ELECTRICITY RETAIL RATE DESIGN IN A DECARBONIZING ECONOMY: AN ANALYSIS OF TIME-OF-USE AND CRITICAL PEAK PRICING

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Overview and motivation

Currently, only a few, often bigger consumers, are directly active in electricity forward and wholesale markets. For most end users the interface between the supply and demand-side is the retail rate. Traditionally, electricity retail rates have been mostly flat, i.e., a constant price per kWh of electricity consumed. The flat rate reflects the average cost of electricity supply. Important developments on both the supply and demand-side have led to an increased importance of retail rate design. On the supply side, the share of intermittent renewable generation in the power mix is rising in many countries. This change in the supply mix leads to more volatility in power prices and more value that can be derived from demand flexibility. On the demand side, opportunities for end-users to better manage their electricity consumption are significantly increasing, enabled by digitalisation and the adoption of electric vehicles, heat pumps, stationary batteries, and other controllable loads. In theory, optimally, end users are exposed to changing system conditions by having the retail rate passing-through hourly wholesale prices (Borenstein and Holland, 2005). Such rates are often called real-time pricing (RTP). In practice, even though RTP is technically feasible via the adoption of smart meters, many consumers do not want to be directly exposed to the inherently volatile wholesale prices. Especially the occurrence of very high price events creates acceptability issues, this is evidenced by the Texas energy crisis in February 2021 and the EU energy price crisis that has been ongoing since the Summer of 2021.

In this paper, we analyse how well alternative electricity rate designs, acting as a sort of intermediary between flat rates and RTP, can reflect wholesale electricity prices and incentivize valuable load shifting and shedding. Trabish (2022) reports that there were over 150 rate design policy initiatives in 2021 addressing new forms of time-varying rate structures in the United States (US). We focus on two popular rate designs of such kind: time-of-use rates (TOU) and critical peak pricing (CPP). TOU rates are predefined, e.g., a year ahead, and calibrated on historical price data. Typically, the rates are differentiated based on seasons, type of day (workdays or weekends), and time of the day (so-called peak, shoulder, or off-peak hours). The idea behind TOU rates is that consumers are to a certain extent exposed to the time-varying conditions in wholesale electricity markets while the rates are kept predictable, and consumers are protected from unexpected price shocks. CPP are specifically designed to address the costs associated with the highest net demand days of the year. At moment of tight system conditions, the system operator announces on a short notice, e.g., day-ahead, a critical peak pricing event. The maximum number of price events per year is predefined. As a compensation to partake in a CPP program, consumers often receive a discount on their regular rate.

The large majority of research on alternative rates has focussed on how consumers respond to time-varying rates (other than flat rates), i.e. the imperfection of the consumer response. Faruqui & Sergici (2013) provide an extensive survey of global experiences with consumer responses to time-varying rates, reviewing the results of 34 studies encompassing 163 experimental treatments in four continents and seven countries. Few academics have investigated the link between wholesale prices and TOU tariffs, i.e., the imperfection of the proxy. These authors emphasize that TOU rates only capture a small fraction of welfare benefits when compared RTP (Borenstein, 2005; Holland & Mansur, 2006; Spees & Lave, 2008; Hogan, 2014; Jacobsen et al., 2020). The main argument is that TOU rates are not dynamic enough the capture the sudden price spikes in which most value lies that can be derived from demand-side flexibility. Because of that reason, CPP is generally considered a more efficient "second best" (Blonz, 2022).

Considering the accelerating trend of electrification of heating and transport, an important reality that the existing literature has disregarded so far is that a large fraction of demand flexibility, especially at household level, is expected to come in the form of frequent within-day(s) "load shifting", or even, "appliance scheduling" (CPUC, 2022). Frequent within-day load shifting has very different properties than adjustments in load in independent hours conditional to changes in the magnitude of hourly prices. More precisely, in the case of within-day load shifting, relative price differences between hours are more important than absolute price differences. In addition, the existing literature also considers mostly thermal-based systems, while with more RES penetration, among other effects, the intra-day volatility of prices is increasing, making frequent within-day shifting more valuable than before. We argue that in such context the potential of TOU to induce valuable load shifting is not well captured by the existing literature. We also investigate the effectiveness of combining TOU with CPP.

Methods and data

We introduce two groups of methods: time series analysis and simulation models. Regarding the former, as in the literature (Hogan, 2014; Jacobsen et al., 2020), we compute Pearson correlations between RTP and TOU rates. We also propose the Spearman rank correlation between both price series as a more accurate metric when thinking about frequent within-day load shifting. We also evaluate both metrics with and without the consideration of scarcity prices to estimate the impact of CPP. Regarding the latter, we build a simulation model in which load is represented with a linear demand function (as in Borenstein, 2005; Holland & Mansur, 2006; Spees & Lave, 2008) and, as an alternative, consider load scheduling, modelled by an optimization considering scheduling constraints of flexible load. We proxy the impact of TOU combined with CPP by passing-through a limited number of scarcity prices.

We compute all metrics using data from three different power systems in the US (ERCOT, CAISO and ISONE) for a period between 2011-2020. ERCOT has a high penetration of wind, CAISO has a high penetration of solar PV, while ISONE does not have significant penetration of intermittent renewables. We test several TOU designs, which differ seasonally and per day-type. The within-day varying time blocks (peak, off-peak,..) are based both on real-world rates and a partitioning algorithm by Yang et al. (2019). We calibrate the magnitude of the rates using a linear regression with the coefficients being dummies representing the different fixed time blocks (Jacobsen et al., 2020). We evaluate the performance of the TOU rates (combined or not with CPP) by calculating our metrics of interest using the TOU rates calibrated on historical data (wholesale prices of Y-1 to Y-3) and unseen test using data (wholesale prices of Y).

Results

The time series analysis confirms that the out-of-sample Pearson correlations between TOU tariffs and wholesale prices are low (typically <0.4) but show that these significantly improve when passing-through a limited number of scarcity prices, indicating the usefulness of CPP. We find that out-of-sample Spearman rank correlations of TOU rates and wholesale prices are relatively high (typically >0.8) and that rank correlations are especially high during summer when load is highest. These results give an indication that, conditional upon power system characteristics and their specific design, TOU tariffs can lead to a high proportion of the valuable load shifting volumes, while an additional well-targeted CPP program can capture the value of demand shedding during scarcity moments. We further confirm and illustrate these findings by the simulations with the different representations of the demand-side.

Conclusions and future work

Our conclusion is that TOU rates, especially when thoughtfully designed and accompanied with a well-targeted CPP program, are more recommendable than the existing literature suggests. We recommend the acceleration of the adoption of TOU rates accompanied by CPP as a valuable intermediate step towards more efficient electricity retail rates that balance efficiency considerations and consumer/political pressures for bill stability. We see three avenues of future research. First, so far, we have evaluated the performance of TOU rates by analysing their performance versus out-of-sample wholesale prices. However, the metric we are really interested in is the welfare implications of having imperfect retail rates. Second, we are interested in doing the same analysis for existing or simulated power systems with higher penetration of intermittent renewables and storage. It could be in such systems our findings do not hold anymore as price profiles become highly unpredictable. Third, we want to investigate more advanced retail rate plans that find a right balance between better reflecting wholesale prices while limiting electricity bill volatility, examples are RTP accompanied with insurance schemes or load profile hedges.

References

Blonz, J.A., 2022. Making the Best of the Second-Best: Welfare Consequences of Time-Varying Electricity Prices. J. Assoc. Environ. Resour. Econ.

Borenstein, S., 2005. The Long-Run Efficiency of Real-Time Electricity Pricing. Energy J. 26, 93–116.

Borenstein, S., Holland, S., 2005. On the Efficiency of Competitive Electricity Markets with Time-Invariant Retail Prices. RAND J. Econ. 36, 469–493.

CPUC, 2022. Advanced strategies for demand flexibility management and DER customer compensation.

Faruqui, A., Sergici, S., 2013. Arcturus : International Evidence on Dynamic Pricing. Electr. J. 26, 55–65.

Hogan, W.W., 2014. Time-of-use rates and real-time prices 1–8.

Holland, S.P., Mansur, E.T., 2006. The Short-Run Effects of Time-Varying Prices in Competitive Electricity Markets. Energy J. 27, 127–155.

Jacobsen, M.R., Knittel, C.R., Sallee, J.M., Van Benthem, A.A., 2020. The use of regression statistics to analyze imperfect pricing policies. J. Polit. Econ. 128, 1826–1876. https://doi.org/10.1086/705553

Spees, K., Lave, L., 2008. Impacts of Responsive Load in PJM : Load Shifting and RTP. Energy J. 29, 101–121.

Trabish, H.K., 2022. Outlook: A new recognition is coming of rate design's critical role in the energy transition [WWW Document]. Publ. Jan. 19, 2022, Util. Dive. URL https://www.utilitydive.com/news/2022-outlook-a-new-recognition-is-coming-of-rate-designs-critical-role-in/611756/

Yang, H., Wang, L., Zhang, Y., Tai, H.M., Ma, Y., Zhou, M., 2019. Reliability evaluation of power system considering time of use electricity pricing. IEEE Trans. Power Syst. 34, 1991–2002.