UNDERSTANDING RESIDENTIAL WITHIN-DAY ELECTRICITY DEMAND

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Overview

In light of the ongoing and anticipated major developments in energy markets, there is an increasing interest in understanding the daily demand for electricity. In particular, with increased intermittency in electrical grids, and an increased focus on so-called "smart grids", opportunities for influencing residential demand for electricity at the hourly level are higher than before. Yet, not enough is currently known regarding how individual households consume electricity at the hourly or higher frequency, and even more, about how to conceptualize the factors which drive consumption at these time-frequencies. Providing an economic framework for understanding household consumption of electricity at the hourly level is precisely the task taken up in this paper. In particular, we provide and develop a demand-system based framework for understanding three distinct aspects related to hourly electric demand: (a) how can hourly demand for electricity be understood in a consistent and rigorous demand framework? (b) to what extent are household specific-characteristics, in particular specific end-use holdings, important in determining demand? And, (c) what is the structure of household response to alternative pricing schemes, particularly so-called dynamic pricing? An important aspect motivating our analysis is the focus on consumer utility, which is derived from usage of energy service, implying that demand for different hours of the day are not necessarily independent; for certain times, they may be substitutes or complements, and this property may be dependent upon prices. Put another way, given that households consume services, and services may be time-dependent, so too may hourly demand for electricity.

In contrast, much of the theoretical literature on dynamic pricing of electricity largely (with excpetions, Holland and Mansur, 2006) assumes constant-across-the-hours price elasticities (Borensten, 2005; Savolaionen-Kopsakangas and Svento, 2012) while empirical literature on dynamic pricing has faced difficulty in estimating cross-hour elasticities (Allcott, 2011). Indeed, constant-across-the-hours price elasticities is an important aspect leading to welfare gains from dynamic or time-of-use pricing. Our objective in this paper is to present a framework that allows utility to depend upon electricity consumption across time periods within a day, and where each time-period's consumption is treated as a separate commodity. The resulting demand system, which is flexible enough to accommodate many characteristics of interest, including time-varying elasticities, is estimated using unique and rich household-level data set, hourly consumption at the household and end-use level. The parameter estimates are subsequently used to explore welfare implications at the household level of alternative dynamic pricing schemes. The contribution of this paper are thus two-fold: First, we provide a consistent framework for understanding how the elasticity of substitution affects the outcome of dynamic pricing schemes, allowing us to evaluate welfare implications of different pricing schemes. Secondly, we have more detailed data than most previous literature, with detailed information about electricity usage at the hourly and end-use level, enabling us use household-specific information to drive the model.

Data and Methods

Although electricity usage in most empirical analysis is thought of as one homogeneous good, a more plausible approach is to acknowledge the derived nature of electricity demand by treating electricity usage across hours as separate bundle of goods. For example, electricity usage in the morning, when the household wakes up and make breakfast, is very different from electricity during mid-day, when the household is away from home and use little electricity, or electricity usage during the evening, when the household cooks dinner and watches TV. Following this line of thought, we define a demand system for daily electricity demand, where electricity demand during different time-periods of the day are treated as separate commodity groups. In more detail, we specify a Exact Affine Stone Index (EASI) demand system (Lewbel and Pendakur, 2009), refered to as an implicit Marshallian demand system. This demand system is more flexible than the Almost Ideal Demand System (AIDS) in terms of Gorman rank restriction.

Further, our framework allows for welfare implications of a price to vary across hours, accommodating the possibility that even when prices are constant across hours and households, welfare implications may differ substantially across both dimensions. This is achieved by constructing so-called Stone Lewbel price indices (following Lewbel (1989)), which exploits variation in the composition of expenditures within commodity groups (hours) to identify household-level commodity price indexes.

The data used in this paper originates from a metering campaign commissioned by the Swedish Energy Agency, with a total of 389 households, of which 200 were villas and the remaining flats, had metering devices installed that measured electricity consumption at the appliance level for ten-minute intervals. In addition, outdoor temperature was also metered at ten-minute intervals, and the data was supplemented with survey information on household characteristics.

Results

We find residential electricity demand to vary substantially within a day, with compensated own-price elasticities varying between -1.049 and -1.344. Further, we find statistically significant cross-price elasticities for the morning and evening time-periods, and that some time-periods are complements and others are substitutes. Finally, income elasticities to be close to unity for all time-periods. These elasticities are illustrated in Table 1 below:

	Price Morning	Price Work	Price Dinner	Price Evening	Income
Morning	-1.068***	0.864***	0.033	-0.555*	1.001***
Working hours	0.891***	-1.344***	0.014	-0.221	0.984***
Dinner	0.039	0.0025	-1.344***	0.170	0.974***
Evening	-0.665*	-0.256	0.149	-1.049***	0.976

* p<0.05, ** p < 0.01, *** p < 0.001

Conclusions

Preliminary results suggest substantial variation in electricity demand within a day. In particular, we find that the substitution of electricity across time-periods varies, and that some time-periods are complements and others are substitutes. This have important implications for the design of pricing schemes, but also illustrate that the response to more common type of price schemes varies within a day. The results presented in this extended abstract will be accompanied by welfare computations for different pricing scenarios, as well as the resulting load profiles for different pricing schemes.

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