Households' response to changes in electricity pricing schemes: bridging microeconomic and engineering principles

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Overview

This paper presents a computational take on households' response to price changes. Many studies use assumptions (i.e., price elasticities) that were estimated using historical information; however, if a price change has not been experienced in the past, the response may not be statistically predicted. While other papers have explored price response behavior internally through microeconomic principles, a household's utility is maximized by many factors that affect its electricity use, including the construction of the dwelling, outdoor air temperature, and efficiency of the air conditioner. We have superimposed a physical model, which determines hourly power loads, with a utility maximization component.

The dwelling itself is calibrated to one in Saudi Arabia, but we test households that have various preferences in their utility function, levels of thermal insulation, and income. We further analyze a wide range of electricity pricing schemes; some are progressive tariffs, while one is defined hourly. The extent to which the prices are raised in the alternative schemes has never been experienced in Saudi Arabia. Our analysis shows that households with low electricity preferences exhibit a larger short-run response than would be derived from the aggregate price elasticities estimated statistically. Moreover, improved building insulation affects the household's decision-making process.

Methodology

The residential electricity use model described by Matar (2016) is augmented with a utility equation and a monetary budget constraint. The model produces hourly electricity load demand using the electricity consumption of heating, ventilating, and air conditioning (HVAC) systems as the foundation upon which other end-uses are added. Other end-uses, such as the direct use of lights and appliances, and their associated heat gains, are considered. It simulates the conductive, convective, and radiative heat gains that occur in the envelopes of residences by taking into account outdoor conditions and residence characteristics. The heat gains through the enclosure structure do not occur instantaneously in the model; this is due to the thermal resistance the materials in the structure impose. The required operating level of the HVAC system to achieve some desired indoor air conditions is hence calculated.

Due to non-convex features that a physical model would bring, however, it cannot be directly used within the optimization framework. Thus, we solve the electricity simulation first, then we feed the results into the utility-maximization problem. To do this, we solve for utility for several indoor thermostat set points, and identify the case that maximizes the household's utility. Essentially, we incrementally raise the indoor air temperature until the utility begins to decline. For the time being, only the thermostat set points in the summer, spring, and fall are examined for a price response measure to assess the viability of this methodology. Other behavioral features, like turning off the lights, could be incorporated once the methodology is deemed sound.

The residential model is currently calibrated to a villa in the central region of Saudi Arabia, as described in more detail by Matar (2016), with the current local pricing structure applied to households.

We further examine several electricity pricing designs, ranging from flat tariffs, progressive tariffs, to one that incorporates hourly pricing. If the electricity price is raised to a point where the electricity consumption produced by the physical model is either untenable given the household's income, or producing higher utility when we gradually raise the thermostat set point, we loop back and specify a set point temperature that is higher by half a degree Celsius, and repeat the solution process. The code does this repeatedly until the electricity use and other expenditures can be accommodated by income, and the subsequent values of utility, resulting from the marginally higher indoor temperature, is lower than that of the previous run. If this procedure is triggered, we would have lower electricity use than in the base case. We can then compute the price elasticity, ex-post, for a household with the specified utility function, income, and physical structure.

We adopt a Cobb-Douglas utility function to represent the household's preferences for this demonstration. The household has a choice between electricity use and the consumption of other goods and services; the units of for electricity are annual MWh, whereas others' are dollars spent annually, setting the price of other spending to unity. For the sake of illustration, the electricity expenditure share parameter is varied from 9 to 18 percent of total expenditure. This generalizes a household by using multiple preferences for electricity. The annual household income in thousands of dollars. It has been set to the average household income in Saudi Arabia; however, we also produce Engel curves to look at the effects of income on expenditure.

Results, discussion, and conclusions (more detailed in the full paper)

The base household, living in a dwelling with less effective insulation and has a low preference for electricity, responded with a much greater elasticity than aggregate estimates in the literature show. The short-run price elasticities found in this analysis ranged from -0.05 to -0.35 in the summer and -0.06 to -0.54 in the spring and fall, depending on the price scheme analyzed. It would raise its thermostat set point that varies by pricing scheme, and live in a slightly less thermally comfortable environment, to spend less on electricity. The household living in a more-efficient environment would obviously spend less on electricity to start with, and based on our analysis, higher electricity prices do not alter their decisions; their price elasticity would effectively be zero. This result was not anticipated, but it is intuitive after the fact. Keeping everything else constant, households in residences that have energy efficiency measures in place would not react to a price change as drastically as those that are not as efficient.

The Engel curve dealing with electricity expenditure for a household with a low preference for electricity. Indeed, the results are consistent with intuition; as incomes decline, the household would be more willing to raise the thermostat set-point in order to reduce spending. For the *flat tariff* and *TOU scheme* scenarios, we observe a near-linear trend as income falls from 34,314 to 29,167 thousand dollars per year. In a *doubled progressive tariffs* case, the decline is more rapid at lower income levels. The case in which a household has a higher share of electricity expenditure only shows a reaction for *doubled progressive tariffs* and incomes at 32,600 dollars per year or less. It is a single reduction that is maintained at below that income level.