Two-Period Household Electricity Demand Estimation with Limited Data

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Overview

Worldwide the installed base of residential smart meters is rapidly growing. IHS, a market research firm, expects installed meters capable of two-way communication to grow from 18% of the 1.43 billion world-wide installed meters in 2011 to 35% of installed meters by the end of 2016 (Pele, 2014). This growth has enabled the possibly of time-based rate programs at the household level and the possibility of capturing economic efficiencies associated with closer alignment of consumer consumption decisions with actual production and delivery costs. Various proposals for residential time-based pricing range from real-time pricing with price charged to consumers changing hourly or more frequently, to pricing based on time-of-use pricing with price charged to customers changing for different blocks of time during a day often corresponding to peak and off-peak demand periods.

A major benefit of time-based pricing is expected to be reduced need for intermittently utilized peak-capacity infrastructure. A recently completed survey conducted the United States Federal Energy Regulatory Commission provides some insights on adoption of time-based pricing among U.S. households (FERC, 2012). The survey indicates the potential and actual residential peak use reduction response increased by approximately 33% among U.S. residential consumers between 2008 and 2012, with time-of-use pricing now accounting for about 12% of all reported demand response potential, even though residential advanced metering penetration increased from 4.7% to 23.9% over the same time period. From the survey, it appears the small potential response in residential demand shifting capacity may be due to limited implementation of time-based pricing structures made available to residential consumers. The total number of residential customers in the U.S. purchasing electricity through time-of-use pricing increased from 1.1 million in 2010 to nearly 2.1 million in 2012, with most of the increase resulting from growth in one North American Electricity Reliability Council region (FERC, 2012).

One potential obstacle to adoption of time-based pricing is lack of information about how residential consumers are likely to alter consumption behavior after a new pricing contract is introduced. Before offering any new time-based price alternative, firms must make some assessment of anticipated consumer behavior and design a pricing contract based on that assessment. Any errors in anticipated consumer response can lead to unanticipated results and profit losses. To date, most work on time-of-use demand has utilized experimental data generated by pilot studies where selected households were exposed to time-of-use pricing while others were not. Faruqui and Sergici (2010) review 15 pilot studies and find that time-of-use contracts drop household peak demand between 3% and 6%, while critical-peaking pricing tariffs reduce peak demand between 13% and 20%. However, most studies are based on small numbers of households. In addition, studies utilizing volunteer households may suffer from sample selection bias leading to higher estimates of household substitution behavior since households more likely to benefit from time-based pricing are likely to adopt and change behavior when compared to the general population (e.g. Allcott, 2011). Even in an experimental setting, sample selection bias may still be an issue and difficult to assess.

Methods

This paper develops an approach to estimate two-period (peak and off-peak) household electricity demands that can be implemented using smart-meter household data where household consumption is historically based on block price rate structures rather than time-of-day pricing. This allows initial estimates of likely household behavior to be developed before initiating time-of-day pricing. The approach is based on an S-Branch utility tree structure (Brown and Heien, 1972) and is particularly well suited to model household electricity consumption since it is able to identify subsistence and, by implication, discretionary consumption in both the peak and off-peak hours and the substitution elasticity associated with adjusting consumption between the two time periods.

Borenstien (2009) and Ito (2012) show that household electricity consumers appear to respond to average pricing rather than marginal pricing as had previously been emphasized in the literature. We use this approach, in conjunction with demands derived from an S-Branch utility, to obtained instrumental variable estimates for model parameters representing household demand for peak and off-peak consumption periods. Estimation is based on a method of moments approach using a two equation system composed of one demand equation and one equation representing the marginal rate of substitution condition between discretionary consumption in the peak and off-peak periods. Identification of all parameters requires additional instruments related to demand shifts that might include temperature, day of the week, and season.

Results

We show that using hourly data, like that typically obtained from smart meter implementations, aggregated for peak and off-peak time periods, and prices that result from block pricing based on increasing rates per unit as consumption increases so that there is price variation for each household, all demand parameters are identified and can be estimated. We demonstrate our approach using Monte Carlo techniques.

Conclusions

The two-period residential demand estimation approach developed in this paper should allow firms to utilize more accurate ex ante assessments of anticipated consumer behavior in their initial design of time-based pricing contracts. This should enable increased pilot programs among power providers due to reduced risk of poorly designed contracts and higher rates of participation among households since contract terms would initially incorporate more accurate evaluations of household preferences.

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