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Can adoption of rooftop solar panels trigger a utility death spiral? A tale of two U.S. cities

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ABSTRACT

The growing penetration of distributed energy generation (DEG) is causing major changes in the electricity market. One key concern is that existing tariffs incentivize ‘free riding’ behavior by households, leading to a cycle of rising electricity prices and DEG adoption, thereby eroding utility revenues and start a death spiral. We developed an agent based model using data from two cities in the U.S. to explore this issue. Our model shows worries about a utility ‘death spiral’ due to the adoption of rooftop solar, under current policies and prices in the U.S., are unfounded. We found, consistently for a number of scenarios, that, while the residential segment is impacted more heavily than the non-residential segment, the scale of PV penetration is minimal, in terms of overall demand reduction and subsequent tariff increases. Also, the rate of adoption would probably be smooth rather than sudden, giving the physical grid, the utility companies, and government policies enough time to adapt. Although our results suggest that fears of a utility death spiral from solar systems are premature, regulators should still monitor revenue losses and the distribution of losses from all forms of DEG. The concerns should lead to a more focus on tariff innovations.

1. Introduction

In this paper, we examine the extent to which solar photovoltaic (PV) penetration can erode utility revenues and undercut the traditional financial model of power companies, leading to a so-called ‘death spiral’ of the utility business. This question is important not only for the companies and their stakeholders, but also for policymakers who expect incumbent utilities to make significant investments to support the transition to a decarbonized electricity sector.

Ever since its inception, the electricity sector has been made up of large, central generating companies that operate very reliable equipment and distribute power to customers. New distributed generation technologies with low entry costs, however, have the potential to affect the physical and financial structure of the industry. Rooftop solar PV is one such small-scale technology that can be adopted by a large proportion of a utility company’s customers.

The traditional pricing models permitted by U.S. regulators require utilities to cover most of the fixed costs of their investments and operations through charges based on the amount consumed, with a small, fixed, monthly charge for recovering the fixed costs plus a regulated profit. Consequently, any reduction in sales due to distributed power could lead to companies charging their remaining customers higher rates, which, in turn, could lead to more customers installing solar – or economizing in some way, a factor that is beyond the scope of our model. If this cycle of price increases and additional installations happens at a high enough rate, utilities could enter into what has been called a ‘death spiral.’ This loss of revenue and demand can have far reaching impacts as utilities still need to build and maintain transmission and distribution capacity to provide reliability, reliability that extends to homes with solar panels on the roof. Under existing pricing policies, PV owners do not pay utilities for this service for that part of their power demand that is met by PV.

Worries about a utility death spiral abound. *The Economist* argues that the electricity industry in Europe faces an existential threat.[1] The Edison Electric Institute, a U.S. industry association, warns that the electric industry faces ‘disruptive challenges’ comparable to the effect of mobile

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[1] Briefing: How to lose half a trillion euros, The Economist 12th October 2013, http://www.economist.com/news/briefing/21587782-europes-electricity-providers-face-existential-threat-how-lose-half-trillion-euros (last Accessed 12 December 2015).

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phones on wire-based technologies.[2] In Hawaii, the penetration of rooftop solar PV is one of the highest in the world, with approximately 12% of all households having solar panels [1]. This penetration has contributed significantly to a 21% decline in residential electricity sales since 2007 (See Appendix A of Supplementary material for more details). Over the past decade German utilities have written off substantial assets in what looks like a death spiral. An alternative view of the German situation [37], however, is that the write-offs are due more to the actions of generators than to the penetration of solar [38,39] (see Appendix B of Supplementary material for a summary of the argument).

This prospect of a 'death spiral,' raises two important issues: what is the scale of the effect resulting from the expansion of rooftop solar installations and what is the rate at which the effect will occur? In this paper, we investigate these two issues as well as the higher level issue, important for policymaking, of the robustness of the findings.

In order to address these questions, we develop an agent based model (ABM) in which building owners adopt rooftop PV panels depending on the perceived payback period for their investments, given rooftop PV costs and utility electricity prices. The perceived payback period is influenced by a contagion effect that depends on the number of panels installed in their geographical vicinity. This effect is applied only to residential customers. The measure is a rough proxy for attitudes toward either the early adoption of technology or environment, which are determinants of technological dispersion [2,3]. Our agent based model allows us to estimate not only the size of the effect, but also the rate at which customer adoption affects the revenues of the utilities. With sensitivity/post-solution analysis of the model we learn much about its robustness, our third main issue. Finally, the agent based model affords incorporation of imitation effects (influences from neighbors) and, in the future, other customer behavior.

We assess two locations in the U.S., Cambridge, Massachusetts, and Lancaster, California, under realistic market conditions. We track the installed capacity, solar generation, net demand, and rate impacts over a 20-year period and in 200 scenarios to reveal a range of potential outcomes. We find that, under realistic assumptions regarding rooftop PV adoption, the consequences for the electric transmission and distribution business are limited if the revenue from residential and non-residential segments are combined. Moreover, we find that change is smooth, rather than rapid, affording time for policy responses should predictions of the model prove significantly mistaken.

The main body of this paper is organized as follows. In the next section, we present some of the growing literature pertaining to the effects of DEG and of the adoption of solar PV. In the following section, we describe the important features of our two study cities, Cambridge, Massachusetts, and Lancaster, California, as they relate to adoption of rooftop PV. Section 4 provides an overview of our agent based model, including a description of its overall motivation and its detailed mechanics. The Setups subsection discusses the default scenarios for Cambridge and Lancaster, and describes their calibration to real data.

Section 5 presents the results of applying our model to two pricing scenarios, with runs simulating 20 years of activity. We then present our findings from an extensive and systematic robustness analysis of the modeling assumptions, anchored in the default scenarios. A clear picture emerges from these findings, which we explain in the Discussion section. The conclusion contains comments on the policy implications of our findings, assesses limitations of this study and points toward promising opportunities for future research.

2. Literature review

Much of the recent research on distributed PV market fits into three interconnected areas. The first focuses on the patterns of distributed PV adoption and potential market size. The second covers the implications for utilities and their business models. The third seeks to quantify the value of solar to the grid, in order to provide fair pricing mechanisms and market designs. This paper falls within the first two areas and touches on the value of solar in reducing net electricity demand.

A 2008 National Renewable Energy Laboratory (NREL) study undertaken by Navigant Consulting modeled the market penetration of rooftop PV in each of the 50 U.S. states, and in several scenarios [4]. The analysis first calculated the technical potential of rooftop PV by inventorying the usable roof space in the U. S., including the effects of shading, building orientation and roof structural soundness. A simple payback period for rooftop PV investments was calculated, so as to arrive at an economic potential. In the base case, the business as usual scenario, a total of 1566 MW and 57 MW of rooftop PV was projected to be installed in California and Massachusetts, respectively, by 2016.

A 2010 paper, also by NREL, used a similar approach to calculate rooftop PV adoption and identify the factors that have the greatest impact on PV penetration [5]. The analysis found that lower PV costs had the largest impact on increasing PV adoption, followed by policy options that improve the economics of PV, including net metering incentives and policies pricing carbon emissions of competing energy sources.

Several factors restrict the viability of rooftop PV. A 2015 NREL study identified the limiting factors for rooftop PV, as opposed to the larger opportunities presented by community solar installations [6]. The analysis found 81% of residential buildings in the U.S. have enough suitable space for a 1.5 KW PV installation. Assuming 63% of households consists of non-renters, the study estimates that 51% of households could install 1.5 KW PV systems.

Graziano and Gillingham [7] examined the spatial pattern of rooftop PV adoption in Connecticut. They found that higher density housing and a bigger share of renters decreases adoption. Interestingly, their research also found a 'neighbor effect' from recent nearby adoptions that increased the number of installations within 0.5 miles in the following year. They found this neighbor effect diminished over time and space.

Rai and Robinson [8] developed and attempted to empirically validate a spatial agent based model of rooftop PV adoption that incorporates economic as well as behavioral factors. In another study, Robinson and Rai [9] analyzed the adoption of residential photovoltaic technologies in Austin, Texas using a geographical information system integrated agent based model using data from 2004 to 2013. They found that financial aspects had well predicted the rate and scale of PV adoption, but the social interactions were critical to predict spatial and demographic patterns. They argued these results could be useful to design locationally target rebates and achieve cost effective results.

Utilities are facing the prospect of customers reducing their net electricity purchases as they adopt rooftop PV. Cai et al. [10] simulated the feedback of utility costs and lower sales in a California utility's territory to assess the implications of rooftop adoption. They found that the 'death spiral' feedback reduces the time it takes for PV capacity to reach 15% of peak demand only by a maximum of four months. By implementing a fixed connection charge for rooftop PV, the utility would delay the time needed for PV capacity to reach 15% of peak demand by two years. Overall, the authors found utilities could lose a significant portion of their high income customers, which increases risks to the utility, since low income customers are more sensitive to price increases. The logistic curve, which we use in the sequel, represents a starting point for representing consumer behavior.

Darghouth et al. [11], however, claimed that there is an overlooked feedback loop that can temper the death spiral argument: increased PV deployment leads to a shift in the timing of peak prices that could reduce bill savings received under net metering in a time varying rates context. They found that, for the US, the two feedback effects nearly offset one another and therefore produced modest net effects, a result

2US Energy: Off the grid, Financial Times 13th January 2015, http://www.ft.com/cms/s/0/b411852e-9b05-11e4-882d-00144feabdc0.html#axzz3uNxNbw72 (last Accessed 12 December 2015).