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The impact of state policy on deployment and cost of solar photovoltaic technology in the U.S.: A sector-specific empirical analysis

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ABSTRACT

Using a panel database for 27 programs in 16 U.S. states over 1998–2009, we assess the impact of 12 state-level policies on the cost and deployment of solar photovoltaic (PV) technologies for two sectors defined by system sizes: residential (<10 kW) and commercial (10–100 kW). We first examine the impact of policies on the deployment of solar PV. We show that cash incentives increase the deployment of commercial systems. We also show that interconnection standards potentially promote the deployment of residential systems, whereas property tax incentives potentially foster the deployment of commercial systems. We next examine the impact of policies on the cost of solar PV, and show that the key policies have different effects on costs. The cost of residential systems declines faster if there are cash or property tax incentives in place, whereas the presence of interconnection standards potentially accelerates the decline in commercial system costs. Further, states with a renewable portfolio standard see residential system costs potentially declining slower than states without such a policy. As solar PV is at the brink of becoming cost competitive, our findings assist regulators in fine-tuning their set of support tools.

1. Introduction

1.1. Motivation

Solar photovoltaic (PV) technology has attracted a lot of attention in the policy circles over the past decade. The modest environmental impacts along the value chain, avoidance of fuel price risks, and the ability to meet peak electrical demand incentivize private and public investment in solar PV [1]. Further, the benefits of solar PV lie in fostering "green" jobs; in improving energy security via distributed, domestic energy generation; and in reducing the load on the grid by encouraging private households to consume locally generated power [2].

Given that solar is not cost competitive with most conventional energy sources yet [3], a lot of solar installations have been due to policies [4]. The creation of such rapidly expanding markets has led the solar industry to achieve unprecedented economies of scale as well as learning-by-doing, encouraging global trade, and resulting in significant cost reductions [5,6]. In order to help solar PV reach a significant portion of its technical potential, it is imperative to understand the effectiveness of past policy – in terms of what has worked well, and why. Specifically, it is important to understand the impact of policy in driving down cost, as cost remains the single most important obstacle to reaching solar PV's full potential.

The market for PV in the U.S. is driven by federal, state, and local government incentives, including up-front cash rebates, production-based incentives, purchase requirements on electricity suppliers, and federal and state tax benefits. Though there are some policies at the federal level, such as the income tax incentive, most of the renewable energy policy action is happening at state-level, with considerable variations in not only how policies are designed but also how they are implemented [7–12]. Given that states differ in policy implementation as well as deployment and cost of solar PV systems [9], this variation creates a good backdrop for an *empirical* study on the impact of state-level policies on deployment and cost of solar PV in the U.S.

Thus, though some work exists on the impact of U.S. state-level policy on the deployment of renewable energy generation capacities [7,8,11,12]; on the deployment of solar PV [10,11]; and on the

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Abbreviations

PV	photovoltaic
BOS	balance-of-system
KW	kilowatt
MW	megawatt
DSIRE	database of state incentives for renewable energy
OLS	ordinary least squares
PCSE	panel corrected standard errors
ci	cash incentives
iti	incomes tax incentives
sti	sales tax incentives
rps	renewable portfolio standard
sggpp	state government green power purchasing
mugpo	mandatory utility green power options
contra	contractor licensing
ecert	equipment certification
saccess	solar access
net	net metering
ics	interconnection standards

cost of solar PV [13,14], the discourse suffers from two major limitations: first, there is no work that focuses on the impact of state policies on cost; and second, there is no work that focuses on the impact of policies on cost on a sector-wise basis. Section 1 in the Online Appendix provides a comprehensive literature review for the interested reader.

1.2. Our work

The focus of this study is to examine the impact of state government policies on the diffusion and cost of solar PV in the U.S. These two are inter-related: as system costs for solar-PV go down, solar PV becomes more competitive and, therefore, deployment should go up; and, as more solar PV is installed, system costs should go down due to learning-by-doing [5,6]. Policies play a major part in both increasing deployment of solar PV and reducing system costs: not only directly but also indirectly through each other.

The diffusion of solar PV can be traced by examining the capacity of annually installed PV systems, which allows for a relatively straightforward investigation of the impact of state-level policies on state-level solar PV deployment. However, the case of solar PV costs is not as straightforward, and requires to understand the likely impact of state-level policies on various components of solar PV systems.

Solar PV system costs are typically divided into two categories: (a) hardware costs and (b) non-hardware – or soft – costs. Hardware costs can be further subdivided into (a.1) module cost that correspond to the cost of solar modules; and (a.2) non-module cost, which includes other physical components, such as inverters, transformers, cabling, racks, etc; and soft costs that contain business development, labor, and permitting and interconnection costs, including related transaction costs. The commonly used term – balance-of-system (BOS) – costs represents the pre-incentive difference between the total system cost and module costs.

The reduction in module costs can be attributed to many factors, such as learning-by-doing, scale in production, and investment in R&D [5]. So-called technology-push policies that incentivize R&D target reducing the cost of solar PV by increasing efficiencies of solar system components such as PV cells. So-called demand-pull policies that promote learning-by-doing by cumulative deployment over time and production scale by creating large enough demand that drives investment into renewable technologies. Modules are globally-traded commodities, resulting in their cost being affected by global policies as a whole, and making it difficult to isolate the impact of local (i.e., state-level) policies.

On the other hand, BOS costs are typically local in nature, and there is reasonable regional variation due to direct cost reductions (e.g., lower transaction costs related to permitting and siting) as well as indirect cost reductions – via learning-by doing [6]. For example, residential customers in Germany pay 25% less for a solar PV system than U.S. customers, with most of the cost-differential in BOS costs [15,16]. Furthermore, a recent study by Sun Run – a solar system installer in the U.S. – finds that local permitting and inspection processes, which are a direct result of local policies, add about an average of $0.5/W to the BOS costs in the U.S. [17]. This clearly suggests that local (i.e., state-level) policies influence BOS costs, and raises the question as to which policies influence BOS costs and by how much. This is what our study sets out to do.

Given that it is more relevant to assess the impact of policies on BOS costs, henceforward, our analysis will focus on the link between policies and BOS costs. Further, given that decision-making is different in residential, commercial, and utility-scale sectors, defined as systems in the range <10 kW, 10–100 kW and >100 kW, respectively, our analysis is differentiated at the sector level.

2. Model

As mentioned in Section 1.2, we are interested in assessing the impact of state-level policy on the deployment and cost of solar PV in the U.S. This is essentially an *ex-post* empirical analysis that uses available data to derive correlations between policies and deployment as well as cost. Multi-variable regression analysis is considered the ideal tool to perform this task [18].

This paper uses a regression model with fixed-effects to estimate the impact of state-level policy on deployment and cost of solar PV systems in various programs – essentially focused deployment efforts, primarily simulated by financial incentives, with some offered by states while others offered by utilities or non-profit organizations. That is, programs are the "units" in our analysis.[2]

Given that different policy designs may be targeting solar PV deployment and cost differently; and there may also be non-policy factors that affect solar deployment and cost-reduction; the model includes detailed policy and control variables for a state's electricity market and political environment. Without variables controlling for differences in market size and political environment, the results could be biased and may lead to invalid policy interpretations. The model can be written as:

$$Y_{it} = \alpha_0 + \beta^* \mathbf{R}_{it} + \delta^* \mathbf{W}_{it} + \gamma^* \mathbf{S}_i + \theta^* \mathbf{T}_t + \varepsilon_{it}, \quad (1)$$

where "*i*" is the program, and "*t*" is the year of the specific observation; Y_{it} is the dependent variable; $\mathbf{R}_{it}$ is the vector of 12 state-level policies, described in Section 3.2; and $\mathbf{W}_{it}$ is the vector of five economic and political control variables, described in Section 3.3; $\mathbf{S}_i$ is the vector of state fixed-effects dummy variables; and $\mathbf{T}_t$ is the vector of year dummy variables.

The dependent variable ($\mathbf{Y}_{it}$) represents one of six variables under study. Three of these correspond to BOS cost (in $/W) and the rest correspond to the capacity installed in a year. Within each category, these variables correspond to the residential, commercial, and utility sector. The dependent variables ($\mathbf{Y}_{it}$) and control variables ($\mathbf{W}_{it}$) are continuous variables, whereas the policy variables

[2] We elaborate in detail the difference between programs and policies in Section 3.2.4. For time being, it suffices to say that programs are the units in our analysis, with multiple programs contemporaneously existing in a state, resulting in any state-level variable influencing multiple programs.