Household Demand for Solar PV and Price Discriminating Subsidies

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Research Objective

Substantial federal and state tax expenditures subsidize adoption of clean energy and energy efficiency technologies in order to mitigate damages from unpriced pollution caused by conventional electricity production. Federal subsidies to residential solar energy technologies since 2006 alone total more than $3.5 billion (Borenstein and Davis 2015). Politicians prefer such subsidies to the pollution taxes that economists generally agree can achieve efficient pollution abatement. However, evaluations of such programs indicate their net benefits may be negative, i.e., they deliver abatement at costs that exceed the value of avoided pollution (e.g., Fowlie, Greenstone, Wolfram 2015; Gillingham and Tsvetanov 2015; Hughes and Podolefsky 2015; Rogers and Sexton 2015). Moreover, subsidies accrue predominantly to high-income individuals, posing equity costs greater than those of alternative pollution control policies, e.g., pollution taxes (Borenstein and Davis 2015).

Given the recent prominence of clean technology and energy efficiency subsidies in federal and state pollution control regimes, and amid new and accumulating evidence of their efficiency and equity costs, this research proposes to estimate the potential for efficiency and equity gains from (price) discriminating subsidies for clean technology adoption. Drawing principally on rare household-level solar photovoltaic (PV) adoption data, we will model the household adoption decision as a function of home characteristics, household demographics, peer influences, political party affiliation and voting behavior, and climate and weather. Such a model is, itself, valuable from a policy perspective because balance of system costs of solar PV, which include marketing costs, have declined only modestly even as technology costs have fallen dramatically. Balance of system costs can be reduced insofar as regulators and private firms alike can readily identify and target likely adopters. Moreover, equipped with such a model, we will estimate the willingness to pay for rooftop solar PV and distinguish from free riders those marginal adopters whose decisions are likely to be influenced by policy. These marginal adopters are likely to be poor relative to inframarginal adopters, presenting opportunity for improvements in efficiency and equity from price discriminating policy. We will simulate discriminating rooftop solar subsidy programs to determine their efficiency and equity implications relative to the prevailing, undifferentiated clean technology and energy efficiency subsidy programs that ignore predictable components of demand.

Background

Though economists widely recognize pollution taxes or tradable permit systems to be first-best policies to correct pollution externalities, subsidies for clean technology and energy efficiency investments are increasingly prevalent pollution control mechanisms. Federal tax credits for such investments since 2006 total in excess of $18 billion (Borenstein and Davis 2015). Thirty-four U.S. states provide additional rebates, while 43 implicitly subsidize distributed solar electricity generation via generous net-metering policies (Rogers and Sexton 2015).

Given the low marginal cost of solar generation, such investment subsidies effectively operate as subsidies to clean electricity generation that displace polluting, conventional generation. However, incentives for renewable energy technology adoption typically do not account for spatial and temporal heterogeneity in the value of their intermittent generation (Callaway and Fowlie 2015; Baker, Fowlie, Lemoine 2013; Novan 2014), much as subsidies for electric vehicles do not vary according to the technologies that generate their electricity (Zivin et al. 2014; Holland et al. 2015). As Callaway, Fowlie, and McCormack (2015) noted, the failure of incentives to reflect variation in external costs and benefits across regions precludes efficient allocation of investments across technologies and regions. Central to the motivation for this paper, however, is the observation that even were such incentives tailored to, e.g., regional variation in displaced emissions, such policies may yet yield an inefficient allocation of investment because of inframarginal adopters. For instance, the California Solar Initiative differentiated the magnitude of solar PV rebates according to expected system performance. Yet, Rogers and Sexton (2015) estimate that statewide renewable generation could be increased by at least 13% if installed solar capacity were reallocated from rooftops in low-solar-irradiance regions to regions with greater solar energy resources.

Recent empirical research suggests clean technology and energy efficiency investment subsidies induce pollution abatement at costs that may well exceed the social benefits. Fowlie, Greenstone and Wolfram (2015) estimate that costs of a federal home weatherization program substantially outweigh private and social benefits from the energy efficiency investments. Hughes and Podolefsky (2015) estimate that the California Solar Initiative abates carbon dioxide emissions at a cost between $130 and $196 per ton, in excess of conventionally employed estimates of the social cost of carbon (e.g., Callaway, Fowlie, and McCormack 2015; Fowlie, Greenstone, and Wolfram 2015). Rogers and Sexton (2015) estimate the cost of avoided CO2 emissions from the California Solar Initiative to be between $144 and $202. Gillingham and Tsvetanov (2015) estimate that a Connecticut solar rebate program delivers carbon dioxide abatement at a cost of $135 per ton.

The high cost of pollution abatement from rooftop solar adoption incentives stems, in large measure, from free riding by inframarginal adopters that limit the additionality of public expenditure. Rogers and Sexton (2015), for instance, estimate that the public cost per additional watt of rooftop solar capacity is approximately equal to the full cost per watt of additional utility-scale solar capacity. These high costs undermine the rationale for distributed renewable generation. A policy that differentiated between inframarginal and marginal adopters could increase the responsiveness of clean technology demand to state and federal incentives and lower the cost of abatement.

Independent of the value of household solar adoption modeling from the perspective of price discriminating regulators, such demand estimation is directly valuable as a mechanism to lower the costs of residential rooftop solar PV. Though costs of PV systems have declined dramatically over the past decade, the gap between the cost of large and small systems has widened, reflecting reductions in panel costs and relatively little change in installation costs (Borenstein 2013). The cost to solar installation firms of acquiring a customer is estimated at $0.40 per watt or about $2,000 per average system. The cost of identifying a customer constitutes as much as 10% of system cost. Leads are traditionally generated by word of mouth, referral bonuses, and by yard

signs, ignoring the potential to predict adopters. By generating a household level adoption model, this research extends work the research team has independently and jointly undertaken to understand the importance of peer effects on adoption. Such a model can contribute to technology diffusion by lowering the cost of adoption.

Data and Methods

Following Bollinger and Gillingham (2012), household adoption is estimated as a function of household demographic characteristics, home characteristics, including cardinal direction of street-facing rooftop, neighborhood characteristics, including characteristics of previously installed PV systems, and system cost net of state and federal incentives. Distinct from Bollinger and Gillingham (2012), however, and unique to this proposed research, we will estimate a logit model of individual household adoption decisions in each period using a household panel. This approach and related linear probability models can investigate the mechanisms of peer influence identified in Bollinger and Gillingham (2012) and more precisely estimate marginal effects of household characteristics unencumbered by the measurement error implicit in mean zip-code or Census block-group characteristics. These household and neighborhood characteristics will be interacted with cost variables to separately estimate price responsiveness across customer types. To the extent communities with low solar uptake are more price elastic, subsidies targeted to these communities will achieve greater marginal effects on take-up and potentially yield desirable distributional outcomes.

A distinct contribution within this modeling approach will be the identification of causal effects due to solar PV system visibility. Bollinger and Gillingham (2012) identified positive and economically significant causal peer effects that increased over time and increased panel system size. But data limitations overcome in this proposal precluded them from identifying the mechanisms by which previous neighborhood adoption decisions influence contemporaneous adoptions. This research will estimate within the household adoption model the causal effects of solar PV system street visibility. Bollinger and Gillingham (2012) and Graziano and Gillingham (2014) provide suggestive evidence that adoption is increasing in the visibility of previously adopted systems due to information transfer and other peer effects. Survey results also indicate that observing “another home or business” with rooftop solar is more important to individual adoption decisions than other marketing approaches and information transmission mechanisms, e.g., peer recommendation and direct mail. Furthermore, this team’s preliminary research in pursuant to a Department of Energy Small Business Innovation Research grant indicates that the visibility of installed solar PV systems increases the likelihood of future adoptions by neighboring households. Own system visibility is also expected to increase the likelihood of adoption. Visible systems may confer reputational benefits (Sexton and Sexton 2014). And they permit adopting households to spur future adoptions among neighbors to the extent visibility of existing installations increases propensity to adopt.

Causal effects of visibility are estimated by exploiting plausibly exogenous variation in the cardinal direction of street-facing rooftops. Specifically, electricity generation in North America is maximized by orienting PV systems south. For existing home adoptions, whether south facing rooftops are street-facing or not is presumably random. Moreover, households located opposite a given home are expected to be otherwise similar, and, therefore, exhibit otherwise similar propensities to adopt solar.

Household-level adoption decisions are observed in two distinct, confidential data sets. Approximately 140,000 adoptions are observed in California Public Utility Commission records of all residential solar PV adopters who applied for rebates under the California Solar Initiative. The program offered rebates per watt of installed capacity that declined overtime from $2.50 to $0.20. Notably, we observe household address and host customer names for each adoption, as well as system cost, total rebate, and system performance characteristics, including tilt and orientation. Similarly, we observe from 2008 to 2015 approximately 7,000 solar PV installations, and customer names and addresses in confidential data from the Connecticut Green Bank, a state authority that provides rebates for residential PV adoptions in the service areas of the two large investor owned utilities in Connecticut. These addresses are geolocated, and geospatial processing is used to determine whether panels are located on street-facing rooftops. For a subset of the installations in Connecticut, system street visibility is validated by inspection, indicating geoprocessing algorithms that are approximately 85% accurate. Non-adopting households are observed in proprietary DataQuick records of all home sales since 1995, as well as county and municipal parcel records.

Household demographic characteristics are obtained from Census data. We will pursue access to confidential, block-level demographics available at Census Data Centers. Home characteristics, including age, square-footage and lot size, as well as home loan characteristics are obtained from DataQuick. Following Kahn and Vaughn (2009) and Sexton and Sexton (2014), we include household political characteristics, including own party affiliation, neighborhood party affiliation, and neighborhood support for relevant political outcomes as reflected in election returns.

Because we observe price and rebate variation overtime, we can estimate distinct demands for demographic subgroups that yield willingness to pay estimates that could inform the offer of differentiated incentives, e.g., subsidy magnitudes, to the subgroups in order to deliver incentives to marginal adopters as opposed to inframarginal adopters. We will thus simulate the cost-effectiveness and distributional impacts of policies that differentiate incentives according to observable characteristics that predict demand. The impacts will be compared to those of existing, undifferentiated solar incentive programs to estimate potential gains from price discrimination. Importantly, our demand estimation will rely upon data that could be available to regulators who wish to implement targeted policies for clean technology and energy efficiency investments. Moreover, regulators could presumably price discriminate more effectively by relying upon individual tax records to which we do not have access.

Research Team

Steven Sexton is assistant professor of public policy and economics at Duke University and is a faculty fellow of the Duke Energy Initiative. Bryan Bollinger is assistant professor of marketing at Duke University. Kenneth Gillingham is assistant professor of economics at Yale University and an NBER research fellow. The research team can leverage existing research and partnerships, as well as rare access to confidential and proprietary data in order to execute the research outlined in this proposal. The team has access to confidential, household-level, identifiable records of solar PV adoptions and to proprietary DataQuick records of home characteristics, including sales prices. Moreover, though unnecessary for the proposed research,

existing partnerships with ClearGrid and a Duke University Energy Initiative project are likely to soon permit access to a database of solar PV adoptions outside California and Connecticut compiled by detection of solar PV systems in satellite imagery. Research assistance will be provided by a Duke University environmental economics PhD student.

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CONFLICT OF INTEREST STATEMENT

Steven Sexton declares no financial or other interests that might bear on the proposed work.

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