TIMING IS EVERYTHING: OPTIMAL EV CHARGING TO MAXIMIZE WELFARE

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Overview

Worldwide sales and new registrations of electric vehicles (EVs) start to have an exponential trend. The U.S., China and Europe are the leading developers and adopters of EVs, which will increase their electricity demand in the short and long run (IEA, 2017). The surge in power demand for charging the EVs can be met efficiently during early morning hours of low electricity demand, large wind generation and a large unused generation potential of the existing power plants in Texas. Furthermore, EVs are the key enabling technology for decarbonizing transportation and reducing air pollution in cities, as long as their power supply is clean.

Previous literature has detailedly modelled the environmental impacts and economic benefits of EVs charging in the U.S., given current users' (non-optimal) charging patterns and for marginal increases (Holland et al., 2016; Graff Zivin et al., 2014; Archsmith, 2015). My research assesses the charging schedule that maximizes welfare (private marginal generation cost and environmental damages) and two implementing tariff structures (hourly, day/night) for the estimated number of EVs in Texas. The results aim at informing policy and incentives (real time pricing, automated chargers) that can guide users to charge the EVs during the economic optimal hours.

Research approach

I develop partial equilibrium models of the wholesale electricity market in Texas (ERCOT) which replicate and calibrate the baseline (decentralized market problem with invariant tariff) and simulate how EV charging should be spread among hours to maximize welfare (First Best/Social Planner with hourly tariff) and surplus.[1] The models simulate via nonlinear optimization the hourly electricity demand, fossil fuel generation, EV charging, prices, carbon, sulfur, nitrogen oxide, and PM 2.5 emissions for Texas.

I estimate the fossil fuel supply curve using the aggregate hourly fossil generation, heat input data, and monthly fuel costs for ERCOT generators in 2017 (EPA, 2019; EIA, 2017). Furthermore, I use the exogenous variation of hourly load and wind to estimate wholesale hourly marginal emissions (CO_2, SO_2, NOx, and PM2.5) and air pollution damages (EPA, 2019, ERCOT, 2019). I use data on actual EV mileage by auto model in Texas, from the 2017 National Household Travel Survey (DOT, 2018), and owners' current non-optimal charging patterns from the EV Project in Houston and Dallas respectively (DOE, 2013). The model also considers the hourly charging restrictions on the amount of energy that an EV can withdraw from the grid (Level 1 and 2 chargers). Finally, I simulate how day-night tariffs based on the socially optimal hours from the Planner's problem and charging generation costs and full social costs can implement second best solutions in a decentralized market.

Results

The welfare maximizing charging schedule is the opposite of current patterns: while users charge mostly in the evening (18-23 H) since they do not face an hourly price and due to convenience, EVs can be charged at the lowest marginal social cost during the first hours of the day (0-4 H). Unconstrained first best charging leads to welfare gains of up to 42% of wholesale prices over current non-optimal patterns: an average of 10.44 USD per MWh charged and lower carbon and air pollution damages than current charging patterns. Constraining power withdrawals to the current Level 1 and 2 chargers limits using energy from those hours with lower prices and marginal carbon emissions and reduces welfare gains. Nevertheless, even under the most restrictive L1, most EV charging can be done early in the morning leading to welfare gains very similar to the first best (9.91 USD per MWh charged).

Even in the absence of emissions pricing on EV charging, the private surplus maximizing charging schedule is similar to the welfare one due to the overlap of low prices and low marginal carbon emissions from hours 0 to 4. However, environmental damages increase at a much larger rate than prices from 5 to 8 AM, and the surplus maximizing schedule draws more power between those hours than the welfare one, leading to larger carbon emissions and air pollution than current charging patterns, and lower efficiency gains than the first best.

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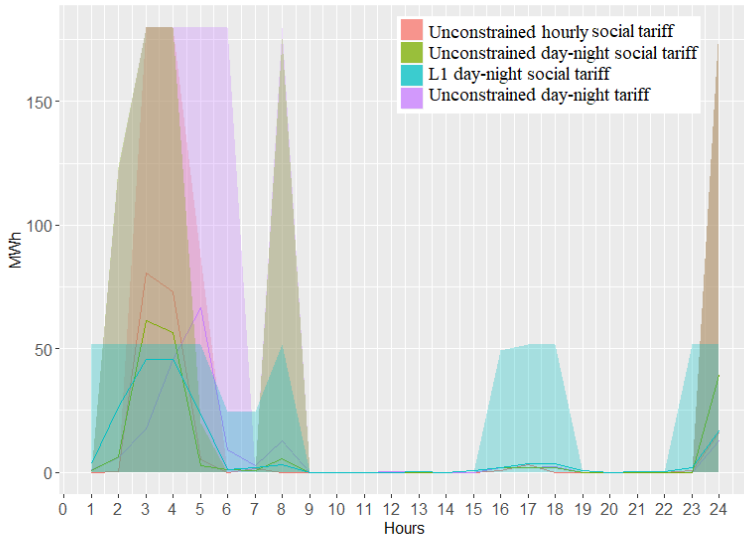
[1] The low level of imports makes ERCOT an ideal case for simulations.

Figure 1. EV charging schedules



*The bands depict a 95% confidence interval, while the solid lines represent averages.

The second best day-night tariff charging only generation costs leads to an EV charging schedule that withdraws most power during 4-5 AM and it captures up to 93.7% of the gains of the first best. However, this less granular period pricing reduces generation cost effectiveness and increases environmental damages compared to even the surplus maximizing charging. On the other hand, the day-night tariff reflecting social costs leads to a charging profile that charges mostly from 3-4 AM, delivers more benefits (up to 98.3% of the gains of the first best) and reduces carbon emissions and air pollution damages below those of the current charging patterns. I also show how the optimal schedule varies throughout seasons due to variation in demand and the marginal generator supplying power.

Conclusions

The surge in power demand for charging new EVs in Texas can be met efficiently during the first hours of the day. However, current charging patterns are the opposite due to a lack of appropriate time variant pricing. Even a day-night and an hourly tariff based on current wholesale prices (private generation costs no emissions taxes) can guide users to charge their EVs efficiently due to the overlap of low prices and low marginal carbon emissions during the early morning. Furthermore, charging EVs early in the morning will cause the lowest price increase in electricity from meeting the upcoming surge in transport electrification demand.

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