Drivers of U.S. Residential Solar Adoption and Implications for Electricity Rate Reform

Severin Borenstein Lucas W. Davis*

October 2025

Extended Abstract

1 Introduction

Distributed solar advocates and some policymakers see widespread adoption of residential PV generation as an important part of a strategy for decarbonization. Others see it as a high cost option that should play a much more limited role. Across US electricity distribution utilities, there is enormous variation in the share of customers who have installed solar. Behind-the-meter solar PV generation ranges from 0% to over 20% of total gross load.

The question of what moves a household to adopt solar has been studied extensively. In nearly all cases, however, researchers have looked at the micro level adoption decisions of households, within a utility or comparing across the boundaries of utilities. These studies have been very helpful in identifying the roles of information

*(Borenstein) Haas School of Business at University of California, Berkeley and Energy Institute at Haas; *severinborenstein@berkeley.edu*. (Davis) Haas School of Business at University of California, Berkeley and Energy Institute at Haas; *lwdavis@berkeley.edu*. We are grateful to Fiona Burlig, Duncan Callaway, Joachim Seel, and seminar participants at UC Berkeley for helpful comments. We have not received any financial compensation for this project nor do we have any financial relationships that relate to this research. The analysis relies entirely on publicly-available data and all data and code will be posted on our websites upon completion of the project.

availability (Sommerfeldt, Lemoine and Madani, 2022), peer effects (Bollinger and Gillingham, 2012), local supply competition (Gillingham et al., 2016), environmental/political leanings (Corbett et al., 2022), and rate design and subsidies (Borenstein, 2017; Buchsbaum, 2023). But such studies necessarily have limited variation in some of the key drivers, including retail electricity prices and the incentives of utilities.

In this study, we approach the question from a more macro perspective, building a nationwide dataset of utility distribution service territories, residential solar adoption, and characteristics of the utilities and their customers. Our approach lacks the granular data of household-level characteristics that previous studies have leveraged, but in exchange we are able to study much greater variation in utility structures (e.g., investor-owned, government, or co-op), regulatory and political settings, and, most important, retail price levels. We also are able to include service territory-level average measures of household characteristics that are often not available at the customer level, such as income, political leaning, and rental versus owner-occupied housing. Our approach is not a substitute for the micro-level studies, but we believe that it yields some valuable insights that complement the findings from those previous studies.

Our paper contributes to the existing literature on the economic determinants of rooftop solar adoption. Previous studies have looked at the effect of investment subsidies (Hughes and Podolefsky, 2015; O'Shaughnessy et al., 2021), feed-in tariffs (De Groote and Verboven, 2019), and alternative subsidies and tariffs (Feger, Pavanini and Radulescu, 2022). Borenstein (2017) examines the effect of net metering and other financial incentives in the context of California. Our study explores similar themes, but with a national focus. Our work is closest to Lemay, Wagner and Rand (2023), which uses broad-based estimates of rooftop solar penetration from Google Project Sunroof, but does not produce estimates of the causal elasticities of price, owner-occupied housing or other factors.

Our finding that rooftop solar adoption is highly sensitive to energy prices connects the paper to an existing broader literature on the price elasticity of demand

for electricity (Reiss and White, 2005, 2008; Deryugina, MacKay and Reif, 2020; Buchsbaum, 2023). One of the most interesting parts of this literature looks at how households respond to nonlinear prices (Ito, 2014; Shaffer, 2020). Moreover, the sensitivity of adoption to prices underscores the importance of pricing electricity at social marginal cost, a significant theme in recent research Borenstein, Fowlie and Sallee (2021); Borenstein and Bushnell (2022*a*,*b*).

Our paper is also motivated by and related to previous studies that have quantified the environmental benefits of solar (Borenstein, 2012; Callaway, Fowlie and McCormick, 2018; Sexton et al., 2021), documented distributional effects of rooftop solar (Borenstein and Davis, 2016; Darghouth et al., 2022; O'Shaughnessy, Kim and Darghouth, 2023; Borenstein and Davis, 2025), examined the pass-through of solar subsidies (Pless and Van Benthem, 2019; Hughes and Podolefsky, 2015), and examined peer effects (Bollinger and Gillingham, 2012; Wolske, Gillingham and Schultz, 2020; Gillingham and Bollinger, 2021) and political ideology (Dokshin and Gherghina, 2024).

While our study sheds light on the role played by electricity prices, utility structure, and household-level characteristics, there are also national-level factors that drive residential solar adoption. Probably most importantly, solar panel prices have continued to decline over time. In addition, the U.S. federal tax credit decreased from 30% to 26% in 2020, before increasing back to 30% in 2022, and then expiring at the end of 2025. Our setting is not well suited for quantifying the impact of these national-level factors, but the paper does discuss this broader context and points to relevant related research.

2 Data and Variable Construction

The foundation of our analysis is the utility-level data on solar adoption from the Energy Information Administration's Form 861. The Form 861 data also contain information on number of customers, revenues, and consumption, which we combine with utility level data on fixed monthly charges to derive the average volumetric price

charged by each utility. The Form 861 data also indicate the ownership structure of the utility—investor-owned, government, or co-op. We combine these data with census information for each utility's service territory—median income, rental/owner-occupied shares, housing ownership and density—and data on the political leanings of residents in the territory. We create a panel of data on approximately 900 utilities. The panel runs from 2014 to 2023, though most of the identifying variation is in the cross-section.

3 Empirical Analysis

We do not include variables for specific state or utility-level solar policies. We do this for two reasons. First, the most important policy—net energy metering—has been adopted by nearly all utilities to some extent, but they are highly idiosyncratic in their details, generosity, and actual implementation. Second, the size of the local PV industry clearly affects its political influence and plays a role in the policies adopted, so policy measures are endogenous. Instead, we count on the Democratic vote share, rental/owner-occupied share, and other variables to capture the underlying tendency for favorable policies towards rooftop PV.

From these data, we seek to explain the variation in PV adoption rates across utilities and time. One concern is the potential endogeneity of the utility price. Because virtually every utility's residential price is above its private marginal cost (**?**), adoption of solar reduces utility revenues by more than it reduces utility costs, eventually leading to the need for increased rates. We instrument for utility volumetric price with the same utility's price in 2012, when rooftop PV was extremely rare and had virtually no impact on retail rates.

We estimate a constant elasticity specification of PV penetration rates - i.e., share of residential customers with solar - on average volumetric price, median income, owner-occupied share of housing, Democratic share of votes, service area demand density, non-profit utility dummy, and state and year fixed effects. In most parts of the country, the state fixed effects control for variations in insolation, though we are working

on getting better measures of the solar resource by utility. The estimated coefficient on the effect of average volumetric rate is slightly greater than 2 (p-value=0.000), implying that a 30% higher volumetric rate (about the interquartile range in the data for a given year) increases the PV adoption rate by about ??60%. We also find that the share of owner-occupied homes has an elasticity of nearly 2 (p-value 0.000), implying that a 10% higher rate of owner occupancy (about the interquartile range) increases the PV adoption rate by about ??20%. The Democratic vote share in the 2020 presidential election also is estimated to have a significant impact with an elasticity of about 0.5 (p-value=0.019), but after controlling for political leanings and owner occupancy, income level is not statistically significant.

A frequent concern among distributed solar advocates is that for-profit utilities are more motivated to fight policies that would support distributed solar in order to increase their own profits. Our analysis (and summary statistics), however, does not support this. Our estimates suggest that nonprofits - government-owned and co-op - utilities lower PV penetration by about 20%, an effect that is statistically significant (p-value 0.01).

4 Conclusion

In New York, Massachusetts, California, and a number of other states committed to reducing greenhouse gas emissions, high electricity rates are often cited as a barrier to building electrification, because high rates undermine the economics of heat pumps and electric vehicles compared to natural gas space and water heating and gasoline-powered vehicles. Lowering rates, however, would make the economics of rooftop solar less attractive to residential customers. In California, Massachusetts and New York, at least, marginal volumetric prices have been estimated to be two to three times higher than optimal levels. Such an extreme drop in retail price seems unlikely due to the revenue hole it would create. But our work suggests that there is another significant political barrier: Adjusting retail prices to optimal economic levels could reduce the market for rooftop solar by 75% or more. Our results also suggest that

converting utilities to non-profits would be more likely to harm than to boost the rooftop solar industry.

References

Bollinger, Bryan, and Kenneth Gillingham. 2012. "Peer Effects in the Diffusion of Solar Photovoltaic Panels." *Marketing Science*, 31(6): 900–912.

Borenstein, Severin. 2012. "The Private and Public Economics of Renewable Electricity Generation." *Journal of Economic Perspectives*, 26(1): 67–92.

Borenstein, Severin. 2017. "Private Net Benefits of Residential Solar PV: The Role of Electricity Tariffs, Tax Incentives, and Rebates." *Journal of the Association of Environmental and Resource Economists*, 4(S1): S85–S122.

Borenstein, Severin, and James B Bushnell. 2022*a*. "Do Two Electricity Pricing Wrongs Make a Right? Cost Recovery, Externalities, and Efficiency." *American Economic Journal: Economic Policy*, 14(4): 80–110.

Borenstein, Severin, and James B Bushnell. 2022*b*. "Headwinds and Tailwinds: Implications of Inefficient Retail Energy Pricing for Energy Substitution." *NBER Environmental and Energy Policy and the Economy*, 3(1): 37–70.

Borenstein, Severin, and Lucas W Davis. 2016. "The Distributional Effects of U.S. Clean Energy Tax Credits." *NBER Tax Policy and the Economy*, 30(1): 191–234.

Borenstein, Severin, and Lucas W Davis. 2025. "The Distributional Effects of U.S. Tax Credits for Heat Pumps, Solar Panels, and Electric Vehicles." *National Tax Journal*, 78(1): 263–288.

Borenstein, Severin, Meredith Fowlie, and James Sallee. 2021. "Designing Electricity Rates for an Equitable Energy Transition." *Energy Institute Working Paper*, 314.

Buchsbaum, Jesse. 2023. "Are Consumers More Responsive to Prices in the Long Run? Evidence from Electricity Markets." *University of Chicago Working Paper*.

Callaway, Duncan S, Meredith Fowlie, and Gavin McCormick. 2018. "Location, Location, Location: The Variable Value of Renewable Energy and Demand-Side Efficiency Resources." *Journal of the Association of Environmental and Resource Economists*, 5(1): 39–75.

Corbett, Charles J, Hal E Hershfield, Henry Kim, Timothy F Malloy, Benjamin Nyblade, and Alison Partie. 2022. "The Role of Place Attachment and Environmental Attitudes in Adoption of Rooftop Solar." *Energy Policy*, 162: 112764.

Darghouth, Naïm R, Eric O'Shaughnessy, Sydney Forrester, and Galen Barbose. 2022. "Characterizing Local Rooftop Solar Adoption Inequity in the U.S." *Environmental Research Letters*, 17(3): 034028.

De Groote, Olivier, and Frank Verboven. 2019. "Subsidies and Time Discounting in New Technology Adoption: Evidence from Solar Photovoltaic Systems." *American Economic Review*, 109(6): 2137–2172.

Deryugina, Tatyana, Alexander MacKay, and Julian Reif. 2020. "The Long-run Dynamics of Electricity Demand: Evidence from Municipal Aggregation." *American Economic Journal: Applied Economics*, 12(1): 86–114.

Dokshin, Fedor A, and Mircea Gherghina. 2024. "Party Affiliation Predicts Homeowners' Decisions to Install Solar PV, but Partisan Gap Wanes with Improved Economics of Solar." *Proceedings of the National Academy of Sciences*, 121(29): e2303519121.

Feger, Fabian, Nicola Pavanini, and Doina Radulescu. 2022. "Welfare and Redistribution in Residential Electricity Markets with Solar Power." *Review of Economic Studies*, 89(6): 3267–3302.

Gillingham, Kenneth, Hao Deng, Ryan Wiser, Naim Darghouth, Gregory Nemet, Galen Barbose, Varun Rai, and Changgui Dong. 2016. "Deconstructing solar photovoltaic pricing: The role of market structure, technology, and policy." *The Energy Journal*, 37(3): 231–250.

Gillingham, Kenneth T, and Bryan Bollinger. 2021. "Social Learning and Solar Photovoltaic Adoption." *Management Science*, 67(11): 7091–7112.

Hughes, Jonathan E, and Molly Podolefsky. 2015. "Getting Green with Solar Subsidies: Evidence from the California Solar Initiative." *Journal of the Association of Environmental and Resource Economists*, 2(2): 235–275.

Ito, Koichiro. 2014. "Do Consumers Respond to Marginal or Average Price? Evidence from Nonlinear Electricity Pricing." *American Economic Review*, 104(2): 537–563.

Lemay, Amélie C, Sigurd Wagner, and Barry P Rand. 2023. "Current status and future potential of rooftop solar adoption in the United States." *Energy Policy*, 177: 113571.

O'Shaughnessy, Eric, Galen Barbose, Ryan Wiser, Sydney Forrester, and Naïm Darghouth. 2021. "The Impact of Policies and Business Models on Income Equity in Rooftop Solar Adoption." *Nature Energy*, 6(1): 84–91.

O'Shaughnessy, Eric, James Hyungkwan Kim, and Naïm Darghouth. 2023. "Technological Diffusion Trends Suggest a More Equitable Future for Rooftop Solar in the United States." *Environmental Research Letters*, 18(2): 024024.

Pless, Jacquelyn, and Arthur A Van Benthem. 2019. "Pass-Through as a Test for Market Power: An Application to Solar Subsidies." *American Economic Journal: Applied Economics*, 11(4): 367–401.

Reiss, Peter C, and Matthew W White. 2005. "Household Electricity Demand, Revisited." *Review of Economic Studies*, 72(3): 853–883.

Reiss, Peter C, and Matthew W White. 2008. "What Changes Energy Consumption? Prices and Public Pressures." *RAND Journal of Economics*, 39(3): 636–663.

Sexton, Steven, A Justin Kirkpatrick, Robert I Harris, and Nicholas Z Muller. 2021. "Heterogeneous Solar Capacity Benefits, Appropriability, and the Costs of Suboptimal Siting." *Journal of the Association of Environmental and Resource Economists*, 8(6): 1209–1244.

Shaffer, Blake. 2020. "Misunderstanding Nonlinear Prices: Evidence from a Natural Experiment on Residential Electricity Demand." *American Economic Journal: Economic Policy*, 12(3): 433–461.

Sommerfeldt, Nelson, Ida Lemoine, and Hatef Madani. 2022. "Hide and seek: The supply and demand of information for household solar photovoltaic investment." *Energy Policy*, 161: 112726.

Wolske, Kimberly S, Kenneth T Gillingham, and P Wesley Schultz. 2020. "Peer Influence on Household Energy Behaviours." *Nature Energy*, 5(3): 202–212.