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Overcoming barriers and uncertainties in the adoption of residential solar PV

Varun Rai [a, b, *], D. Cale Reeves [a], Robert Margolis [c]

[a] LBJ School of Public Affairs, The University of Texas at Austin, USA
[b] Mechanical Engineering Department, The University of Texas at Austin, USA
[c] National Renewable Energy Laboratory, Washington D.C, USA

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ABSTRACT

In recent years decreasing hardware costs have driven down the installed price of solar photovoltaic (PV) systems and spurred adoption. However, system cost is not the only barrier faced by solar adopters. Potential adopters also face various informational barriers, leading to high indirect costs during the information search process. There is a significant gap in the literature for empirical work on solar adoption linking how the information context (installer marketing; neighbors with solar, i.e., peer effects; etc.) interacts with a potential adopter's motivations to impact decision outcomes. To address this gap we present results of a new survey on the decision-making process of residential PV adopters in northern California. The main aspects of our analysis include: salient motivating factors, information gathering process, peer effects, role of installers, and factors driving the choice of outright purchase versus third-party ownership (e.g., leasing) modes of adoption. We find that installers and neighbors play important, but often supplementary, roles throughout the decision-making process and have influence on both the decision to adopt as well as on the mode of adoption. Furthermore, expected financial returns and concerns about operations and maintenance are the main determining factors for the mode of adoption.

1. Introduction

Stabilizing global CO_2 emissions to avoid catastrophic climate change while meeting the increasing global demand for energy will require drawing on a variety of methods, including significantly scaling up the use of solar photovoltaic (PV) generation [1]. Potential to scale up solar PV generation exists at both the utility level [2] and at the residential level [3], on which this work focuses. Decreasing hardware costs combined with policy support in the form of federal, state, and local incentives [4–7] is driving down installed prices of solar PV systems, thereby spurring demand [8]. However, system cost is not the only barrier faced by solar adopters; potential adopters also face various informational barriers, leading to high non-monetary (i.e., indirect) costs during the information search process, which can be quite intensive for a capital-intensive durable like a solar PV system [9,10]. Furthermore, novelty of the technology combined with expectations of rapid technology improvement and cost reductions accentuate the real options (i.e., "wait and watch") problem for technologies likes solar PV [11]. Addressing these barriers requires a better understanding of the household decision-making process associated with the adoption of capital-intensive consumer energy technologies.

The literature on residential solar adoption [9,10,12–19], while growing, is still in early stages. In particular, there is a significant gap in empirical work on solar adoption linking how the information context (installer marketing; neighbors with solar, i.e., peer effects; information from utilities; etc.) interacts with a potential adopter's motivations to impact decision outcomes such as the duration of the decision period and the mode of adoption (for example, buy or lease). Addressing these questions could provide insights for addressing barriers to solar adoption more effectively and for improving the effectiveness and efficiency of utility solar programs more generally.

This paper seeks to contribute to the body of growing literature focusing on the design of policies and programs to speed the diffusion of novel consumer energy technologies. To that end, we analyze the results of a new survey on the decision-making process

* Corresponding author. 2315 Red River St., The University of Texas at Austin, Austin, TX 78712, USA.
E-mail address: raivarun@utexas.edu (V. Rai).

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of residential PV adopters in northern California, with a particular focus on adopters' information-search process and how it impacts the ultimate mode of acquisition (buy or lease) by overcoming barriers and uncertainties with PV adoption. Accordingly, we focus on identifying factors that initiate the decision-making process, are important during it, and inform the mode of final adoption.

2. Related literature

Information and the costs of acquiring it are central to understanding individual decision-making [20,21]. The main function that information plays is in enabling economic agents to calculate benefits and costs (to assess relative utilities) of decision alternatives. Behavioral factors (such as risk aversion, anchoring, decision heuristics, etc.) and social factors (such as norms, trust-based information networks, etc.) are of special interest because of the way they expose different individuals to different sets of information [15,21–24], thereby giving rise to the bounded rationality of individual decision-makers [21]. As such, an important question is: how and from whom do individual decision-makers seek the necessary information and form expectations about technological trajectories[1] to aid their decision-making? We address this question in the context of residential solar PV adoption process.

From their initial exposure to solar through the final decision to adopt, adopters of solar PV use information gathered from a variety of sources to reduce the uncertainties associated with adopting solar [21,25–27]. Recent work has explored the role of peer effects [10,28], uncertainty [19], business models [8,12,18,29], electricity rates [13,30], and discount rates [12,18] in residential solar adoption and found a linkage between factors in the decision-making process (such as motivations to adopt, perceived uncertainties, sources of information, etc.) and the mode of acquisition – buying outright or leasing [10,13,17]. Importantly, certain contexts modify the informational requirements. For example, Rai & Robinson [10] find that peer effects (the influence of one's neighbors) decrease the duration of the adoption decision period; peer effects are interpreted as a pathway that provides valuable information to potential adopters that helps reduce uncertainties inherent in adopting an emerging technology like PV.

Uncertainties about technological performance are an important driver for the choice of adoption mode: buying versus leasing. Drury et al. [13] posit three characteristics that explain the increasing trend toward third-party ownership (TPO), which includes leasing and power purchase agreements (PPA), of residential solar PV in California: it reduces the upfront financial burden – both overnight costs and costs associated with securing financing; it removes some of the complexities and uncertainties associated with adopting a new technology; and it re-frames the financial benefits of adoption as a simple-to-perceive monthly savings. Using more nuanced household-level survey data, Rai & Sigrin [18] find a similar market-expanding effect for TPO – specifically leasing – in the Texas market. However, in contrast to Drury et al. [13], they do not find a demographic difference between adopters that pursue leasing and those that buy outright. Instead, they find that leasing is preferred by customers who have a tighter cash flow situation: the individual-level discount rate of lessees was 8–21% points higher than those who bought their PV system. Accordingly, Rai & Sigrin concluded that in the early phases in a market the TPO model is able to penetrate the "information-ready but cash-poor" market segments [18].

While the literature has begun to empirically address the behavioral drivers and information processes involved in customer decision-making in solar adoption, much of the current work aggregates household-level heterogeneity. Understanding household-level heterogeneity is important for estimating demand [31], for building detailed spatio-temporal models of adoption [32–34], and for identifying and addressing information gaps and other barriers faced by different customer segments [16]. In this paper we analyze a new household-level dataset from a survey of residential solar PV adopters to specifically address the following questions: (i) what are the salient motivational factors that drive households to consider solar in the first place, (ii) where do potential adopters get their information from during the research (i.e., information gathering) period, and especially what is the role of peer effects and installers (i.e., the supply side) in this process, and (iii) what drives the decision to buy versus lease solar?

3. Data and methodology

The analysis in this paper uses a dataset composed of a survey of households that chose to adopt solar PV systems. As explained below, the survey data is further augmented with utility solar program data on those systems. Between April and June of 2014, a survey was conducted of residential customers in northern California who had completed installing solar PV systems. The goal of the survey was to characterize the decision-making process undertaken by PV adopters. The survey was sent to 2131 customers, of which a total of 380 completed responses were received (18% response rate). Section 4.1 and Supplemental Information (SI) provide more detailed description of the sample.

The survey collected information from respondents across eight broad categories: system details, purchase/leasing/power purchase agreement (PPA) details, decision-making process, financial aspects, sources of information, post-installation evaluation compared to prior expectations, environmental attitude, and demographics. There were a total of 57 questions distributed across the eight categories, resulting in 206 individual variables.[2] These data are matched by customer to the solar program dataset, which contains system-level details of the individual PV systems such as nameplate capacity, date of interconnection, total system cost, and rebate received. Most survey respondents (97%) were successfully matched to corresponding system-level data in the program dataset.

The analysis in this paper focuses on adopters' decision-making process – the process that PV adopters went through when deciding to adopt solar. The main aspects of our analysis include: salient motivating factors ("spark events"); information gathering process; role of installers; and factors driving the choice of buy versus third-party ownership (TPO) modes of adoption (i.e., lease or PPA). We use two methodological approaches to conduct the analysis. First, we use simple descriptive statistics: Fishers Exact test for independence and contingency tables to explore the demographics of the sample, the methods of acquisition employed by respondents, and their responses to questions relevant to their decision-making process. Unless otherwise noted, only results of tests that are significant at $\alpha = 0.05$ are presented. Second, we use a multivariate econometric model to identify determinants of the

[1] In the case when the decision involves the adoption (or not) of new technologies, an important consideration is the agents' expectations about the future technological trajectory, i.e., how the cost-quality frontier of the technology will evolve over time. A common assumption in the literature is that of rational expectations, which assumes agents' expectations to be the same as the actual market outcome (see Dubé et al., 2014 for more discussion on this issue). This can be problematic for new technologies, for which there is little past experience or data to form such expectations upon [38].

[2] A full table of relevant survey results is presented in SI-1.