# 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:

[MODEL1]

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. 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 variations during the peak rate period. It is rather likely that they adjusted their consumption behavior in and near peak hours. 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 of two hours.

## 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.\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, as the response variable, $kWh\_{ith}$ that 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 two-hour-length intervals included in rate period $p$. Table \ref{Table:Average-Treatment-Effects-in-the-Peak-Rate-Period} summarizes the regression results.

The measured peak-rate-period ATEs re-confirm the finding suggested in \cite{Peaking-Interest:How-Awareness-Drives-the-Effectiveness-of-Time-of-Use-Electricity-Pricing\_Prest\_2020}: 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 \ref{Table:Average-Treatment-Effects-in-the-Peak-Rate-Period}, 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 sources of electricity savings 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 drivers of electricity savings to the TOU tariff structures is quantified in the following section.