4 Dynamics of Household Electricity Consumption under Time-Of-Use Electricity Pricing

The results from my empirical analysis clearly indicate that under Time-Of-Use (TOU) electricity pricing, residential electricity consumption is driven by various factors, such as the timing when electricity is consumed, daily HDDs, and the magnitude of price increases in the peak rate period. In other words, within-household electricity consumption behavior shows multidimensional dynamics. Based on my empirical ﬁndings, I will discuss the dynamics in detail in the following sections. Furthermore, I will also discuss its policy implications.

4.1 Multidimensional Dynamics of Household Electricity Consumption

4.1.1 Household Consumption Behavior in and near the Peak Rate Period

Exploring participating households’ electricity consumption, following a time sequence around the peak rate period, facilitates comprehending how they adapted to the deployment of TOU electricity pricing more completely. Intuitively, residential consumers can respond to a peak TOU price by conserving their electricity consumption during peaks, leading to an overall reduction in their demand for electricity. Instead of reducing their electricity consumption, they can shift it to oﬀ-peak hours so as not to be subject to the peak rate as much as possible. In this case, the level of their net electricity consumption is maintained. Of course, those two ways of responding to the time-varying price structure can co-occur. Because those two ways of reacting to the time-varying tariﬀ scheme reshape load curves around the peak rate period, it is natural to examine the TOU-tariﬀ-inducing electricity savings as a whole from a time-moving perspective in order to grasp the dynamics of households’ behavioral changes. In the following paragraphs, interpretations of the changes in households’ consumption behavior relevant to each of the two channels of electricity savings are followed by a policy implication suggested through them.

Regarding residential electricity demand for non-temperature-control uses, the leading reaction of the treated households to the TOU tariﬀs was to reduce their heating-irrelevant consumption around the peak rate period. As discussed, to the magnitude of the peak-hour price changes under the TOU program, the not-for-heating electricity savings were directly proportional in the peak rate period while inversely proportional in the pre- and post-peak intervals. In the case of Tariﬀ Group A, although there was almost zero price variation relative to the ﬂat rate in the before- and after-peak intervals, the amount of electricity savings for that group was nearly the same in all three intervals. Meanwhile, despite the price decreases, the remaining tariﬀ groups (maintained or) conserved their consumption in both intervals. In sum, the price changes in the peak rate period caused a spillover eﬀect in those pre- and post-peak intervals: reductions in electricity consumption for non-temperature-control uses. In other words, with respect to non-temperature-control-related electricity consumption, the households allocated to the treatment group responded to the TOU program, on the whole, not through load-shifting but load-shedding.

With respect to temperature-control-use-related household electricity consumption, Figure XYZ depicts that the treated households’ primary response to the TOU program was also load-shedding. The program caused savings in for-heating electricity use during the peak rate period, especially around moderate values of daily HDDs. In the pre-peak interval, heating-associated electricity savings only occurred on days with low temperatures. In the post-peak interval, although high daily HDDs incurred additional electricity consumption after introducing TOU tariﬀs, which might be a consequence of load-shifting or rate decline, its amount was not large enough to oﬀset, for given heating needs in a day, the savings in the preceding intervals.

Measuring the electricity savings of the households in Tariﬀ Group D relative to Tariﬀ Group A validates the load-shedding interpretations. Suppose that for the treated residential consumers, load-shifting is a primary countermeasure against the TOU program. Then residential consumers in Tariﬀ Group D, compared to those in Tariﬀ Group A, had more incentive to reallocate a portion of their electricity consumption to oﬀ-peak hours because they faced a much larger price increase in the peak rate period. So in both near-peak intervals, the savings for Tariﬀ Group D must be signiﬁcantly smaller than those for Tariﬀ Group A. However, Figure XYZ, which shows point estimates obtained by setting Tariﬀ Groups A and D as the control and treatment groups, respectively, does not demonstrate a meaningful diﬀerence between them. That is, load-shifting did not play a role in reshaping households’ load proﬁles in and near the peak rate period.

Going through the curves of the predicted savings related to temperature-control electricity use for the three intervals simultaneously but by taking account of their time sequence suggests a signiﬁcant implication of the eﬀectiveness of the TOU prices in the peak rate period. According to Figure XYZ, as the magnitude of the peak-hour price escalations increases, the temperature-control-related savings in the pre-peak interval expanded proportionally, while those in the peak rate period decreased gradually. Collectively, it is likely that a larger pre-adjustment leads to smaller reductions in electricity demand for heating during peaks, which in turn results in limited additional consumption in the post-peak interval. Considering that the TOU tariﬀs are intended to conserve electricity consumption during the peak rate period, it is inferable that fewer savings caused by too large pre-adjustment deteriorate the performance of the TOU tariﬀs.

4.1.2 Household Consumption Behavior over Daily Heating Degree Days

My empirical results obviously illustrate that the eﬀectiveness of the TOU tariﬀs, as measured by the amount of the induced electricity savings, nonlinearly varies with daily HDDs. As discussed, the total electricity savings caused by the deployment of TOU pricing consists of two elements: the savings from electricity consumption for non-temperature-control uses and those from electricity consumption for temperature-control uses. By deﬁnition, the savings originating from non-for-heating electricity consumption are independent of daily HDDs. Hence, the nonlinearity in the eﬀectiveness of the TOU structures is utterly attributable to the other source of electricity savings, electricity consumption for heating which Figure XYZ conﬁrms.

The nonlinear relationship between the amount of TOU-price-causing electricity savings and daily HDDs indicates an interesting characteristic of the tariﬀ structure: the day-varying eﬀects of TOU pricing on residential electricity consumption. Daily HDDs, one of the critical determinants of for-heating-relevant electricity consumption, ﬂuctuate day by day. Therefore, it is intuitive that in response to daily changing household heating needs, the total amount of TOU-price-inducing electricity savings also alters every day.

The day-varying eﬀectiveness of TOU electricity pricing suggests an implication in connection with Real-Time Pricing (RTP), a type of time-varying electricity tariﬀ structure.[[1]](#footnote-1) Contrary to TOU pricing, rates typically change hourly under RTP. So compared to TOU pricing, RTP has an advantage in reﬂecting generation costs contemporaneously. Economists, therefore, prefer RTP to TOU pricing. But because TOU-tariﬀ-inducing electricity savings covariate with daily HDDs, TOU electricity pricing can somewhat emulate the favorable feature of RTP, especially on days with moderate temperatures. For example, on typical winter days in Ireland, Tariﬀ Group A’s heating-associated electricity savings in the peak rate period were more than half of the total savings under the TOU program. In other words, the time-varying rate structure already induced substantial reductions in electricity consumption according to across-day variations in generation costs, even though there were only within-day price variations under the structure. Consequently, in that case, the additional gains obtained by switching to RTP might not be signiﬁcant as economists have expected.

4.2 Policy Implications

4.2.1 Time-Of-Use Pricing with Additional Dynamics over Daily Heating Degree Days

The U-shaped curve of temperature-control-use-associated electricity savings in the peak rate period is not a desirable feature of TOU pricing. The fundamental intention of the time-varying tariﬀ scheme is to reshape load proﬁles, especially in the peak-demand period, to avoid excessive investment in power generation capacity. So a higher amount of savings in electricity consumption for heating on freezing days (i.e., on days in which the grid is most burdened) serves the purpose of the price scheme. In light of that, the U-shaped evolving pattern of the savings over daily HDDs is unattractive because on days with high heating needs, the price structure induces even less savings in for-heating-relevant household electricity consumption.

An alternative electricity pricing scheme, a TOU-like tariﬀ structure with additional ﬂexibility in price variations across daily HDDs, could address the disadvantage of typical TOU pricing revealed from my analysis (i.e., fewer electricity savings on days with very low temperatures). My empirical ﬁndings illustrate two important relationships between TOU-tariﬀ-inducing electricity savings and the price variations in the peak-demand hours. First, the savings from electricity consumption for non-temperature-control uses are directly proportional to the size of price increases during peaks. Second, raising the magnitude of price changes in the peak rate period somewhat inhibits heating-related electricity savings from disappearing even at a high level of daily HDDs. Those two points collectively imply that scaling up the size of rate changes in the peak rate period as daily HDDs escalate allows for achieving more considerable TOU-price-inducing savings in residential electricity consumption.

Figure XYZ depicts the predicted electricity savings under the alternative pricing scheme. (...)

4.2.2 Home Automation Technologies

As noted in Section XYZ, under the TOU program, households’ adjustments to their consumption behavior for temperature-control electricity use during the pre-peak hours seem to result in fewer savings in the following period (i.e., the peak rate period). In Figure XYZ, the gap in the temperature-control-related savings at given daily HDDs between the lowest and the highest peak-hour rate changes, therefore, might be understood as potentially attainable savings when the pre-adjustments are suppressed. This explanation motivates the necessity of adopting home automation technologies, like Programmable Communicating Thermostats (PCTs), to restrict such adjustments only to the peak rate period. Considering the fact that households generally set a target temperature instead of micromanaging their heating devices according to ever-changing outside temperatures, PCTs with recommended default settings for temperature-control use of electricity are highly likely to contribute to minimizing the behavioral changes before the peak rate period. Moreover, the beneﬁts obtained by utilizing the automated instruments provide legitimacy for the ongoing SEAI-oﬀering Home Energy Grants, in which heating controls are an essential part.[[2]](#footnote-2)

Conﬁning the impact of TOU prices on household electricity consumption for temperature-control uses to the peak rate period by exploiting an automation technology provides more than realizing the potential electricity savings in the period. As discussed in Section 4.1.2, TOU electricity pricing can induce substantially larger electricity savings on days when the temperatures are more extreme and the demand on the grid is higher, even though the rates under the tariﬀ structure do not vary across days. Because an automated system for heating controls causes additional savings in electricity consumption for temperature-control uses during peaks, especially on typical winter days in Ireland, the savings are comparable to those from more granular types of dynamic price schemes.

5 Conclusion

The primary aim of various types of time-varying electricity pricing is to reshape load curves, especially around the peak-demand hours. Under the dynamic pricing of electricity, prices—more precisely, price variations—, which reﬂect instantaneous generation costs, are utilized to incentivize consumers to change their consumption behavior. Therefore, their responsiveness to the price changes in the tariﬀ structures determines whether the time-varying electricity prices, including TOU pricing, will work as intended. In this paper, I quantify how sensitively households adjust their electricity consumption in response to TOU prices in and near the peak rate period. The results from my empirical analysis reveal two interesting points: household electricity consumption, consisting of two categories of electricity use—, non-temperature-control and temperature-control—, 1) sensitively responded to the magnitude of the price changes in the peak rate period, and 2) also depended on daily heating degree days as well as the point electricity was consumed in time for a given rate change. In other words, my empirical analysis discloses the multidimensional dynamics of households’ responses to the TOU tariﬀs.

Those ﬁndings provide important policy implications for TOU electricity pricing. First, along with residential consumers’ high price sensitivity, the nonlinearity in their responses to daily heating needs proposes an alternative pricing scheme: TOU pricing with additional ﬂexibility induced by synchronizing the magnitude of the peak-demand-hour price jumps with daily heating degree days. Second, taking a close look at the relationship between the size of the peak-hour price increases and the savings from electricity consumption for temperature-control uses in chronological order emphasizes the importance of adopting home automation technologies, like Programmable Communicating Thermostats (PCTs), to improve the performance of TOU pricing.

My empirical ﬁndings and the policy implications derived from them ultimately indicate that an integrated understanding of the multidimensional dynamics of households’ responses to TOU electricity pricing is required to make the price structure function with its full potential as a demand management tool. Furthermore, even for stakeholders in the electricity market, such as power generators, regulators, and policymakers, comprehending how electricity consumption reacts to the time-varying pricing is critical because consumers’ behavioral changes are an important piece of information in their decision makings.

1. [Harding and Sexton](#br25) ([2017](#br25)) provides a detailed description of various kinds of time-varying electricity tariﬀ structures. [↑](#footnote-ref-1)
2. Sustainable Energy Authority of Ireland (SEAI) is Ireland’s national sustainable energy authority whose goal is to promote and assist the development of sustainable energy in Ireland. And detailed information about Home Energy Grants is available at <https://www.seai.ie/grants/research-funding/>. [↑](#footnote-ref-2)