



Smart meter devices and the effect of feedback on residential electricity consumption: Evidence from a natural experiment in Northern Ireland[☆]



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ABSTRACT

Using a unique set of data and exploiting a large-scale natural experiment, we estimate the effect of real-time usage information on residential electricity consumption in Northern Ireland. Starting in April 2002, the utility replaced prepayment meters with advanced meters that allow the consumer to track usage in real-time. We rely on this event, account for the endogeneity of price and payment plan with consumption through a plan selection correction term, and find that the provision of information is associated with a decline in electricity consumption of 11–17%. We find that the reduction is robust to different specifications, selection-bias correction methods and subsamples of the original data. The advanced metering program delivers reasonably cost-effective reductions in carbon dioxide emissions, even under the most conservative usage reduction scenarios.

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1. Introduction and motivation

Residential buildings account for a large share of the world's energy consumption, and offer a natural target for policies that seek to reduce CO₂ emissions from (fossil-fuel) power generation, dependence on imported fuels, and vulnerability to supply shocks. For these reasons, there is tremendous policy interest in programs to reduce energy consumption and increase energy efficiency in the residential sector.

It is difficult for consumers to keep track of current electricity usage and/or predict future electricity demand.¹ Many observers

argue that providing better information and feedback on consumption helps improve energy conservation and energy efficiency in the residential sector—by itself or when combined with other traditional policy tools such as economic incentives, pricing and regulation. Earlier evaluations of information-based approaches, however, relied on short-lived pilot projects or small groups of households, which resulted in small sets of data (Ehrhardt-Martinez et al., 2010; Fischer, 2008), and have been complicated by self-selection issues due to the voluntary nature of certain initiatives, such as utility-provided audits (Hartman, 1988; Waldman and Ozog, 1996).

Recent technological advances, such as “smart” and advanced meters and the associated infrastructure (advanced metering infrastructure, or AMI), can give consumers feedback on consumption by combining frequent automated usage readings with accessible displays. AMI has received much recent attention and, at least in the US, generous federal funding. Despite the scale of support from the government and the utility industry, there has been little evaluation of these programs.

In this paper, we use an advanced metering implementation in Northern Ireland to provide the first large-scale evidence of the effect of usage feedback on residential consumption. Specifically, we estimate household response to the provision of immediate feedback about electricity consumption.

Northern Ireland is a unique setting for studying residential energy consumption for three reasons. First, the retail residential rates are

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¹ Other goods that share these features include, for example, cell phone minutes and internet access time (Grubb, 2009). Della Vigna and Malmendier (2006) and Lambrecht and Skiera (2006) study preferences for three-part tariffs and flat rate even when the consumer would save money by choosing alternate pricing schemes, which they attribute to underestimating the variance of future demand, risk and loss aversion, and disutility associated with the price per se.

among the highest in the United Kingdom and Europe, but, until recently, consumers lacked an alternative provider for electricity. This suggests that they may be willing to make behavioral changes to save on their energy bills when given an opportunity to do so.²

Second, there are a host of payment plan options for electricity in the Northern Ireland market. These include credit accounts, direct debit accounts, and prepayment accounts. The variation in attributes across plans allows us to identify the effect of price and changes in other important plan features.

Third, one of these plans (prepayment) recently experienced an exogenous change in technology (the keypad) which provides immediate feedback about usage. Moreover, because this plan requires prepayment, it suggests that households on it will be monitoring their usage. The switch away from the previous meter that served prepayment customers, which did not have these capabilities, occurred in April 2002. We interpret this as the treatment in a natural experiment and use it to identify how electricity consumption was affected among the “treatment” customers. Our “controls” are customers in other plans (which do not use AMI meters and do not provide real-time information about usage to the consumer). This is a large scale natural experiment, since 14% (over 75,000) of the NIE customer base was on a prepayment plan at the time of the switch to the keypad metering technology.

Economic theory does not predict unambiguously the effect of information on electricity usage on electricity consumption. Gans et al. (2011) develop a simple theoretical model where the fraction of energy wasted is controlled with monitoring and information, which can be either substitutes or complements. In this framework, there are countervailing incentives to substitute electricity savings for savings on monitoring. Whether feedback (i.e., the keypad) about usage enables consumers to reduce their electricity demand (through conservation or energy-efficiency investments) is, therefore, an empirical issue.

We examine this matter using data from 18 waves of Northern Ireland's Continuous Household Survey (from 1990 to 2009), which we merge with price and plan information from the electricity utility, and weather data. Our dataset is a multi-year cross-section and is comprised of over 45,000 usable observations. Despite the single-provider electricity market, prices varied over time and across payment plans during our study period. Since electricity price depends on the plan, but plan choice may depend on unobserved household characteristics that influence both consumption and plan selection, we implement the Dubin and McFadden (1984) correction in our demand equations. We also account for unobserved heterogeneity using geographic fixed effects. We find that controlling for housing type, heating, household characteristics and selection into the plan, the keypad results in 11–20% less electricity use.

The keypad may provide a cost-effective alternative to large scale rebate or efficiency incentive programs in meeting emission reduction and demand response goals. In terms of CO₂ emissions, we find that the keypad delivers emissions reductions at a cost per tonne of CO₂e of £25 or less, where £25 is the price of carbon used by the UK government in its policy analyses (DECC, 2009). Other benefits of the keypad or similar usage feedback systems, which we do not try to assess in this paper, include reduced metering, billing, outage investigation and fraud-related costs for the utility, reductions in conventional air pollution associated with power generation, and improved energy security.

The remainder of the paper is organized as follows. Section 2 reviews the previous literature. Section 3 describes the utilities of Northern Ireland, prices and plans for the residential sector. Section 4 presents the model and the empirical approach. Section 5 describes the data. Section 6 presents the results. We offer concluding remarks in Section 7.

² These incentives should be particularly strong for so-called “fuel poor” households. Government estimates suggest that about one-third of the households in Northern Ireland are “fuel poor,” with fuel poverty being defined when 10% or more of the household income is spent on all household fuel use (Department for Social Development Northern Ireland, 2006).

2. Previous literature

Imperfect information and uncertainty about the price of electricity have received much attention in the energy economics literature. Shin (1985) discusses consumers' use of the average price of electricity (as opposed to the marginal price) when it is difficult to track due to seasonal price changes, block tariffs, and fuel surcharges. Hassett and Metcalf (1993) and Metcalf and Rosenthal (1995) study the effects of uncertainty about future energy prices on the pattern of energy efficiency investments. Ito (2010) summarizes alternative models of consumer behavior in the presence of block pricing, showing that people will invest effort in finding out the price of energy only to the point in which the gains from re-optimizing consumption decisions exceed the cost of the effort spent monitoring and investigating prices.

In contrast, the literature on consumer response to information about energy usage (as opposed to price) is relatively scant. Traditionally, utilities have provided information to a customer about his or her energy consumption level (and on how to reduce it) by offering free or low-cost audits.³ Individualized audits, however, are typically utilized by only a small fraction of the customer base. Because they are voluntary, it is likely that people who reduce energy use after an audit would have done so anyway. Hartman (1988) finds that audits do decrease energy usage, but that failure to account for self-selection grossly overstates the impact of the audit program. To illustrate, during 1977–1981 (his study period) the average conservation truly attributable to the program is 951 kWh/yr—only 39% of the savings calculated based on a naïve comparison between participants and non-participants.

Waldman and Ozog (1996) use a sample of participants and non-participants in a choice-based sampling framework, and assume that, absent any type of incentive, there is a “natural” level of conservation, which they identify using the consumers who are not aware of the existence of utility incentives (and consequently receive zero incentive). They estimate that the program truly accounts for only 71% of the total conservation, the remaining 29% being “natural” conservation (i.e. that would have happened regardless).

While audits are typically one-off events, recently attention has been focused on ways to provide continuous, or at least frequent, feedback to consumers about their energy usage. Darby (2006) surveys earlier studies involving the provision of information, both direct (“immediate, from the meter or an associated display monitor”), and indirect (“feedback that has been processed in some way before reaching the energy user, normally via billing”). Reductions in consumption are in the 5–15% and 0–10% range, respectively. These are in line with the estimates documented in the review by Ehrhardt-Martinez et al. (2010).⁴

³ These are often included in the utilities' Demand Side Management (DSM) programs, along with other initiatives for encouraging conservation and peak load management. See Loughran and Kulick (2004) and Auffhammer et al. (2008) who compute the cost per kWh saved by DSM programs in the US in the 1990s. Dulleck and Kaufmann (2004) use monthly time series data for household electricity usage in Ireland from 1976 to 1993 and relate them to Demand Side Management policies that provided information and offered minor incentives to customers. Their analysis is constrained by the fact that they observe only aggregate data, so they estimate a seasonally-adjusted time-series model of energy usage. They find that the introduction of information programs reduces long-term electricity usage by 7%.

⁴ One way to enhance or manipulate the feedback provided by regular utility bills is to augment it with “social norms” contents. In a randomized field experiment involving 80,000 households in Minnesota, information about the energy usage of neighbors and visual cues about doing “better” or “worse” in electricity usage relative to similar neighboring homes has been found to reduce energy consumption by 1.9% relative to the baseline (Allcott, 2011). The effect decayed over time, perhaps because of the diminishing scope for learning from a neighbor's bill over time. Effects of similar magnitude (2% and 1.2%, respectively) were observed in similar large-scale randomized trial experiments in Sacramento, California, and Portland, Oregon (Ayres et al., 2009). These declines in usage were sustained over time, and were generally proportionally larger among households with large pre-treatment consumption. In one of the two study locales (Sacramento) electricity consumption actually increased among households with low pre-treatment usage.

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