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Lower electricity prices and greenhouse gas emissions due to rooftop solar: empirical results for Massachusetts

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HIGHLIGHTS

- Implied price of PV up to 10% greater than the annual average price.
- PV saves Massachusetts rate-payers $184 million in 2010–2012.
- Annual savings are greater than the cost of solar renewable energy credits.
- Savings rise longer lifetime of PV systems and pay period for SREC's shortened.
- PV reduces emissions of CO_2 and CH_4 by 0.3% relative to the annual average.

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ABSTRACT

Monthly and hourly correlations among photovoltaic (PV) capacity utilization, electricity prices, electricity consumption, and the thermal efficiency of power plants in Massachusetts reduce electricity prices and carbon emissions beyond average calculations. PV utilization rates are highest when the thermal efficiencies of natural gas fired power plants are lowest, which reduces emissions of CO_2 and CH_4 by 0.3% relative to the annual average emission rate. There is a positive correlation between PV utilization rates and electricity prices, which raises the implied price of PV electricity by up to 10% relative to the annual average price, such that the average MWh reduces electricity prices by $0.26–$1.86 per MWh. These price reductions save Massachusetts rate-payers $184 million between 2010 and 2012. The current and net present values of these savings are greater than the cost of solar renewable energy credits which is the policy instrument that is used to accelerate the installation of PV capacity. Together, these results suggest that rooftop PV is an economically viable source of power in Massachusetts even though it has not reached socket parity.

1. Introduction

Generating electricity using photovoltaic cells (herein PV) creates costs and benefits at several scales. For individuals that install PV capacity (rooftop PV[1]) and either sell this electricity to the grid or use it to reduce purchases from the grid, the economic costs and benefits are straightforward. Benefits include prices for electricity that are lower than purchases from the grid, both now and in the future. These benefits are compared to the cost of purchasing and installing PV and the risk of system failure and/or loss.

Costs and benefits expand when analysts quantify the impacts of rooftop PV on the electrical grid. At this scale, costs include difficulties managing the power system that are caused by the intermittency of solar insolation. Over seconds and minutes, intermittency increases the need for balancing reserves, which are used to restore the balance between the supply of and demand for electricity (Hirth and Ziegenhagen, 2013; Hirth, 2012; Nichaolson et al., 2010). Over minutes to hours, intermittency complicates the dispatch and cycling of capacity, which increases the need for back-up capacity (Mount et al., 2012; Weigt, 2009). Both aspects of intermittency increase price risk (as measured by increased variance of spot prices) for utility managers and policy makers (Woo et al., 2011).

Rooftop PV also creates several benefits for the grid. Renewable sources of power, such as PV, have very low marginal costs, and therefore can bid into wholesale electricity markets at very low prices (Jensen and Skytte, 2002; Wurzburg et al., 2013). This moves the supply curve to the right, which reduces the price for electricity that is purchased by the grid and ultimately charged to

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[1] We define rooftop PV as small units (less than 6 MWh) that qualify for Solar Renewable Energy Credits in Massachusetts.

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consumers. In addition, the decentralized nature of PV can reduce the need to transmit power, which may reduce congestion costs.

These effects are amplified in locations where utilization rates for PV capacity are positively correlated with high rates of electricity consumption. Most power systems dispatch generating units in merit order, such that units with the highest costs operate only during periods of high consumption. In addition, congestion costs likely increase during periods of high consumption. During these periods of peak use, positive correlations with the quantity of electricity generated by rooftop PV lowers the need to dispatch the most expensive generating units, which lowers the price of electricity supplied by the grid. This reduction is termed a demand reduction induced price effect (DRIPE).

The effects of PV (and other intermittent sources) on electricity prices are the focus of considerable research. These efforts fall into two categories; simulation-based studies that use models of the electricity market and empirical studies that use statistical techniques to analyze *ex post* data (see Wurzburg et al., 2013 for a review). Efforts that fall into the second category use a variant of the following highly stylized equation:

$$P_t = \alpha + \beta_1 Load_t + \beta_2 RE_t + \beta_3 NRE_t + \beta_4 PFF_t + \beta_5 Dum_t + \mu_t \quad (1)$$

in which P is the price of electricity during time period t, $Load$ is the electricity load, RE is the quantity of electricity provided by renewable sources, NRE is the quantity of electricity provided by other sources (e.g. coal, nuclear), PFF is the price of a fossil fuel that is used to generate electricity, Dum are dummy variables that represent temporal patterns (weekly, monthly, seasonal), and μ is a regression residual.

Statistical estimates of Eq. (1) focus on β_2. A negative value indicates that increased generation of electricity from renewable resources reduces electricity prices. Consistent with the notion that renewables lower the price of electricity, a review of empirical studies (Wurzburg et al., 2013) concludes that "electricity prices generally tend to fall due to increased renewable production (i.e. $\beta_2 < 0$).".

Despite this conclusion, the results may be affected by a variety of issues. Here we focus on the frequency of the data that are used to estimate Eq. (1), how Eq. (1) is specified, and how electricity prices are measured. While many studies generate statistical estimates from hourly data, other studies use daily data (e.g. Clo et al., 2015). Using daily data may obfuscate the effect of PV generation on electricity prices. Merit order dispatch can cause the hourly price of electricity to vary greatly throughout the day. This hourly variation is diminished when prices and load are compressed to a daily time-step (Jonsson et al., 2010).

Furthermore, using daily data complicates the interpretation of statistical results. Some of the daily time series contain a unit root (e.g. Clo et al., 2015). The presence of a unit root can cause standard diagnostic statistics to indicate a relation when none is present (Hendry and Juselius, 2000). To avoid this source of confusion, some statistical models that are estimated from daily data specify the first differences of the dependent and independent variables (e.g. Wurzburg et al., 2013; Gelabert et al., 2011). Although this specification eliminates spurious regressions, taking the first difference eliminates the long-run relation among variables (Baltagi, 2008). And there is no need to do so. Several techniques are available to estimate the long- and short-run relations among variables that contain a stochastic trend (e.g. Stock and Watson, 1993; Johansen and Juselius, 1994).

The relation between electricity prices and generation from renewable resources may be clouded by specifying a linear relation between price and the fraction of load supplied by a particular generation type. Even if the marginal cost of production rises smoothly with load and there is no discontinuous jump between sources, the relation between the fraction of load generated by a given generation type and price is non-linear. Similarly, the linear relation between price and load in Eq. (1) is unlikely given the highly non-linear hourly relation between price and consumption that is described by Karakstani and Bunn (2008). This may be one reason why the effect of generation by renewable resources on electricity prices varies by the level of demand (e.g. Wurzbug et al., 2013; Gelabert et al., 2011).

Finally, the ability to quantify the effect of PV on electricity prices may be affected by the measure of electricity prices. Many studies use wholesale prices. But this price includes several components. In Massachusetts, the wholesale locational marginal price includes an energy cost component, a congestion component, and a loss component. Because PV may affect these components differently (or not at all), using an aggregate measure of electricity prices in statistical models may diminish their ability to quantify the relation between prices and PV.

Beyond its effect on the price of electricity, correlations among PV capacity utilization, electricity consumption, and the thermal efficiency of power plants may reduce greenhouse gas emissions beyond emission rates based on an annual average. PV does not emit greenhouse gases directly, and this reduction usually is evaluated relative to the annual average emission rate of fossil fuel power plants. But this comparison may understate the reduction because the efficiency of fossil fuel power plants is negatively correlated with ambient temperature (Arrieta and Lora, 2005; Mehdi and Amir, 2012). If present, a positive monthly correlation between ambient temperature and PV capacity utilization rates would reduce the need to generate electricity using fossil fuels when these units are least efficient. As such, PV may reduce carbon emissions by a quantity greater than the average annual emission rate.

Based on these economic and environmental benefits, several US states have laws that seek to accelerate the installation of rooftop PV. In 2008, Massachusetts adopted An Act Relative to Green Communities (GCA), which coordinated efforts to reform the Commonwealth's energy strategy. Among its many components, the GCA establishes targets for the quantity of electricity generated by renewable fuels. Specifically, the act requires utilities to purchase 15% of their electricity from renewable resources by December 31, 2020. Towards that end, the GCA helps increase PV capacity from 0.373 MW at the start of 2010–15.2 MW by the end of 2012 (MA DOER).

As part of an effort to assess the GCA, we quantify the system-wide reductions in electricity prices and carbon emissions that are generated by the 14.8 MW increase in PV capacity in Massachusetts. Results indicate that rooftop PV reduces carbon and methane emissions by an additional 0.3% relative to the annual average emission rate. The implied price for electricity generated by rooftop PV is up to 10% greater than the annual average price of electricity such that the average MWh of electricity generated by rooftop PV reduces electricity prices \$0.26–\$1.86 per MWh. When these price reductions are applied to all MWh consumed, rooftop PV saves Massachusetts rate-payers \$184 million between 2010 and 2012. These savings are greater than the cost of solar renewable energy credits (SRECs), which is the policy instrument that is used to accelerate the installation of PV capacity. These savings rise when the present value of the system-wide price reductions generated by rooftop PV are compared to the payments for SRECs.

These results, and the methods used to obtain them, are described in five sections. In the second section, we describe the data compiled and the methodology that is used to calculate the monthly efficiency of gas-fired power plants in Massachusetts, the hourly generation of electricity by rooftop PV, and the effect of this generation on greenhouse gas emissions and electricity prices. The results are described in section III and discussed in section IV.