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The hourly income elasticity of electricity

Mattias Vesterberg

Center for Environmental and Resource Economics (CERE), Umeå School of Business and Economics, Sweden
Industrial Doctoral School, Umeå University, Sweden

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ABSTRACT

Using a detailed data set on appliance-level electricity consumption at the hourly level, we provide the first estimates of hourly and end-use-specific income elasticities for electricity. Such estimates are informative about how consumption patterns in general, and peak demand in particular, will develop as households' income changes. We find that the income elasticities are highest during peak hours for kitchen and lighting, with point estimates of roughly 0.4, but insignificant for space heating.

1. Introduction

In this paper, we estimate hourly and end-use-specific income elasticities for residential electricity demand in Sweden. Such estimates provide insight into how within-day electricity usage patterns change with income, and whether this effect differs across end uses, i.e., appliances grouped into heating, kitchen, lighting and residual. In particular, we are interested in understanding whether changes in income will magnify the costs and inefficiencies associated with peak demand. For example, a household with higher income might use more advanced appliances for cooking, or cook more elaborate food, and therefore use more electricity in the kitchen. Because kitchen appliances are typically used during the morning and evening (assuming the household is at work during mid-day), we would expect kitchen usage to be more income elastic during traditional dinner hours and less so during night time or mid-day which are typically associated with little or no kitchen usage. Similar arguments can be made for the other end uses. Thus, in general, we expect household energy usage to be more income elastic during hours associated with greater electricity consumption, i.e., peak demand hours.

Previous studies in the extensive literature on electricity demand are mostly concerned with monthly or annual electricity usage, and, as far as we are aware, none has ever had the data available to estimate how income elasticities differ between hours. Using a detailed data from the Swedish Energy Agency, we are able to provide the first estimates of how changes in income affect the within-day usage pattern of electricity for different end-uses. Daily end-use-specific income elasticities are then derived from these hourly estimates. As such, we provide one coherent framework for exploring both changes in usage levels and changes in usage patterns.

Understanding households' electricity usage patterns has lately been a subject of economists' and policy makers' interest (Borenstein (2005), Allcott (2011), Kopsangas-Savolainen and Svento (2012) and Energimarknadsinspektionen (2010)). Obviously, the economic literature on peak demand goes even farther back; see e.g., Steiner (1957). However, technological advances, cheaper monitoring equipment and the expansion of intermittent production has led to a recent surge of interest in this topic.

Because supply of power has to equal demand for power in every moment in time, and if black-outs are to be avoided, capacity has to be extended to meet demand at its peak, or demand has to be reduced to meet capacity. However, because retail prices usually are the averages over, e.g., a month, consumers have no monetary incentives to adjust usage to the momentary variation in availability of electricity. This is likely to result in very high demand

E-mail address: mattias.vesterberg@umu.se.

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for certain peak hours, e.g., cold work days during winter. Such price inelastic short-term behavior implies that sufficient generating capacity has to be built to satisfy extreme levels of demand. Note that if capacity is operating close to maximum, it only takes a small increase in demand to require an extension of capacity. If capacity is a substantial part of the cost structure (i.e., high fixed costs), the capacity reduction that could result from improving price responsiveness is then a substantial potential source of welfare gains (Borenstein (2005) and Kopsangas-Savolainen and Svento (2012)).

Economists have since long advocated pricing schemes that better reflect the availability of electricity, so called real time pricing (RTP). The idea is to let prices vary by hour to inform consumers about current supply and demand, hoping that consumers shift usage from expensive hours (i.e., peak hours) to cheap hours (off-peak hours). In theory, such pricing schemes lead to substantial efficiency gains even if consumers are only modestly price responsive (Borenstein (2005) and Kopsangas-Savolainen and Svento (2012)). However, the practicability of RTP has been questioned (see e.g., Allcott (2011) and Vesterberg and Krishnamurthy (2016)) and, at least in the case of Sweden, households' interest in such contracts seems to be small, with less than one percent of all households on such contracts (Energimarknadsinspektionen, 2014). The issues of peak demand will thus likely remain unsolved, at least in the near future. An important question from a policy perspective is then whether peak demand and the associated costs are expected to be magnified by rising income in the future.

Previous literature suggests that residential electricity usage increases with income, but that the effect is rather small. For example, Parti and Parti (1980) find the elasticity to be 0.15. Krishnamurthy and Kriström (2015) find similar results using OECD data (between 0.05 and 0.12) and also find that income elasticity does not vary across countries. Nesbakken (2001), using Norwegian data, finds the income elasticity to be 0.13 for households with electricity heating and roughly 0.05 – 0.06 for mixed heating. Damsgaard (2003) finds similar results using Swedish data. See also Kristrom (2008) for a review and a comparison with income elasticity of energy in general. The general conclusion to draw from previous studies is that the income effect is rather small, and that results tend to differ substantially depending on e.g., type of data (Kristrom, 2008). Only a few previous studies have provided end-use-specific estimates of the income elasticity. In their seminal paper, Dubin and McFadden (1984) find an income elasticity of 0.02 for space and water heating. Bartels and Fiebig (2000) find annual income elasticities of 0.68 for lighting, 0.26 for water heating and 0.68 for pool pumps. Most previous estimates of income elasticities are based on monthly or annual data. However, understanding the relationship between income and electricity usage at the hourly level is important because demand and supply have to balance at the hourly level. Hence, it is important not only to know whether higher income leads to higher monthly or annual electricity usage but also to understand when consumers increase their use of electricity during a day as their income increases.

Further, understanding how income elasticities of electricity vary between hours and end uses allows policy makers to assess complex policies and marketing strategies that target a specific appliance or end use. Unfortunately, the data required for such an analysis is scarce, and as far as we are aware, no estimates of hourly income elasticities of electricity demand exist, certainly not on the end-use level. Our analysis thus adds to this sparse literature.

In this paper, we estimate hourly and end-use specific income elasticities of residential electricity demand using a seemingly unrelated regression framework. We also explore heterogeneity in income elasticities between income groups, housing types and heating systems. Finally, we explore whether income elasticities differ between cold and warm months.

The rest of this paper is structured as follows. Section 2 describes the data used in this paper, including summary statistics of relevant variables. The estimation framework is presented in Section 3, together with the calculation framework for aggregating from hourly to daily estimates, followed by results in Section 4. Section 5 concludes with a discussion on the implications for peak demand.

2. Data

The data used in this paper originate from a metering project commissioned by the Swedish Energy Agency between 2005 and 2008. The purpose of this project was to increase the quality of data on residential electricity usage, and to assess the potential for energy conservation and increasing energy efficiency. We provide a brief overview of the data here, and refer the reader to the Energy Agency's report (Zimmerman, 2009) for more details. The same data material is used in Vesterberg and Krishnamurthy (2016). In total, 389 households, sampled by Statistics Sweden (see https://www.energimyndigheten.se/Statistik/FESTIS/Elmatning-i-bostader), had metering equipment installed on all appliances that are permanently connected to a wall socket. Appliances such as vacuum cleaners, which are usually not connected, were not included in the metering campaign. Roughly 150 different appliances were metered, with each household having a maximum of 46 appliances metered at a time. In addition, each detached house in the sample had individual recorders for both outdoor and indoor temperature, and both usage and temperature data were recorded at ten-minute intervals. 200 of the metered homes were detached houses, and the remaining were 189 flats, of which 21 flats have missing data on household characteristics and are excluded from our analysis. A majority of the households were located in the Mälardalen region, with only 10 households each located in northern and southern Sweden. Because this is a limited geographical region, the variation in temperature across households is relatively small; however, variation in other household characteristics is substantial. Overall, the rather narrow geographic spread of the sample tends to reduce the external validity of the quantitative results. Nonetheless, provided that households in the rest of Sweden have patterns of behavior which are not very dissimilar, we anticipate that the qualitative results of our analysis will broadly hold.

The metering project was carried out between 2005 and 2008 and each household was metered for between 15 days and 16 months. Fig. 1 illustrates when households were metered. As is evident, roughly 10 to 30 households per month were metered during 2005 and 2006, and 20 to 30 households per month during 2007 and

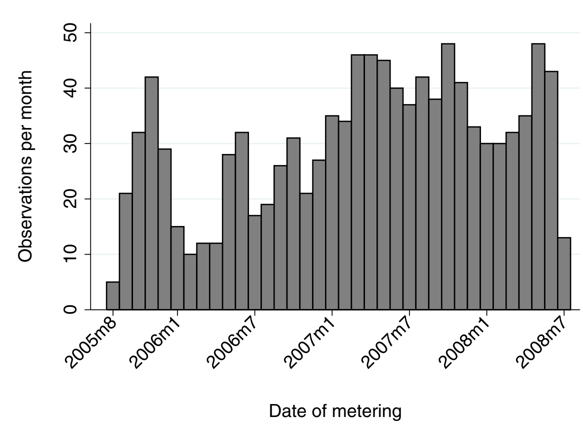

Fig. 1. The distribution of number of households metered across months and years, starting in August 2005 (2005m8).