# 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:

[MODEL]

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.), during which the inefficiency of fixed flat rate tariff is greatly intensified, show dominant electricity savings. The figure also shows reductions in household electricity consumption in intervals of two hours before and two hours after the peak rate period (i.e., the pre-peak interval from 3:00 p.m. to 5:00 p.m. and the post-peak interval from 7:00 p.m. to 9:00 p.m., respectively), even though the reductions are not statistically significant, except for the immediate meter-reading after the peak period. The insignificant changes 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. In both two-hour intervals, the counterintuitive changes might indicate that households adjusted their consumption behavior to avoid the incident of paying higher prices absolutely. In other words, the peak-hour price increases under the TOU tariff structures were likely to cause some spillover effects in the hours leading up to and following the peak rate period. For this reason, in the following empirical analysis, the focus is on household electricity demand responses to the time-varying prices at the three intervals.

## Hourly Average Treatment Effects around the Peak Rate Period

Estimating by-tariff-group ATEs in and near the peak rate period allows us to understand how different the relationship between the size of changes in household electricity consumption and the magnitude of the peak-hour price increases is in the three intervals of two hours (i.e., the pre-peak, peak, and post-peak intervals).\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}.} As demonstrated in the table, household demand for electricity during the peak rate period tends to decline with the degree of price increases in that period, even though the point estimate for Tariff Group C is an exception. Moreover, the marginal gain of the peak-rate-period price increases under the TOU program is clearly diminishing.

Interestingly, the table also shows that the implementation of the TOU tariff structures resulted in reductions in household electricity consumption, which are statistically different from zero, even when TOU prices were lower than the flat rate of 14.1 cents per kWh in the pre- and post-peak intervals.\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 off-peak intervals suggest that the impact of the price increases in the peak rate period overtook the impact of the price drops in those off-peak intervals. Therefore, in the following empirical analysis, I will focus on linking household electricity consumption in the pre- and post-peak intervals with the price increases in the peak rate period, instead of the price decreases in those intervals. Note that it is difficult to find any evident correlation between the point estimates in the two intervals and the magnitude of the peak-rate-period price increases.