HOW DOES DISTRIBUTED GENERATION AFFECT ECONOMIC EFFICIENCY IN ELECTRICITY TARIFFS?

Mohammad Ansarin; Rotterdam School of Management, Erasmus University, Netherlands; ansarin@rsm.nl
Yashar Ghiassi-Farrokhfal; Rotterdam School of Management, Erasmus University, Netherlands; y.ghiassi@rsm.nl
Wolfgang Ketter; University of Cologne, Germany; ketter@wiso.uni-koeln.de
John Collins; University of Minnesota, MN, United States; jcollins@cs.umn.edu

Overview

Distributed renewable energy sources (D-RES) are rapidly expanding in many regions. This growth is mostly intended to displace shrinking electricity generation from fossil fuels and other pollutant sources. However, electricity tariffs, the common method for pricing residential electricity consumption, have been designed for passive subscribers with no generation units. These tariffs were designed with specific goals in mind, one of which is economic efficiency (Reneses and Ortega 2014). This goal may be significantly impacted as D-RES increases (Borenstein 2016). Multiple new tariffs have been proposed for a high-DRES application, but their economic efficiency has not been previously considered or compared quantitatively with traditional tariffs.

In this paper, we study these economic ineffiencies for multiple commonly-used and -discussed tariffs in the renewable energy era. We vary residential D-RES generation, then calculate economic inefficiency per tariff as consumption dead-weight loss, similar to that done for energy fuel subsidies by (Davis 2017). Our quantitative results are based on per-minute household data from Austin, TX, USA, for the full year of 2016. We find that tariffs differ greatly in how sensitive their deadweight loss is to D-RES generation changes. Particularly poor are the economic efficiencies of flat-rate and increasing-block pricing tariffs. When elasticity is high, a demand charge tariff falls behind these two traditional tariffs in economic efficiency. Similar to studies without D-RES (e.g. (Burger et al. 2019), household demand elasticity appears to be a strong influencer of dead-weight loss.

Methods

We chose multiple tariffs, picked as representative cases for the many tariff mechanisms possible in the design space. Summarized in Table 1, these tariffs represent traditional designs (Flat-rate tariff), the status quo[1] (increased block pricing, i.e. Conventional tariff), and three commonly-debated proposals for change (Real-Time Pricing, Two-Tier Time-of-Use pricing and Demand Charges). These tariffs vary on how they charge households for their electricity purchase and (for D-RES owners) sale. However, each tariff is calibrated by the utility to be cost-sufficient, i.e. return total revenue equal to total costs of electricity trade.

Economic efficiency can be thought of as how well each consumer is paying equal to their personal value for a given product. Similar to (Burger et al. 2019), we calculate deadweight loss as the lost economic efficiency from a price mismatch between the real costs of electricity trade (last row of Table 1) and the tariff price. We use similar elasticity values of -0.1 and -0.3, based on short-run and long-run estimates of electricity demand elasticity, respectively. For each tariff and elasticity, we vary D-RES generation from 0 to 100% of households owning D-RES. To separate randomization effects from those attributable to D-RES generation, we repeat calculations for each generation ratio 10 times.

Our quantified results use real-world data from Austin, TX, USA, for the year of 2016. Per-minute household (solar PV) generation and consumption data for 144 households was collected from the Pecan Street Dataport.[2] To calibrate tariffs, real-time locational-marginal prices and tariff prices were collected from the same time and locale.

Table 1 - Tariffs used in this study

#	Tariff Name	Consumption Price	Generation Credits	Capacity Price
1	Conventional	Increased-Block Pricing	Flat rate	N/A (in consumption price)
2	Flat-rate	Flat rate	Flat rate	N/A
3	Time-of-Use (TOU)	High daytime (6-22) prices, low nighttime (22-6) prices	Hourly market prices (plus subsidy markup)	Separate fixed charge
4	Real-Time Pricing (RTP)	Hourly market prices	Hourly market prices (plus subsidy markup)	Separate fixed charge
5	Demand Charge (DC)	Hourly market prices	Hourly market prices (plus subsidy markup)	Monthly demand charge of household peak
-	*real costs*	*real-time market prices*	*real-time market prices (plus subsidy markup)*	*Fixed charge (based on overall demand peak)*

[1] This tariff design is currented subscribed to by our dataset's household population. More information at https://austinenergy.com/ae/residential/rates/residential-electric-rates-and-line-items

[2] More information at https://www.pecanstreet.org/dataport/

Results

Our results are summarized in the two plots in Figure 1, which we briefly review here. We first review the low-elasticity scenario (bottom plot). All tariffs start at relatively different total dead-weight losses when D-RES ratio is zero. The DC and RTP tariffs have very low total deadweight loss, at about \$235 and \$208, repectively. In relative terms, these are about 0.2% of total electricity costs for the household population. However, the TOU tariff has higher deadweight loss (1.2% of total costs), while the Conventional and Flat tariffs perform worst (3.8% and 2.9% of total costs, respectively).

As D-RES generation increases, the TOU tariff remains a middle-ground in economic efficiency between the traditional (Flat-rate and Conventional) tariffs and the RTP and DC tariffs. The Flat-rate tariff initially performs better than the Conventional tariff. However, with more D-RES the former catches up to the latter in dead-weight loss, creating similar amounts of economic inefficiency. In addition, we see a small peak for the DC tariff's deadweight loss when 75% of households are prosumers. As households add D-RES, their individual peaks become less representative of capacity costs, leading to more significant price distortions and thus more deadweight loss. However, D-RES also reduces the overall peak capacity and thus overall capacity costs, weakening the influence of capacity charge distortions on deadweight loss. These countervailing influences balance out at a generation ratio of about 75%.

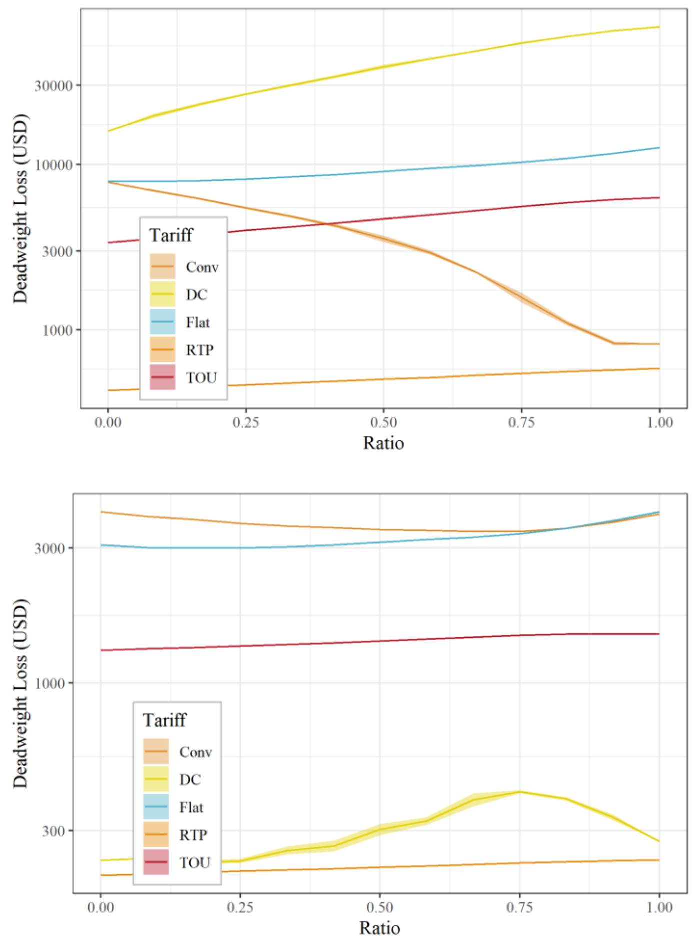

Figure 1 – Total deadweight loss per D-RES generation ratio per tariff for high (top) and low (bottom) elasticity scenarios. Ribbons show one standard deviation.

In a high-elasticity scenario (Figure 1, top), some results are similar; e.g. the RTP shows the lowest dead-weight loss across all D-RES ratios. However, some results differ: the Conventional tariff starts near the flat-rate tariff but decreases significantly as D-RES increases. In addition, the DC tariff shows extremely high dead-weight loss ratios (at about 17% of total costs), due to its mis-representation of capacity costs with demand charges. Unlike the low-elasticity scenario, the price distortion from demand charges dominates trends and causes a significant increase in deadweight loss as D-RES increases.

Conclusions

Overall, dead-weight loss differs greatly per tariff and per D-RES generation ratio. Some tariffs show relatively stable economic efficiency as D-RES generation expands (RTP, TOU) while others show significant fluctuations (Flat-rate, DC, Conventional). In addition, these trends are strongly dependent on households elasticity, i.e. how strongly households react to price changes. A tariff suitable for high-elasticity regions may show very different results when applied in a low-elasticity region.

D-RES expansion may be a non-issue for economic efficiency concerns in some situations (i.e. in terms of tariffs, household behavior, consumption trends) but an important one for others. This study aimed to separate the two. Pricing generation credits too high or low can also bias a household's decision about how much D-RES to install. In the future, we intend to look into the economic inefficiencies from these pricing choices.

References

Borenstein, Severin. 2016. "The Economics of Fixed Cost Recovery by Utilities." *The Electricity Journal* 29 (7): 5–12. https://doi.org/10.1016/j.tej.2016.07.013.

Burger, Scott P, Christopher R Knittel, Ignacio J Pérez-Arriaga, Ian Schneider, and Frederik vom Scheidt. 2019. "The Efficiency and Distributional Effects of Alternative Residential Electricity Rate Designs." Working Paper 25570. National Bureau of Economic Research. https://doi.org/10.3386/w25570.

Davis, Lucas W. 2017. "The Environmental Cost of Global Fuel Subsidies." *The Energy Journal* 38 (01). https://doi.org/10.5547/01956574.38.SI1.ldav.

Reneses, J., and M. P. Rodriguez Ortega. 2014. "Distribution Pricing: Theoretical Principles and Practical Approaches." *Transmission Distribution IET Generation* 8 (10): 1645–55. https://doi.org/10.1049/iet-gtd.2013.0817.