# Average Responses to Time-of-Use Prices

**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:

[Econometric Specification]

The term $kWh\_{itw}$ is the electricity consumption by household $i$ on the day $t$ during the half-hourly time window $w$. The indicator variable $\mathbb{1}\big[ \text{Treatment \& Post} \big]\_{it}$ is equal to 1 only if household $i$ is in the treatment group and the day $t$ is in the treatment period. The terms $\alpha\_{iw}$, $\gamma\_{tw}$, and $\delta\_{m}$ 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 $\beta\_{w}$, 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 \ref{Figure:Half-Hourly-Average-Treatment-Effects} summarizes the estimated ATEs in the form of a time profile. As already demonstrated in \cite{Peaking-Interest:How-Awareness-Drives-the-Effectiveness-of-Time-of-Use-Electricity-Pricing\_Prest\_2020}, peak hours (i.e., from 5:00 p.m. to 7:00 p.m.) show dominant electricity savings. The figure also demonstrates reductions in household electricity consumption not only in most of the meter readings prior to the peak rate period but also in three successive meter readings right after the period, even though the reductions, with two exceptions, are not statistically significant. The insignificant reductions in household electricity consumption are interesting because TOU prices in off-peak hours (i.e., prices in the night and day rate periods) were lower than the flat rate in the baseline period. The counterintuitive changes might indicate that households preemptively adjusted their consumption behavior to avoid the incident of paying higher prices. In other words, the peak-hour price increases under the TOU program were likely to cause some spillover effects in the hours leading up to and following the peak rate period. To explore whether households responded to the TOU program outside of the peak rate period as well or not, in the following empirical analysis, I will also pay attention to the off-peak hours, particularly the hours surrounding the peak rate period.

## Hourly Average Treatment Effects around the Peak Rate Period

Estimating by-tariff-group ATEs in and near the peak rate period allows understanding how the relationship between the degree of change in household electricity consumption and the magnitude of a peak-demand-hour price increase evolves in and near the peak rate period.\footnote{In this paper, the effects of four different information stimuli on household electricity consumption are not of interest. \cite{The-Effect-of-Information-on-TOU-Electricity-Use:An-Irish-Residential-Study\_Pon\_2017} studied the effects in detail using the same datasets.} To do so, I run the following regression for each of the four tariff groups:

[MODEL2]

Excepting the dependent variable and the parameter of interest, the econometric model above is the same as (\ref{Eq:Model-Specification\_Half-Hourly-Average-Treatment-Effects}). Specifically, the response variable $kWh\_{ith}$, 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 $\beta\_{p}$ indicate the ATE for each of the three intervals included in rate period $p$. Table \ref{Table:Hourly-Average-Treatment-Effects-in-and-near-the-Peak-Rate-Period} summarizes the regression results.

The measured ATEs for the peak rate period re-confirm the finding provided in \cite{Peaking-Interest:How-Awareness-Drives-the-Effectiveness-of-Time-of-Use-Electricity-Pricing\_Prest\_2020}.\footnote{See Figure 6 in \cite{Peaking-Interest:How-Awareness-Drives-the-Effectiveness-of-Time-of-Use-Electricity-Pricing\_Prest\_2020}.} The table clearly shows that within-household aggregate demand for electricity during the peak rate period declined, with a significance level of 0.01, due to the deployment of TOU pricing. However, based on the point estimates for the four tariff groups, it is unclear whether an incremental change in peak-rate-period price increase induces a statistically meaningful additional change in household electricity consumption or not.

To quantify how residential consumers responded to the TOU program in off-peak hours close to the peak rate period, I also estimate ATEs in periods of two hours before and after the peak rate period (i.e., in pre- and post-peak periods). Interestingly, the table also demonstrates that in the pre- and post-peak periods, the implementation of the TOU tariff structures resulted in reductions in household electricity consumption, which are statistically different from zero, even though TOU prices were lower than the flat rate of 14.1 cents per kWh.\footnote{Even insignificant point estimates (i.e., point estimates for Tariff Groups C and D in the pre-peak interval and Tariff Group C in the post-peak interval) have negative values.} The reductions in both periods surrounding the peak hours suggest that the impact of the price increases in the peak rate period overtook the impact of the price drops in each off-peak period. Therefore, in the following empirical analysis, I will focus on linking household electricity consumption in the pre- and post-peak periods with the price increases in the peak rate period, instead of the price decreases in those off-peak periods.