger than the average sample to a change in tariffs.

This result is not homogeneous across the different tariffs. By comparing the coefficients of groups associated with bi-monthly billing (see Table 6 below and the previous Table 2) it is possible to notice that educated people in this group do not change significantly their consumption with respect to the full sample. However, this result does not hold for monthly-bill and IHD, as educated people reduce their electricity consumption more than the average when they have these stimuli.

This has interesting policy implications, as our results highlight that highly educated people with high information signals (monthly-bills or IHD) are able to respond to changes in tariffs more than the sample average. First, the CBT trial was set up in such a way that participants were fully compensated for losses associated to the change in tariffs. However, if the policy makers are keen to introduce TOU tariffs they should be aware that educated people are likely to save more money during peak hours than the average of the sample.

Second, as education may be considered a proxy for the income level, highly educated people may consume more electricity than less educated people in non-essential activities. Comparing the data on electricity consumption of the highly educated consumers with the less educated, lead to interesting results: the average per-capita electricity consumption during the whole period (control and treatment) is 1.66 KWh per hour for highly educated

[11] Complete results are available from the authors upon request.

people and 1.50 KWh for less educated people. The same results for the treatment period only are lower for both groups (1.61 KWh for highly and 1.46 for less) but highly educated reduce their consumption more than the less educated during the trial. Looking at the percentiles of the consumption distribution emerges that people in the highly educated group consume more than the less educated.

Table 5: Percentiles of consumption, low and high education

	Low Edu	High Edu
1%	0.012	0.015
5%	0.048	0.052
10%	0.085	0.087
25%	0.187	0.192
50%	0.426	0.462
75%	0.97	1.102
90%	1.892	2.094
95%	2.556	2.781
99%	4.031	4.245

Thus, it is possible to assume that highly educated contract their electricity consumption more than less educated because the electricity consumption is associated with non-essential activities. Thanks to the information provided by monthly and IHD installed, it was possible for people in this group to monitor their consumption and reduce it accordingly to the new tariffs.

Finally, the analysis performed on half-hourly basis highlights differences in behaviour across peak hours that did not emerge from previous studies such as Di Cosmo et al. (2014). In particular, Table 6 shows that highly educated people in the IHD group keep electricity consumption low even after the end of the peak tariff at 7PM. This result confirms our previous finding: information is crucial to give people the right signal, but some times may be misinterpreted, leading to over-reaction. In order to understand whether this over-reaction disappears after the first months of the trial or it is stable until the end of the trial, we run the model just for the final months of the trial (from September to December). Our results confirm that highly educated people with IHD installed at home reduced their consumption after 7PM with respect to the control period, but in December this effect weakens (it becomes statistically different from 0 at the 10% level).

Unfortunately, we cannot predict how consumers change behaviour in the long run, as the trial ended in December 2010. However, this result may indicate that there are changes in the behaviour through the end of the trial. Future work in this direction are envisaged in order to understand better the reaction of the participants between the short and the medium term.

Table 6: Estimation Results - Education, peak hours, (KWh/day)

		A	**B**	**C**	**D**	**Treat Period**	**Treat Group**	**Edu Dummy**	**Int. Edu Tariff**	**Weekday Dumm.**	**BH**	**Sunsh.**	**App.**	**Elec. Heat.**
17-1730	**Bimonthly**	**-0.044**	**-0.070**	-0.024	-0.037	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
	Monthly	-0.017	**-0.060**	**-0.050**	**-0.075**	S(-)	NS	NS	NS	S	NS	S(-)	S(+)	S(+)
	IHD	**-0.057**	-0.032	**-0.036**	**-0.063**	S(-)	NS	NS	NS	S	NS	S(-)	S(+)	S(+)
1730-18	**Bimonthly**	**-0.058**	**-0.081**	**-0.039**	**-0.056**	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
	Monthly	**-0.039**	**-0.063**	**-0.067**	**-0.099**	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
	IHD	**-0.077**	**-0.084**	**-0.066**	**-0.071**	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
18-1830	**Bimonthly**	**-0.050**	**-0.080**	**-0.036**	**-0.075**	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
	Monthly	**-0.045**	**-0.070**	**-0.073**	**-0.118**	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
	IHD	**-0.074**	**-0.064**	**-0.080**	**-0.095**	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
1830-19	**Bimonthly**	**-0.038**	**-0.089**	**-0.032**	**-0.077**	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
	Monthly	**-0.052**	**-0.078**	**-0.072**	**-0.111**	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
	IHD	**-0.074**	**-0.056**	**-0.074**	**-0.107**	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
19-1930	**Bimonthly**	-0.008	-0.048	-0.007	-0.018	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
	Monthly	-0.022	-0.036	-0.031	-0.028	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)
	IHD	**-0.040**	-0.035	**-0.029**	**-0.047**	S(-)	NS	NS	NS	S	S(+)	S(-)	S(+)	S(+)

Significant coefficients are in bold. NS=not significant, S=significant, S(-) is significant and negative, S(+) is significant and positive

5 Conclusions

This paper analyzes the half-hourly behaviour of consumers exposed to a change in the electricity tariff and to billing information. In particular, this work uses the data collected during the trial made by the Irish Electricity and Gas Regulation Authority (CER) between 2009 and 2010 to estimate the reaction to a tariff change by different groups of consumers. We focus on the change in consumption during the three schemes applied in the trial (day, peak and night) and during the half-hours immediately before and after these tariffs, focusing on the peak (from 5PM to 7PM) and the night (from 11PM to 7AM) hours. In this large-scale investigation of electricity consumption, TOU pricing and financial feedback influenced the degree to which consumers reduced usage. Consumption reduced during the peak period and then rebounded to pre-peak levels after the period. For households with IHD, reduced consumption persisted for one half hour post-peak.

In the main, the data suggest that households reduced consumption rather than shifting consumption from peak. In particular, one strategy that was expected was that households might simply delay consumption until the end of the peak period. If such a pattern was common across households, post-peak spikes in usages above baseline would have been recorded, but they were not. It is possible that some consumption was shifted from peak, but that it was not done in a coordinated fashion and thus was not visible in the overall numbers. There were some half-hourly periods across the day that had significantly increased consumption, but these periods did not conform to any obvious pattern of usage and these periods had relatively low baseline usage which might have exaggerated these effects

Electricity usage can be construed as an intertemporal choice, in which immediate access to heat, light and entertainment compete and often outweigh delayed financial costs. In line with this interpretation, consumers provided with financial information at the greatest delay (the bi-monthly billing group) were least sensitive to TOU tariffs. In addition, consumers provided with immediate financial information through in-home displays showed the greatest reductions in usage and reductions persisted beyond the end of the peak period.

Our work also analyses the response of highly educated households (i.e. with tertiary degree) and compare them to the reaction of lower educated consumers. The results have some policy implications. First, the education level of the head of the household has an effect on response to tariffs or feedback for consumers in the monthly-bill and the IHD groups. The changes in electricity consumption between the highly educated households and the average sample are not huge, consequently, the introduction of TOU pricing would not be expected to unfairly target low income or low education households. However, our findings show that better educated people are keen to contract their consumption during peak hours more than less educated people, saving more money after the change in tariffs. Our results also show that both in the trial and in the control period, highly educated people consume (on per-capita average) more electricity than less educated people. Education may be considered a proxy of the income level, and the electricity consumption for highly educated consumers may be associated with activities that may be either reduced or postponed.

Second, the impact of IHD on electricity usage was such that even relatively minor increases in peak pricing gave rise to considerable reductions in usage. Given that more punitive tariffs affect behaviour through greater monetary costs on the customer, there is a potential for significant monetary losses by households that fail to respond to peak pricing. By employing IHD, smaller costs with smaller exposure to these negative side effects can have greater impact on consumer behaviour.

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