3 Empirical Analysis and Results

3.1 Household Average Responses to Time-Of-Use Electricity Pricing

3.1.1 Half-hourly Average Treatment Eﬀects

Utilizing a panel DID identiﬁcation strategy, I ﬁrst measure the impact of the TOU prices on 30-minute-interval household electricity consumption. To obtain the Average Treatment Eﬀect (ATE) for each half-hour interval, I estimate the following speciﬁcation:

kWhitw = βw1[Treatment & Post]it + αiw + γtw + δm + ꢀitw (1)

The term kW hitw is the electricity consumption by household i on the day t during the half-hourly time window w. The indicator variable 1[Treatment & Post]it is equal to 1 only if household i is in the treatment group and the day t is in the treatment period. The terms αiw, γtw, and δm are household-by-half-hourly-interval, day-of-sample-by-half-hourly-time-window, and month-of-year ﬁxed eﬀects, respectively. In the speciﬁcation, the point estimates of βw, representing the ATE for each 30-minute interval w, are the parameters of interest. I cluster the standard errors at the household and the day of experiment levels to correct for serial correlation.

Figure [6](#br29) summarizes the estimated ATEs in the form of a time proﬁle. As already demonstrated in [Prest](#br45) ([2020](#br45)), peak hours (i.e., from 5:00 p.m. to 7:00 p.m.), during which the ineﬃciency of ﬁxed ﬂat rate tariﬀ is greatly intensiﬁed, show dominant electricity savings. Although household electricity consumption altered considerably in two-hour-length intervals just before and after the peak rate period (i.e., from 3:00 p.m. to 5:00 p.m. and from 7:00 p.m. to 9:00 p.m., respectively), the TOU prices are unlikely to provoke signiﬁcant changes in households’ consumption behavior, except the immediate meter-reading period, in the intervals. But it is diﬃcult to believe that the participating households managed their electricity consumption precisely along with the price increases in the peak rate period. Rather, it is more likely that they preemptively adjusted their consumption behavior in the hours leading up to and following the peak rate period. For this reason, in the following empirical analysis, I continually focus on household electricity demand responses to the time-varying prices in the three intervals.

3.1.2 Hourly Average Treatment Eﬀects around the Peak Rate Period

Estimating by-tariﬀ-group ATEs around the peak rate period allows us to justify whether or not the law of demand is satisﬁed between the responsiveness of Irish households and the magnitudes of price changes in TOU electricity pricing.[[1]](#footnote-1) To do so, I run the following regression for each of the four tariﬀ groups:

kWhith = βp1[Treatment & Post]it + αiw + γtw + δm + ꢀith (2)

Excepting the dependent variable and the parameter of interest, the econometric model above is the same as ([1](#br14)). Speciﬁcally, the response variable kW hith, which means the electricity consumption by household i on the day t during the hour of the day h, is utilized due to its better accessibility in interpretation. The point estimates of βp indicate the ATE for each of the two-hour-length intervals included in rate period p. Table [4](#br37) summarizes the regression results.

The measured peak-rate-period ATEs re-conﬁrm the ﬁnding suggested in [Prest](#br45) ([2020](#br45)): a critical determinant of the eﬀectiveness of TOU electricity pricing in the peak rate period is nothing more than its existence. As demonstrated in Table [4](#br37), the estimated ATEs for the peak-demand hours generally follow the law of demand. In other words, the reductions in household demand for electricity in the peak rate period grow with the degree of price changes in that period. But the marginal gain of the time-varying price structure is diminishing.

Interestingly, the law of demand does not hold in both the pre- and post-peak intervals. In spite of the price drops in those intervals, compared to the ﬂat rate of 14.1 cents per kWh, the treated households reduced their electricity consumption. Although the mechanism that caused the changes in residential electricity consumption is not explicit, such changes evidently suggest that the households assigned to the treatment group adjusted their electricity consumption not only prior to but also following the price spikes in the peak rate period. That is, the TOU tariﬀs have some spillover eﬀects on household demand for electricity in the oﬀ-peak intervals.

The results discussed above collectively imply that in and near peak-demand hours, at least one of the two distinct channels of electricity consumption from TOU pricing, temperature-control- and non-temperature-control-related electricity consumption, is driven by the magnitude of tariﬀ changes in the peak rate period. Motivated by this implication, the relative responsiveness of the two broad categories of electricity consumption to the TOU tariﬀ structures is quantiﬁed in the following section.

3.2 Breakdown of Household Responses to Time-Of-Use Electricity Pricing

3.2.1 Breakdown of Household Responses around the Peak Rate Period

I decompose TOU-tariﬀ-causing reductions in household electricity consumption around the peak rate period into two parts to determine the share of electricity savings stemming from two distinct sources: non-temperature-control-driven and temperature-control-driven consumption. Here, the non-temperature-control-related electricity savings mean the reductions in electricity demand that are stably achievable regardless of each day’s weather conditions, especially temperatures. That is, the savings associated with non-temperature-control electricity use do not vary across days. On the contrary, the changes related to temperature-control use of electricity strictly depend on daily HDDs, which ﬂuctuate daily. Speciﬁcally, temperature-control-associated electricity savings are additional savings that appear only on days with non-zero daily HDDs due to for-heating electricity consumption in households. Isolating the impact of the TOU prices on household electricity demand for temperature-control use from the total reductions in electricity demand enables us to know how diﬀerently the TOU tariﬀ structures function on the broad types of electricity use from day to day, whose implications will be discussed later.

To break down household responses to the TOU program around the peak rate period, I exploit the following DID-style spline regression model:

kW hith = β1HDDt + β2HDD∗

t

+ β31[Treatment]i + β4HDDt1[Treatment]i + β5HDD∗t 1[Treatment]i

+ β61[Post]t + β7HDDt1[Post]t + β8HDD∗t 1[Post]t

+ β91[Treatment & Post]it + β10HDDt1[Treatment & Post]it

+ β11HDD∗t 1[Treatment & Post]it+ αdw + ꢀith. (3)

Like ([2](#br14)), the dependent variable kW hith is the electricity consumption by household i on the day t during the hour of the day h. There are three indicator variables in the model: the ﬁrst indicator variable 1[Treatment]i has the value of 1 if household i is assigned to the treatment group; the second indicator variable 1[Post]t equals 1 when the day t is in the treatment period; the last indicator variable 1[Treatment & Post]it is equal to 1 only for treatment households in the treatment period. The model also includes interaction terms between HDD-relevant terms and those indicator variables. In the econometric model, HDDt means the daily heating degree days on the day t. And HDD∗t is required to introduce nonlinearity in HDD-associated response to TOU pricing.[[2]](#footnote-2) The terms αiw, γdw, and δmw are household-by-half-hourly-time-window, day-of-week-by-half-hourly-time-window and month-of-year-by-half-hourly-time-window ﬁxed eﬀects, respectively.

The primary coeﬃcients of interest in ([3](#br16)) are β9, β10, and β11. The three coeﬃcients show how much electricity consumption the households assigned to the treatment group reduced after deploying the TOU program compared to those in the control group. To be speciﬁc, β9 demonstrates the change in residential electricity consumption for non-for-heating use. Both β10 and β11 collectively mean the changes in electricity consumed to satisfy household heating needs at given daily HDDs.

Using the point estimates of the three coeﬃcients of interest provided in Table [5](#br38), I graphically summarize the predicted reductions from each of the two categories of electricity consumption in Figure [7](#br30). Regarding the savings in electricity consumption for non-temperature-control use, which are independent of weather conditions, the table and ﬁgure clearly show that the treated households signiﬁcantly reduced their consumption when they were subject to peak-hour prices. Their non-for-heating electricity consumption also decreased in both pre- and post-peak intervals, albeit noisy and relatively smaller in magnitude. The changes in temperature-control-use-associated electricity consumption occurred as well in all three intervals, but its evolving pattern over daily HDDs was quite diﬀerent in each interval. Speciﬁcally, the impact of TOU pricing on residential electricity consumption for heating is U-shaped in the peak rate period, while it is salient only when daily HDDs are suﬃciently large in the two oﬀ-peak intervals. In other words, from the ﬁgure, it is evident that the savings originating from for-heating-purpose household electricity consumption are a nonlinear function of daily HDDs in all three intervals.

The speciﬁcation ([3](#br16)) is also utilized to examine, during the peak rate period, the relationship between the degree of price increases and the electricity savings. The by-tariﬀ-group estimates of the coeﬃcients of interest are presented in Table [5](#br38). As shown in the table, on the whole, the savings from electricity demand for non-temperature-control use tend to be proportional to the size of price risings in peak hours. Moreover, the marginally diminishing eﬀects of TOU pricing, discussed in [Prest](#br45) ([2020](#br45)), seem not to be championed by my point estimates. And the two estimates associated with temperature-control-use-related electricity savings (i.e., βˆ10 and βˆ11) are statistically signiﬁcant only for the case of the smallest price increase (i.e., only for the Tariﬀ Group A). Jointly, those ﬁndings imply two points. First, household reaction to the TOU prices in peak hours diﬀers in non-temperature-control-driven and temperature-control-driven consumption. Second, the savings from non-for-heating electricity consumption do not behave as expected from the previous study. Inspired by those implications, I formulate the resulting variations in household electricity consumption as a linear function of the magnitude of rate changes in the peak-demand hours in the following section.

3.2.2 Around-Peak-Rate-Period Household Responses as a Linear Function of Price Changes

To fully understand how residential consumers adjust their electricity consumption behavior as a set of reactions to the price changes in and near the peak rate period under the TOU price structures, it is necessary to examine the relationship between the size of price increases in the peak rate period and the electricity savings from each of the two distinct channels of consumption for diﬀerent points in time where electricity is consumed. For that reason, I quantitatively determine the relationship by utilizing the following econometric model:

kW hith = β1HDDt + β2HDD∗

t

+ β31[Treatment]i + β41[Treatment]i∆RCi

+ β5HDDt1[Treatment]i + β6HDDt1[Treatment]i∆RCi

|  |  |  |  |
| --- | --- | --- | --- |
|  | + β7HDDt∗1[Treatment]i + β8HDDt∗1[Treatment]i∆RCi  + β91[Post]t + β10HDDt1[Post]t + β11HDD∗t 1[Post]t |  | (5) |

+ β121[Treatment & Post]it + β131[Treatment & Post]i∆RCi

+ β14HDDt1[Treatment & Post]it + β15HDDt1[Treatment & Post]i∆RCi

+ β16HDDt∗1[Treatment & Post]it + β17HDDt∗1[Treatment & Post]i∆RCi + αdw + ꢀith

The model is the same with ([3](#br16)) except for interaction terms between treatment-status-relevant indicator variables (i.e., 1[Treatment]i and 1[Treatment & Post]it) and ∆RCi, where ∆RCi is the diﬀerence between the peak-hour prices in the treatment period and the ﬂat rate in the baseline period. The coeﬃcients of those interaction terms capture the impacts of deploying the TOU tariﬀs on household electricity consumption as a linear function of the degree of peak-demand-hour price changes.

The estimates of the six coeﬃcients of interest (i.e., from β12 to β17) presented in Table [6](#br39) are summarized graphically in Figure [8](#br31). And this ﬁgure, showing estimated treatment eﬀects and predicted electricity savings for each of the three intervals, re-conﬁrms the ﬁnding of price insensitivity in [Prest](#br45) ([2020](#br45)).

In the peak rate period, the non-temperature-control-associated savings increased as the magnitude of rate changes grew. On the contrary, at given daily HDDs, the temperature-control-associated savings, illustrating HDD-varying U-shaped proﬁle, weakly reduced as the size of peak-demand-hour tariﬀ changes increased. As shown in the ﬁgure clearly, the diﬀerences in the predicted electricity savings over the degree of price changes are apparent when the savings stemming from the two distinct sources are examined individually. However, due to the opposite correlations, the diﬀerences for given HDDs are seemingly dampened when the savings are aggregated. Indeed, this empirical result is consistent with the ﬁnding discussed in the previous work that households were unusually insensitive to the size of the price changes in the peak rate period.

The opposite order in estimated treatment eﬀects between the two sources of electricity savings also holds in the two-hour-length pre-peak interval, although in a contrary manner. The interval shows more signiﬁcant savings from electricity consumption for temperature-control use for a more minor change in peak-hour price. By contrast, the variations in non-temperature-control-related electricity consumption caused by TOU prices exhibit an inverse relationship with the price changes in the peak rate period. For the same reason, the aggregated treatment eﬀects of the TOU tariﬀs are seemingly less sensitive to prices. Note that regarding the electricity consumption for heating, the TOU tariﬀs played a role only when outdoor temperatures were suﬃciently low.

Residential consumers adjust their electricity consumption behavior during the two-hour-length post-peak period as well. As in the pre-peak interval, the savings stemming from non-for-heating electricity use increased as the size of peak-demand-hour rate changes diminished. In the case of electricity consumption for heating, the TOU program provoked additional consumption in that interval, especially on freezing days. The amount of the added for-heating-relevant household electricity consumption increased as the price variations in the peak-hour interval diminished. Therefore, the resulting treatment eﬀects (i.e., the aggregated treatment eﬀects) also agree with the ﬁnding of price insensitivity in the previous work.

In summary, under TOU pricing, the level of price changes, not merely its existence, still matters to residential consumers. The empirical results above suggest that the opposite order in estimated treatment eﬀects between non-temperature- and temperature-control uses of electricity makes Irish households appear to violate the law of demand. In other words, due to the opposite order, their high sensitivity to the TOU prices is revealed only when household electricity consumption is disaggregated into the two distinct categories of electricity consumption. Together with the empirical ﬁndings in previous sections, the results imply that three simultaneously interacting factors govern the dynamics of residential electricity consumption under TOU pricing: the timing when electricity is consumed, daily HDDs, and the magnitude of price increases in the peak rate period.

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 surrounding 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 broad categories of electricity use are followed by policy implications drawn from them in the subsequent sections.

Regarding residential electricity demand for non-temperature-control use, the leading reaction of the treated households to the TOU tariﬀs was to reduce their heating-irrelevant consumption around the peak rate period. According to my empirical analysis, as the magnitude of the peak-hour price changes under the TOU program grew, the savings from the not-for-heating electricity use increased, while it diminished 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 (i.e., only 0.1 cents per kWh) 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-driven electricity consumption, the households allocated to the treatment group responded to the TOU program, on the whole, via not load-shifting but load-shedding.

With respect to temperature-control-use-related household electricity consumption, Figure [8](#br31) 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 the 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 [9](#br32), 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 in the two intervals. 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 [8](#br31), as the magnitude of the peak-hour price escalations increased, the temperature-control-related electricity savings in the pre-peak interval expanded, 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 use and those from electricity consumption for temperature-control use. 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 type of electricity consumption, that for heating which Figure [8](#br31) 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 temperature-control-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.[[3]](#footnote-3) 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 price 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 use become larger as the size of price escalation during peak hours increases. Second, raising the magnitude of price change 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 aggregate savings in residential electricity consumption.

Figure [10](#br33) depicts additional electricity savings under an alternative pricing scheme. In the pricing scheme, the peak-demand-hour price jumps as household heating needs become serious. Speciﬁcally, under the alternative pricing demonstrated in the ﬁgure, every time daily HDDs rise by 5, the size of rate change in the peak rate period, which is evenly 6 cents per kWh before the daily HDDs where typical TOU pricing becomes ineﬀective, increases by 6 cents per kW h. As illustrated in the ﬁgure, compared to the case in which the size of peak-hour price growth is ﬁxed at 6 cents, the alternative price scheme can induce additional savings in household electricity consumption, which are highlighted by using three diﬀerent colors in the ﬁgure.

4.2.2 Home Automation Technologies

As noted in Section [4.1.1](#br19), 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 [8](#br31), 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 outdoor 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.[[4]](#footnote-4) 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.[[5]](#footnote-5)

Conﬁning the impact of TOU prices on household electricity consumption for temperature-control use 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 use 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-driven and temperature-control-driven consumption—, 1) sensitively responded to the magnitude of the price change 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 jump with daily heating degree days. Second, taking a close look at the relationship between the size of the peak-hour price increase and the changes in 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, investors, 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. In this paper, the eﬀects of four diﬀerent information stimuli on household electricity consumption are not of interest. [Pon](#br45) ([2017](#br45)) studied the eﬀects in detail using the same datasets. [↑](#footnote-ref-1)
2. Mathematically, HDDt∗ is deﬁned as follows:

   HDD∗t = (HDDt − Knot) × 1[HDDt > Knot], (4)

   where Knot is a reference value at which the slope of the predicted line starts to change. [↑](#footnote-ref-2)
3. [Harding and Sexton](#br45) ([2017](#br45)) provides a detailed description of various kinds of time-varying electricity tariﬀ structures. [↑](#footnote-ref-3)
4. [Fowlie et al.](#br44) ([2021](#br44)) examines default eﬀects in a randomized controlled trial, in which the participants assigned to the control group defaulted into a residential electricity pricing program. Default eﬀects have been studied in a range of settings, such as organ donation ([Johnson and Goldstein](#br45), [2003](#br45); [Abadie and Gay](#br44), [2006](#br44)), car insurance ([Johnson et al.](#br45), [1993](#br45)), and participation in retirement savings plans ([Samuelson and Zeckhauser](#br45), [1988](#br45); [Madrian and Shea](#br45), [2001](#br45); [Choi et al.](#br44), [2019](#br44)). [↑](#footnote-ref-4)
5. 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-5)