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The effect of current and prospective policies on photovoltaic system economics: An application to the US Midwest

Juan Sesmero*, Jinho Jung, Wallace Tyner

Department of Agricultural Economics, Purdue University, West Lafayette, IN 47907-2056, USA

HIGHLIGHTS

- Time-of-day (ToD) pricing can enhance or worsen the economics of PV systems.
- Effect of ToD is independent of demand elasticity if combined with net metering.
- Adoption of PV system requires that Federal Tax Credit cover half of capital cost.
- To induce adoption, ToD must act as a tax on grid electricity.
- Cost-effectiveness of ToD enhanced at higher ratios of on-peak to off-peak prices.

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ABSTRACT

This study models fundamental features of current and prospective policies encouraging adoption of residential photovoltaic (PV) systems. A key finding is that time-of-day (ToD) pricing can enhance or worsen the economics of PV systems. Moreover, increased responsiveness of electricity demand to its price diminishes the effectiveness of ToD pricing in the absence of net metering, but does not affect it otherwise. An application to plausible conditions in the State of Indiana, USA, shows that current policies are unlikely to trigger adoption by a risk-neutral forward-looking residential customer. However, adoption of PV systems can be induced if the Federal Tax Credit is increased to cover 48% of capital cost (instead of the current 30%), which could imply a cost to the Federal Government of about $0.95/kW of installed capacity depending on the panel's size. We demonstrate that implementation of ToD pricing can trigger adoption under a range of on- and off-peak price combinations. But our analysis also shows that the cost-effectiveness of ToD pricing is enhanced at higher ratios of on-peak to off-peak prices.

1. Introduction

Electricity from solar energy is renewable and carbon-free. Photovoltaic systems (PV) that convert solar energy into electricity are already commercially available. To the extent that environmental benefits of solar electricity are not incorporated into its price (relative to other sources such as coal), the supply of electricity from solar energy in the market will be lower than the socially optimum supply. Consequently, governments have tried to support the deployment of PV systems through an array of policy instruments.

Economic analyzes of PV systems in California (Pickrell et al., 2013; Makyoun et al., 2012; Cai et al., 2013; Liu et al., 2014) have shown that current retail electricity prices are close to a level where savings from the PV system cover its cost. While intuition may suggest less promising prospects for PV systems in the US Midwest (due to lower solar radiation and lower electricity prices), Jung and Tyner (2014) find that current policies can lower the cost of generating electricity with the PV system, measured as levelized cost of electricity (LCOE), to the level of mean retail grid price making PV systems cost-competitive. However, the (at least partially) irreversible nature of investment in combination with volatility and upward trend in retail price of electricity may hinder deployment of residential PV systems, even if they are found to be cost-competitive. As shown by previous studies (Hoff et al., 2003; Martinez-Cesena et al., 2013), the combination of uncertainty and irreversibility may induce households to require a retail price of electricity much higher than LCOE before they venture into a PV system.

We use a real options model of investment in a residential PV system to capture key features of the mechanisms through which

* Corresponding author.
E-mail address: jsesmero@purdue.edu (J. Sesmero).

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existing (federal tax credit, home equity loan, and net metering) and prospective (time-of-day pricing) policies incentivize their adoption. We focus on the interaction between time-of-day pricing and other policies, and the role of demand responsiveness in such interaction. This model generates key qualitative insights. First, our analysis demonstrates that time-of-day pricing (ToD) may act as a tax or subsidy on grid electricity. It also reveals that the responsiveness of electricity demand to changes in price (i.e. own-price elasticity and time-of-day substitution elasticity) influences the economics of PV systems if and only if a net metering system is not in place. Therefore demand responsiveness plays no role in policy effectiveness when ToD is combined with net metering.

Calibrating the model to plausible parameter values in Indiana, yields a number of quantitative insights. Our numerical illustration shows that, as currently implemented, existing policies are unlikely to induce adoption. Second, in combination with net metering and home equity loan, the federal tax credit would have to cover about 48% of the PV system's capital cost to induce adoption. Finally, under the current policy scenario, the ToD scheme must act as a tax on grid electricity (i.e. must increase the average price of electricity paid by the household) to incentivize adoption of PV systems. Multiple combinations of on- and off-peak prices can induce adoption of PV systems, but they impose varying effects on the average price of electricity. The magnitude of the effective tax necessary to induce adoption varies from 1 cent per kW h (under an off-peak price of $0.04/kW h and an on-peak price of $0.37/kW h) to 4 cents per kW h (under an off-peak price of $0.11/kW h and an on-peak price of $0.25/kW h). This demonstrates that, among price combinations that can trigger adoption of a PV system, those with higher ratios of on-peak price to off-peak price impose a lower cost to electricity consumers.

2. Policy background and literature review

Borenstein (2007) found that, in California, the LCOE of solar PV system per kW h was $0.17 above the retail price of electricity ($0.32/kW h and $0.15/kW h respectively). Since then, technological improvements have reduced that gap to virtually zero in southern California and to $0.05/kW h in northern California (Pickrell et al., 2013). Furthermore, Makyoun et al. (2012) argues that this technological trend is expected to push PVs' LCOE below $0.15/kW h (in fact to $0.11/kW h) by 2020. In Indiana, Jung and Tyner (2014) found that current policies make LCOE of solar systems about the same as the median retail price of electricity. The US Midwest makes an interesting case for policy assessment because the economics of PV systems are not as favorable (due to lower solar radiation and lower electricity prices relative to California), making policy a necessary condition for adoption.

Many mid-western states have been expanding electricity production from renewables including solar energy. Currently, a mix of federal and state-level policies are in place to support PV panels. Two federal policies currently in effect are the federal tax credit (FTC) and a tax deduction for home equity loan (HEL) interest. The FTC, as established by the Energy Policy Act of 2005 (and extended in the 2016 omnibus budget bill), allows residential consumers to write off 30% of the cost of installing PV systems in their home. Moreover, residential consumers are also allowed to write off interest paid on a HEL taken to finance a solar PV system. This is associated with the general tax deductibility of home loan interest in the U.S.

At the State level, some Indiana residents who own a PV system are allowed to sell electricity produced by the system in excess of their own consumption, back to the grid. This mechanism is commonly called net metering. The net metering system implemented by some Indiana utilities establishes that net excess generation (NEG), which is the production of electricity by the PV system in excess of the residence's consumption, is credited to the customer's next monthly bill. Technologically speaking, net metering is allowed by either a meter that spins forward when electricity is being drawn from the grid and backward otherwise, or by separate meters for inflows and outflows (Poullikkas, 2013). Currently the system provides a fixed rate credit, which means that NEG is credited at a fixed rate regardless of the time of day in which it is generated. Other incentives for PV systems are also in place (Database of State Incentives for Renewables and Efficiency, 2012) but are beyond the scope of this study.

Jung and Tyner (2014) found that in the absence of any of the current policies, LCOE of solar systems is well above the median retail price of electricity. This indicates PV systems are not economically viable without policy. And while the combination of all existing policies equate solar LCOE and mean retail prices (Baseline case, Table 7 in Jung and Tyner, 2014) the presence of uncertainty in electricity price and sunk costs of PV systems may still deter adoption (Dixit and Pindyck, 1994). In other words home owners will require the retail price of electricity to be above LCOE before they take the plunge. This suggests that current policies are insufficient to induce a risk-neutral forward-looking customer to adopt a PV system and that further incentives may be needed.

2.1. A prospective policy: Time-of-day pricing

Electricity markets have distinctive features that set them apart from other markets. Time of day and seasonal demand is volatile. Supply faces binding capacity constraints at peak times, and storage is not economically viable. Moreover marginal cost of producing electricity varies widely due to changes in capacity utilization and source of power (Borenstein, 2002). As a result wholesale prices are extremely volatile. However not all of this volatility is transmitted to retail markets. This implies that prices constitute poor signals of marginal production cost which fail to discourage (encourage) consumption at peak (off-peak) times, exacerbating inefficiencies. Economists have long proposed market mechanisms by which retail prices would adjust to changing wholesale prices. Such mechanisms have been called real-time retail pricing schemes. Concerns about the effect that price spikes may have on customers led many to advocate for an intermediate option where there is one price during on-peak hours and another during off-peak hours. This mechanism is referred to in the literature as time of day (ToD) pricing.

Under a ToD scheme, retail prices at peak times are higher than at off-peak at least partially reflecting marginal generation cost. ToD schemes have been adopted for commercial, industrial, and residential customers in California, and are beginning to get implemented in other states (Huang et al., 2011). An important reason why ToD schemes are being increasingly implemented is the fact that they discourage consumption at peak times which may be an integral part of efficiency-boosting policies. However, the attractiveness of ToD schemes goes beyond efficiency gains in conventional electricity markets. ToD schemes may effectively encourage decentralized power generation systems and, particularly, residential solar PV systems. The afternoon peak for solar systems roughly coincides with the peaks for many utility systems. A ToD scheme implies that savings (or revenue if net metering is in place) per kW h generated by a PV system are highest precisely when the system produces the most (Poullikkas, 2013).