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Reducing household electricity demand through smart metering: The role of improved information about energy saving

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ABSTRACT

The international roll out of residential smart meters has increased considerably in recent years. The improved consumption feedback provided, and in particular, the installation of in-house displays, has been shown to significantly reduce residential electricity demand in some international trials. This paper attempts to uncover the underlying drivers of such information-led reductions by exploring two research questions. First, does feedback improve a household's stock of information about potential energy reducing behaviours? And second, do improvements in such information help explain the demand reductions associated with the introduction of smart metering and time-of-use tariffs? Data is from a randomised controlled smart metering trial (Ireland) which also collected extensive information on household attitudes towards energy conservation and self-reported stocks of information related to energy saving. As with previous results in Ireland, we find that participation in a smart metering programme with time-of-use tariffs significantly reduces demand. Although treated households also increased their self-reported energy-reducing information, such improvements are not correlated with demand reductions in the short-run. Given this result, it is possible that feedback and other information provided in the context of smart metering are mainly effective in reducing and shifting demand because they act as a reminder and motivator.

1. Introduction

Smart metering facilitates real-time communication between the customer and the utility company and enhances the potential for detailed historical and comparative consumption feedback for electricity customers. Coupled with an in-house display, households can view their electricity usage in real-time, and track their energy and cost movements with each and every turn of the switch. Such information can help households to understand what activities consume the most, and then to amend their consumption patterns, behaviours and appliance composition to reduce their electricity bill and carbon footprint. In addition, smart meters facilitate the use of time-of-use tariffs which can help reduce peak demand and smooth daily consumption (termed *demand response* programmes in the literature).[1]1Newsham and Bowker (2010) discuss the main pricing alternatives within demand response trials. These are *time-of-use* (different tariffs for different times of the day), *critical peak* (higher prices applied only on pre-advertised 'event days'), *real time* (tying customer prices to wholesale electricity prices) and *peak time rebates* (refunds for reaching targets during peak/critical times). Additional demand response can be facilitated by coupling the meter with a number of household appliances (thermostats and air-conditioning units, for example) which respond to peak signals from the meter and/or to direct signals from the utility company (known as *enabling technologies*).

Smart metering also provides benefits to other stakeholders of the electricity system. Electricity suppliers and generators benefit from increased grid information and smoother load profiles, both of which improve the operational efficiency and stability of the system (Faruqui et al., 2010). The potential to reduce the number and duration of blackouts (through immediate outage detection) is also highlighted by Krishnamurti et al. (2012). Nationally, potential reductions in total and peak demand and decreased variability will aid in reducing greenhouse gas emissions and, depending on the regulatory framework, the level of carbon tax. For example, Hledik (2009) suggests that the roll-out of a smart grid in the US (which has smart metering and time-of-use tariffs at its core) would reduce CO_2 emissions by between 5 and 16%.

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Quantifying the demand reducing effects of various levels of feedback has been the focus of a large number of studies. Faruqui et al. (2010) review the results of 12 separate trials from the US, Canada, Australia and Japan. They find that direct feedback, in the form of an electronic in-house display (IHD), reduces demand by between 3 and 13% (average 7%). The importance of usability and clarity in such electronic feedback systems has been highlighted in Stevenson and Rijal (2010). Fischer (2008) summarises the results of twenty-two studies between 1987 and 2006. She concludes that the most effective forms of feedback are provided frequently over a long period of time, give appliance-specific breakdowns of consumption and involve electronic interaction with the households. Although not all the studies in her review show reductions, the typical savings are in the region of 5 to 12%. Abrahamse et al. (2005) also emphasise the importance of feedback frequency, but also finds that households responded well to reduction incentives in the form of financial rewards. Darby (2010a), in another extensive review of feedback mechanisms, finds that enhanced billing (more frequent and more accurate consumption information) is not always associated with lower demand, and that there is little evidence that written, generalised information (energy-saving tips) has a significant effect. Similar findings are reported by Ofgem (2011), where the combination of generalised information and historic feedback is found to be ineffective (in the absence of smart meters). Ofgem, however, do generally find that smart metering supporting by an IHD has a significant reducing effect (around 3%). However, they also find that when the meter is installed as a 'routine replacement' and its presence not communicated effectively to the household there is no significant effect.

For time-of-use pricing, trials have shown large and significant peak reductions. Faruqui and Sergici (2011) find that peak-time rebates reduce peak demand by between 18% and 21%, and that adding an 'Energy Orb', which reminds households of peak periods (changes colour depending on the tariff rate applied), increased this reduction to between 23% to 27%. Ofgem (2011) also find significant time-of-use pricing effects, but are smaller in magnitude and up to 10%. Two trials summarised by Faruqui et al. (2010) find that time-of-use and critical-peak pricing (in combination with direct feedback (IHD)) reduce peak and critical demand by 5% and 30% respectively. Newsham and Bowker (2010) also find similar reductions. Finally, Faruqui and George (2005) find that time-of-use rates with a peak to off-peak ratio of two to one produce peak reductions in the region of 5%.

In Ireland, the first major smart meter trial was undertaken between 2009 and 2010 by the Commission for Energy Regulation (CER, 2011c). The trial simultaneously applied various levels of feedback (more accurate and detailed billing and/or an IHD and generalised information/advice on how to reduce) and time-of-use tariffs to a large and representative sample of Irish households. Overall, treated households reduced their total demand by 2.5% and their peak demand by 8.8%. One interesting finding was that household reductions in peak and overall demand were not significantly different across tariff treatments – households seemed to respond to the presence of a peak/off-peak price differential, but not its magnitude. In contrast, differences were observed in the effects of varying levels of feedback, with households receiving an IHD showing the largest reductions of 3.2% and 11.3% respectively (across all tariff rates).

To date, international trials investigating the effects of smart metering, demand response and enhanced feedback have tended to find that these sorts of measures can reduce residential energy demand, shift use away from peak times and give rise to a range of accompanying benefits for households, utility companies and the environment. However, the mechanisms behind residential demand response behaviour are still not fully understood. Underlying an information-led demand reduction is the notion that increased feedback is correcting a market failure brought about by imperfect information. Prior to smart metering, households were consuming in what was unquestionably an informational void, with little understanding of what appliances and behaviours consume the most, and when. The only feedback available was through the utility bill, which aggregated consumption over lengthy periods, disconnected instantaneous usage and behaviours from cost and often provided inaccurate consumption information due to estimation (bills based on previous readings). Smart metering has the potential to reduce this market failure by taking the imperfectly informed consumer closer to a state of *complete* consumption information (in the case of real-time electronic feedback). As highlighted by Gram-Hanssen (2010), such improvements in knowledge are a key component of bringing about a behavioural change.[2] In particular, the importance of gaining a deeper understanding of the inherent *value* that consumers place on feedback has been recently highlighted in the literature. Faruqui et al. (2010) question whether consumers actually use and benefit from this quantitative and qualitative information and incorporate it into their consumption decisions, or if increased feedback simply acts as 'reminders to conserve'. This question is highly relevant for quantifying the effects of feedback in the long term – if it is the latter which is driving reductions, the effect of these reminders may diminish over longer durations and demand reductions could be short-lived.

Whether or not households actually 'learn' something new is the motivation of our first research question – *does the increased consumption feedback provided through smart meters lead to improvements in a household's stock of information about how to reduce their electricity use and which appliances consume the most*? Our second research question then seeks to quantify the effects of such, if present – *do improvements in such information help explain the demand reductions associated with the introduction of smart metering and time-of-use tariffs?* These hypotheses are summarised in Fig. 1.1. A direct causal link between stages 1 and 3 is established in the literature, both in Ireland and internationally (for the most part). Significant links between stages 1, 2 and 3 would suggest that imperfect information prior to smart metering was contributing to overconsumption and that this market failure has been addressed by increased consumption feedback. If a link is observed between stages 1 and 2 but not between 2 and 3, informational improvements are not actually an important driver of demand reductions and feedback has reduced demand through some other mechanism. If this is the case, imperfect information, despite being present, was not causing overconsumption and, in short, there was no market failure to correct.

We use a household's self-reported stock of information to investigate the above. We also focus on *changes* in information rather than the *level* of information, since such indicators may be more robust to individual differences in reporting behaviour. The paper proceeds as follows: Section 2 outlines the data employed for this analysis and describes how 'information' change is measured in the surveys. The econometric methods are described in Sections 3. Section 4 presents the results and Section 5 concludes the analysis.

2. Data — the residential smart meter trial

The Irish residential smart meter trial was carried out between 2009 and 2010 and involved the installation of over 5000 smart meters into residential households (CER (2011a) and CER (2011c)).[3] The overall objective of the trial was to test the impact and viability of smart metering technology in Ireland, and to explore the demand reducing effects of various feedback mechanisms and time-of-use tariffs. Recruitment of the nationally representative stratified random sample involved a number of phased postal invitations (five), with each round adding new participants with the goal of increasing the representativeness of the sample (according to location and electricity use).

[2] Gram-Hanssen (2010) used *Practice Theory* to explore how households reduce their standby consumption. The theory shows how technological configurations, routines, knowledge and engagement interact to bring about changes in household behaviour.

[3] The overall project commenced in 2007 and was overseen by the Commission for Energy Regulation (CER) with trials carried out by *ESB Networks* and *Electric Ireland*. We are grateful to the Irish Social Science Data Archive (www.ucd.ie/issda/) for providing data.