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A machine-learning based approach to the identification of drivers to price responsiveness

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Time-based electricity pricing for domestic electricity users has been effective in reducing peak consumption and facilitating renewable integration. However, introducing time-based pricing programs is faced with challenges such as high investment in enabling technologies and infrastructure upgrade, costs in marketing and consumer enrolment, price unresponsiveness from large portion of households, and adverse selection.

One way to tackle these problems is by selectively enrolling high-potential users, i.e., those who are most responsive to price changes. However, identifying high-potential users is difficult, as there is no prior information on whether a user will be responsive. Therefore, studies have resorted to selecting several key household characteristics that are likely to make the users responsive. For example, some studies attempt to select the high-potential users by deducing the presence of certain appliances, or by segmenting the load profiles using historical consumption data.

However, very few research studies have attempted to identify the drivers of price responsiveness. Most peak demand studies have investigated the drivers of energy consumption and energy conservation, rather than price responsiveness. For the small number of studies that have examined price responsiveness, they either focus on quantifying price responsiveness; or on investigating the effects of a few factors, such as specific appliances or household income. Existing literature fails to provide a comprehensive account of what drives users' price responsiveness.

This article aims to fill this gap by comprehensively identifying the drivers of domestic users' price responsiveness, thus facilitating the selection of high-potential users. It attempts to address the following questions. First, we want to understand which attributes of household drive price responsiveness during the peak. Second, we want to identify what role price change will play in demand reduction. We first survey the literature on all the potential factors that might influence energy consumption behaviour. Based on these potential factors, the drivers of price responsiveness are then identified, and the role of price is studied. The results can then be used to inform high-potential user selection in large-scale application.

We have adopted a two-step machine learning approach to achieve the research aim. First, using a neural network model to estimate baseline energy consumption, we derive the response to price change for each individual household, and subsequently identify the high-potential households. Second, by applying three advanced variable selection models, we identify the drivers that determine the household's responsiveness to price change. This new two-step approach provides direct and effective identification of high potential households and drivers of price responsiveness.

Our approach departs from traditional methods of studying energy behaviour. First, traditional methods often adopt linear modelling, or a modified linear modelling (for example by adding interaction terms), which may not able to capture the relationship between relevant factors and household energy consumption. Our neural network model allows for learning of complex and non-linear relationship between energy consumption and other factors. Second, traditional variable selection methods, such as direct-testing and step-wise selection, cannot produce stable variable selection results. Our methods combine three machine-learning models with variable selection property, which are able to produce stable results and greatly improve the confidence of selecting the real drivers that determine price responsiveness.

Using the data from the smart meter Time of Use trial in Ireland, our results show that the response of energy users to price changes is affected by various factors including demographic and dwelling characteristics, psychological factors, historical electricity consumption, and appliance ownership. In particular, historical electricity consumption, income, the number of occupants, perceived behavioural control, and adoption of specific appliances, including immersion water heater and dishwasher, are found to be significant drivers of price responsiveness. We also find that a continual price increase within a moderate range does not necessarily elicit stronger demand reduction behaviour than lower price increments. In addition, we observe that there is an intention-behaviour gap, where stated intention does not lead to actual peak reduction behavior.

Our results can provide insights into how to best target users for time-based pricing. We conducted scenario analysis to demonstrate the feasibility and the potential of user selection. Our scenario analysis shows that selecting users based on our results significantly reduces total consumption at peak times.

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