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Persistence of the effects of providing feedback alongside smart metering devices on household electricity demand

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ABSTRACT

Using large-sample high temporal resolution data from a smart metering field trial, we econometrically estimate the effects of providing feedback in addition to smart metering devices. We compare consumption levels and patterns between a pilot group that received feedback in addition to smart metering devices and a control group with only smart metering devices. We investigate, in particular, the persistence of the effects and whether the effects differ between periods of high and low household occupancy, i.e. between morning and evening periods, and between weekdays and weekend days. The findings show that feedback is effective, leading to about 5% electricity consumption reduction that is persistent over an eleven month period. Furthermore, our results show that this reduction affects both low and high occupancy periods, suggesting that feedback is associated with rather permanent changes in habitual behavior and/or investments in energy-efficient technologies.

1. Introduction

The roll-out of electricity smart metering devices is well under way in the European Union (EU), with a recent official report indicating that most EU member states are on track to achieve the target of 80% penetration by 2020 (European Commission, 2016). In recent years, many field studies have been conducted to assess the impact of introducing in-house displays on electricity consumption; most of these pilot studies have compared electricity consumption of households with or without in-house displays (or before-after the introduction of in-house displays). Providing households with information on their electricity consumption has mostly been found to be effective in reducing electricity demand (e.g. Wilhite and Ling, 1995; Matsukawa, 2004; Darby, 2006; EPRI 2009; Faruqui et al., 2010, Ehrhardt-Martinez et al., 2010; Gans et al., 2013; Gleerup et al., 2010; McKerracher and Torriti, 2013; Schleich et al., 2013; Houde et al., 2013). However, recent papers stress that providing in-house displays alone may not be sufficient. Tedenvall and Mundaca (2016), for instance, report a less than 2% reduction in electricity consumption over a long-term field study in Sweden; similarly, results from a meta-analysis (Delmas et al., 2013) indicate savings of less than 2% for "robust" studies (those including control groups or accounting for control factors). Such results lead authors to doubt the effectiveness of in-house displays per se and to recommend associating in-house displays with other mechanisms: Buchanan et al. (2015), for instance, recommend adding functions that increase user engagement with in-house displays; Tedenvall and Mundaca (2016) also recommend adding additional measures (especially awareness measures) with in-house displays. Such recommendations are consistent with Abrahamse et al.'s (2005) finding that feedback is particularly effective when it is provided together with information on energy-efficiency measures. These papers (and the fact that smart metering deployment is already well advanced) point to the need to investigate the impact of the presence of feedback *along* in-house displays. The present paper therefore examines households equipped with in-house displays and compares those that receive feedback to those that do not.

Two issues are of interest when focusing on the effects of feedback on in-house display users. First, if feedback affects electricity consumption, do the effects persist or disappear over time? Second, does feedback lead to changes in usage profile (for instance, reduction of the base load)? Households may respond to feedback on their electricity use in two manners: by changing habitual behaviors (such as turning off lights, reducing device usage, or switching off electronic devices rather than putting them in stand-by mode), or by investing in energy efficient technologies (such as purchasing electricity-saving appliances or power strips with on/off switches). While behavioral changes may only have a transitory effect on electricity use if households return to their long-practiced habits after a certain time (e.g. Allcott, 2011), the

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effects of investments should be more persistent. To test persistence, it is necessary to follow consumption over a long period of time.

Usage profile is also susceptible to change based on feedback. Changes in behaviors or investments in air conditioning or electronic media devices are expected to primarily shape electricity consumption during periods of peak household activity (e.g. Torriti, 2012), that is, in the mornings and evenings on weekdays, and on weekends. In contrast, investments in energy efficient refrigerators or freezers should reduce the base load, and hence affect the entire electricity load profile of a household, and be particularly visible in off-activity times (at night and during the day on weekdays). Investigating usage profile changes therefore requires detailed consumption information at the household level and a systematic distinction between different hours and different days of the week.

So far, due to data availability limitations, few studies have explored whether feedback on electricity use resulted in persistent electricity savings or in changes in the usage profile. Relying on data from a field experiment with employees from Google in California, Houde et al. (2013) conclude that real-time feedback delivered via information and information and communication (ICT) technologies had only transitory effects; initial electricity savings disappeared after four weeks. They also find larger reductions during the morning and evening time intervals, i.e. during periods of high household occupancy. Thus, the findings by Houde et al. (2013) suggest that feedback on electricity use mainly leads to transitory changes in household habitual behaviors.

Our paper adds to sparse empirical evidence on the long term effects of feedback on household electricity use and on a user's consumption profile. We employ large-sample high temporal resolution data from a 2010 smart metering field trial in the Austrian city of Linz to econometrically estimate the effects of providing feedback with in-house displays for each hour of the day (distinguishing between weekdays and weekend days). Following household consumption patterns over an eleven-month period, we analyze whether the effects are transitory or persistent, and whether the effects differ between hours of the day and especially between periods of high and low household occupancy, and between weekdays and weekend days. The findings allow us to explore whether the observed effects may be ascribed to changes in habitual behavior or rather to investments in energy efficient technologies.

The paper is organized as follows. The methodology Section 2 describes the field trial, econometric methods, data, and variables. Section 3 presents and discusses the results of the econometric analyses. The concluding Section 4 summarizes the main findings and derives policy implications.

2. Methodology

2.1. Field trial

The field trial in the city of Linz, Austria, originally involved a sample of more than 2000 households for whom the old electricity meters had been replaced by smart meters in 2009. These households were randomly assigned to two groups: the pilot group, in addition to the smart meters, received feedback on electricity consumption, whereas the control group had only the smart meter (no feedback). After correcting for households that either relocated during the field phase or encountered insoluble technical problems, data was available for 1525 households, 775 pilot group households and 750 control group households.

Pilot group households chose how they preferred to receive feedback on their electricity use: either via access to a web-portal or via written information by post. By accessing the web portal, households could see their electricity consumption patterns and electricity costs. Several types of charts and tables allowed for comparison of energy consumption and costs on a yearly (month-by-month comparison), twice-yearly (week-by-week comparison), monthly (day-by-day comparison), or daily basis (hour-by-hour comparison). The web portal also provided information on intermittent loads and (estimated) base loads (i.e. refrigerators and freezers) as shares of the total household electricity consumption. All data was available to the web portal users with a delay of, at most, one day. In comparison, the written feedback was sent to households once a month and consisted of two pages including color-printed information on daily, weekly, and monthly household electricity consumption. Both web portal and written feedback also provided practical information on how to save electricity.

The electricity consumption of households in both pilot control groups was recorded between December 2009 and November 2010. Since the written feedback could only be sent out after the first month of the trial, possible impacts of that feedback could only be expected from the second month onwards, i.e. for the period of January to November 2010. The smart metering systems provided hourly consumption data, which was read at the end of each day by a remote system. In addition to this detailed information on electricity use, information about household appliance stock and socio-demographic characteristics was available for both groups from computer-assisted telephone interviews. For more details on the design of the field trial and on the types of feedback provided, see Schleich et al. (2013). Unlike Torriti et al. (2015), for example, data on actual time use was not available. Finally, upon completion of the field phase, an additional survey asked participants to evaluate the quality of the feedback provided and whether they had implemented any energy-efficiency measures since the beginning of the field trial.

2.2. Statistical models

We employ several econometric models to (i) explore the average effects of providing feedback on electricity use for the entire duration of the field study, (ii) test for persistence of effects over the eleven-month period, and (iii) to test for differences in feedback effects across the 24 hours of the day on weekdays and weekend days.

To analyze the average effect of feedback on household electricity demand for the duration of the field study, we first estimate the following reduced form electricity demand equation

$$electricity_{it} = c + \delta\, feedback_i + \beta\ Z_i + \sum_{m=1}^{11} M_m + \sum_{h=1}^{24} H_h + \varepsilon_{it}, \tag{1}$$

where $electricity_{it}$ is the (log of) electricity use by household i at hour t of a day (t=1–24) and c is a constant term. Electricity is calculated as the average electricity consumption at hour t per month. We thereby distinguish between weekdays (Monday to Friday) and weekend days (Saturday and Sunday), by estimating Eq. (1) separately for weekdays and for weekend days. *Feedback* is a dummy variable indicating that household i received feedback on electricity consumption.[1] Since we use the logarithm of electricity consumption as the dependent variable, δ measures the average percentage difference in hourly electricity consumption between households that received feedback and those that did not. Z_i is a vector of household socio-economic and appliance stock characteristics (which do not vary over time).

Variables reflecting household characteristics include income, level of education, and number of household members. The dummy variable *income* takes on the value of 1 if the household has a household disposable monthly income (including transfer payments) above 2500 €. Similarly, the dummy variable *education* equals 1 if the survey

[1] Note that we do not distinguish whether households received feedback via access to the web portal or via postal mail. We tested for such differences and did not find any statistical differences; as a consequence, we report both feedback types together. As an aside, in Darby's (2006) classification of direct versus indirect feedback, web portal information is somewhat ambiguous because it entails characteristics of direct feedback (immediate and interactive) but also of indirect feedback (it contains information that is processed by the utility company). Our results seem to suggest that web portal information has the same effects as postal mail (indirect feedback).