Drivers of growth in commercial-scale solar PV capacity*

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Abstract

This paper examines the impact of policy incentives for solar power on capacity growth of the commercial market segment. In estimating the relationship between incentives and solar PV capacity, we control for insolation, market factors, and demographic characteristics. We also account for indicators of pro-environmental attitudes and preferences for solar technology. We use county level data from 2005-2013 for 13 states in the Northeast United States including the District of Columbia, and estimate the statistical model using different Tobit estimators. Results indicate that factors affecting financial returns from a solar installation like electricity price and insolation are highly significant. Among policy variables, rebates, solar renewable energy credit price, and sales tax waivers are significant, along with a variable indicating how long a renewable portfolio standard has been present in a state. Income and indicators of environmental preferences are not as important, which is in contrast with findings in the residential solar market. This suggests that commercial installations are driven mostly by its promise of financial returns, and continued growth in this market segment will depend on falling installation costs and availability of incentives.

Keywords: commercial solar PV, solar incentives, renewable energy policies

1 Introduction

The solar photovoltaic (PV) market in the United States has grown dramatically in the last several years, with cumulative capacity growing from 190 MW in 2005 to over 18,000 MW in 2014. Between 2010 and 2014, installed capacity grew by 900% (Hart and Birson 2016). This growth is driven by concerns about greenhouse gas (GHG) emissions, and the environmental and health impacts of energy use, which has led many states to enact policies in support of solar power (DSIRE 2015). In addition, technological advances have dramatically decreased the cost of solar PV installation. From 2005 to 2013, the cost of solar PV installation

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decreased by 66% from \$7.70 per watt to \$2.59 per watt (GTM Research and Solar Energy Industries Association 2014). Declining costs of solar PV systems suggest that solar power will someday reach parity with grid-supplied electricity. However, until that point is reached, solar incentives will continue to play a role in supporting the solar market. In 2013 alone, the federal government provided \$5.3 billion in subsidies and support for the solar market. In addition, state governments have spent millions of dollars in solar incentives.

This paper examines the role of state policy incentives in driving the growth of commercial solar PV capacity. Commercial-scale solar PV is one of the three market segments comprising the total PV market in the Unites States, the other two being residential-scale and utility-scale. The commercial (also referred to as nonresidential) segment initially dominated the PV market with a share of 50% between 2000-2010, but over the years has declined in market share, accounting for 22% of the market between 2010-2015 (Hart and Birson 2016).

There are several reasons why it is important to consider the commercial segment separately from the overall PV market. First, even with its low current market share, it is still a key contributor to continued growth in solar PV capacity, especially with projected declines in the residential market segment (GTM Research and Solar Energy Industries Association 2016). Second, many state and local governments are promoting community solar projects which fall under the commercial market segment (GTM Research and Solar Energy Industries Association 2016, 2017). Community solar is attractive because community engagement around solar projects is valuable to many local governments. Furthermore, community solar expands the customer base for solar PV to those households who are renting or whose properties are not ideal for installation of rooftop solar PV (Coughlin et al. 2016). Several states have special incentives that apply specifically to commercial systems. These programs include Property Accessed Clean Energy (PACE) financing and loan programs for multifamily housing units (DSIRE 2015; PACENation 2017).

In this paper, we examine factors driving growth in commercial PV capacity in the Northeastern United States, using county-level panel data from 2005-2013. We focus on the impact of policy incentives, while controlling for market factors, demographic characteristics, geographical variables, and environmental and technological preferences affecting adoption of solar PV. Empirical findings show that rebates, sales tax waivers, Solar Renewable Energy Credit (SREC) price, and the number of years a Renewable Portfolio Standard (RPS) has been in place are all significant drivers of solar PV capacity. Factors that affect financial returns on solar installations such as solar insolation, electricity prices, and time trend (which captures falling installation costs) have a strong effect on the amount of solar PV capacity installed in a given year. Unlike prior studies focusing on the residential sector, we find that pro-environmental preferences represented by percentage of Democratic party votes, as well as demographic characteristics such as income, are not significant in driving commercial PV adoption. This suggests that the decision to install a PV system is primarily driven by financial considerations. Thus, policies that seek to lower costs and improve payback of PV systems are important to continued growth in this market.

This paper is most closely related to previous studies that examine the different factors affecting growth in the solar PV market. Some studies examine growth in the overall solar PV market whereas others focus on the residential sector. Among those looking at the effect of solar policies on the overall market are Sarzynski, Larrieu, and Shrimali (2012), and Kwan (2012). Sarzynski, Larrieu, and Shrimali (2012) evaluate the effects of different types of incentives on state-level PV capacity in the United States (U.S.) from 1997 to 2009. They found that cash incentives are effective because they help decrease upfront cost, while tax incentives were not effective. Using data from year 2000, Kwan (2012) considers the effect of environmental, political, social, and economic variables on the spatial distribution of residential solar PV in the United States. He finds that solar insolation, electricity prices and financial incentives are key drivers of solar adoption.

Other studies focus on the residential sector. Hughes and Podolefsky (2015) examine the effect of the California Solar Initiative on the number of solar installations between 2007-2012. They take advantage of the difference in utility providers in adjacent areas to provide exogenous variation in rebate rates, and find that a $0.1 per watt increase in the rebate increases installations by 7%-15% per day. Crago and Chernyakhovskiy (2017) use county-level panel data from 2005-2012 to examine the effect of policy incentives for solar PV while controlling for demographic and geographic characteristics. They found that rebates had the most impact on capacity growth, with a $1 increase in rebate leading to a 50% increase in new capacity. In addition, they find that pro-environmental variables were also positively related to solar PV capacity.

Other studies on residential solar PV adoption focus on non-financial factors instead of financial incentives (Krasko and Doris 2013; National Renewable Energy Laboratory 2014). A study by the National Renewable Energy Laboratory (2014) evaluates the effect of market support policies targeted at different states grouped by demographic characteristics and resource availability. Krasko and Doris (2013) use cross section data to examine the role of market creation and preparation policies like interconnection standards, net metering policies, and mandates for renewables and solar. Both studies found market support policies to be effective at increasing overall PV capacity in the United States.

This paper is also related to the broader literature examining the relationship between policy incentives and the growth of other renewable energy sources. A closely related study is that of Hitaj (2013), who examines the effect of state and federal incentives on wind power capacity. The study finds that tax and production incentives, along with access to the electricity grid, are key factors affecting the growth of wind power capacity the United States.

This paper contributes to the literature examining the growth of the solar PV market by identifying factors that are uniquely important to the growth of the commercial solar PV market. To our knowledge this is the first paper that focuses on examining growth in this market segment. We include detailed representation of different policy incentives, which allows us to estimate the individual impacts of these policies. This is in contrast to studies that do not consider policy incentives (Krasko and Doris 2013; National Renewable Energy

Laboratory 2014), group many policies in one variable (Kwan 2012), or focus only on a specific policy (Hughes and Podolefsky 2015). Our estimation strategy use Tobit estimators to account for the high percentage of counties with no PV capacity added for certain years. We also utilize instrumental variables to address possible endogeneity of some policies.

The next section provides background on the solar PV market. Section 3 describes our data and data sources. Section 4 discusses our estimation strategy and empirical results. Section 5 concludes.

2 Trends and incentives in the solar PV market

There has been rapid growth in the commercial solar market since late 2000s, which coincides with the introduction of solar incentives. From 2000 to 2010, there was just over 1,000 MW of commercial solar installed across the country. Over the next three years, growth averaged 1,000 MW per year, reaching a total of 4,051 MW by 2013. Improved SREC market conditions in Massachusetts and New Jersey spurred solar adoption in the Northeast (GTM Research and SEIA, 2014). Additionally, there were several market expansion tools, such as rebates and loan programs, introduced between 2008 and 2010. In the following years, commercial growth slowed as incentives expired, and in 2014 and 2015, commercial solar growth declined 6% and 5%, respectively. Incentive scale-backs were cited as one primary reason for the national decline (GTM Research and SEIA, 2015). In recent years, installed capacity has once again followed an upward trend. The year 2015 saw a 49% year-over-year increase in commercial solar capacity, up by roughly 1,600 MW. Two factors are primarily driving this trend. First, community solar projects boomed in 2016. Second, impending incentive deadlines may have caused a rush of installations.

In order to understand the impact of incentives on solar capacity additions, we describe trends in PV capacity growth, as well as various incentive structures included in our study.

Figure 1 shows the trend in solar PV installations by state in the years covered by our analysis. In total, 1,550 MW of commercial capacity were installed across the Northeast and the District of Columbia between 2005 and 2013. New Jersey and Massachusetts are leaders in installed capacity based on total kilowatts, with nearly 1,000 MW and 260 MW, respectively. Other than Pennsylvania with 111 MW installed, all other states had total installed capacity below 100 MW.

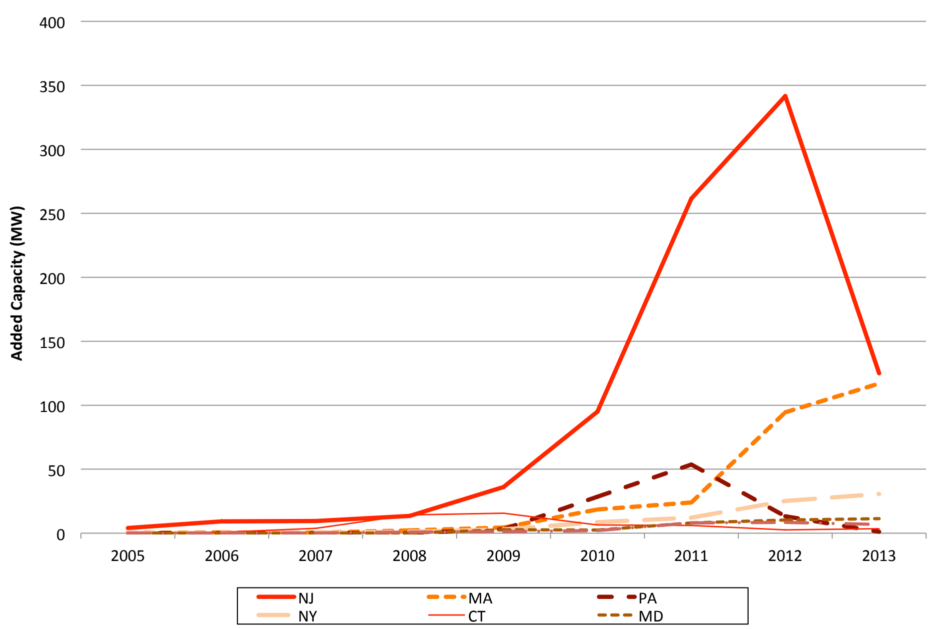


Figure 1: Annual PV capacity additions of selected states, 2005-2013

Figure 2 shows cumulative PV capacity at the county level as of 2013. Considerable heterogeneity exists in the level of solar PV penetration. Our goal in this paper is to examine the effect of different factors affecting annual increases in solar PV capacity, with an emphasis on the impact of policy incentives. Below, we discuss the different incentives relevant to the commercial solar PV market. We also present other important control variables that are included in our empirical model.

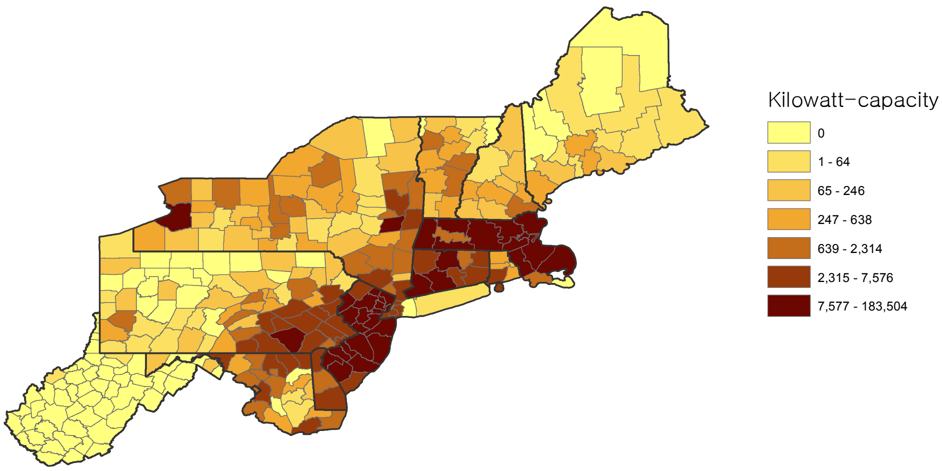


Figure 2: Cumulative solar PV capacity in the Northeast, 2013

2.1 Solar Incentives

Different incentives exist for solar PV adopters. The incentives differ in their magnitudes and the benefits they offer. Rebates and sales tax exemptions decrease the upfront cost of installation, while SRECs provide annual revenue to owners of PV systems. We discuss these incentives and others in turn. Rebate programs obtain funding through surcharges on electricity. Electricity customers pay surcharges per kilowatt hour which provides renewable energy programs with funding. Between 2005 and 2013, eight of the thirteen states in our study used a renewable energy surcharge. The charges range from 0.01 cents per kilowatt hour in Pennsylvania to 0.1 cent per kilowatt hour in Connecticut (DSIRE 2015). State tax credits apply a waiver on the sales tax of all or part of the cost of equipment in a solar installation. These waivers are appealing because they are simple for consumers to understand, and they scale to the size of the installation.

Markets for SRECs exist due to a requirement in certain states that load serving entities (LSEs) source a percentage of generation from solar energy. LSEs receive an SREC for producing a certain amount (typically 1 MWh) of electricity from a renewable energy source. LSEs can also buy SRECs from other renewable electricity producers, including owners of solar PV systems. Higher SREC prices increase revenue for owners of solar installations, decreasing the time required to recoup the initial investment. If LSEs do not have enough SRECs to meet regulatory requirements, they can instead pay the Solar Alternative Compliance Payment (SACP), which is set by state regulatory agencies.

Performance based incentives (PBIs) provide payments based on electricity produced by a solar PV installation. This incentive is based on actual production, as opposed to other incentives that are based on installed capacity. Renewable Portfolio Standards (RPSs) are general mandates for renewable energy, and as such do not incentivize solar directly. The existence of a RPS gives local stakeholders experience with deploying renewable energy sources like solar and wind. Net metering standards provide legal rights for solar PV customers to be compensated for energy fed back into the grid, and increases the value of a solar installation beyond the electricity that is directly used by its owners. Loan programs allow solar PV adopters to pay back the high upfront costs with below-market interest rates. An example is the PACE loan program, which collects payments through annual assessments on property tax bills.

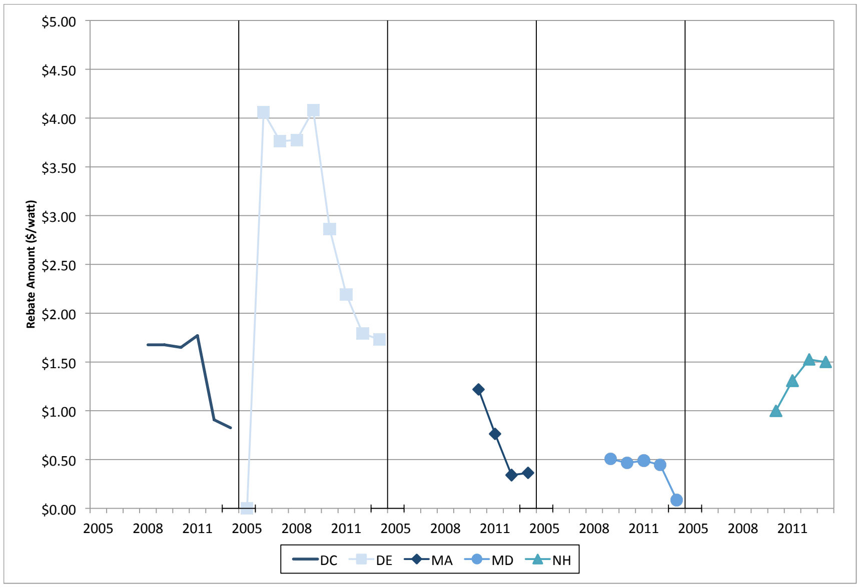
3 Data sources

Data on annual installations of commercial solar PV were obtained from the Open-PV database of the National Renewable Energy Lab (National Renewable Energy Laboratory

2013). We use a lower bound of 10 kW-capacity and an upper bound of 10 MW-capacity to identify commercial installations. In addition to installations identified as commercial in the database, commercial installations also include installations for nonprofit and public organizations (such as school buildings). The data from Open-PV identify the zipcode where installations are located. To generate county level observations, we use a zipcode-to-county crosswalk file from the Missouri Data Center. We obtain 9274 observations of solar PV installations identified by their month, day, and year of installation. These observations are aggregated across 300 counties for every year from 2005-2013.

Data on solar incentives are obtained from the Database of State Incentives for Renewables and Efficiency (DSIRE), as well as state agencies and administrative offices (DSIRE 2015). Data on incentives such as net metering, loan programs, and performance based incentives are obtained from DSIRE and are represented by binary variables which indicate whether or not the incentive was available in a given state for a particular year. Other incentives are measured using specific amounts. The sales tax waiver variable is the sales tax rate for each state. Several states increased the rate during our study period. All of the states in our study have a single tax rate except for New York state, which has a 4% state tax in addition to county-specific tax rates. To represent the impact of Renewable Portfolio Standards, we include a RPS trend variable, similar to that used by Menz and Vachon (2006). This variable indicates how many years the RPS program has been in place.

The rebate variable gives the dollar rebate amount per watt of installed capacity. Rebate data for the states of Delaware, Maryland, New Jersey, New York, Pennsylvania, Rhode Island and Vermont are obtained from state program administrative agencies. Rebate rates for New Hampshire, Massachusetts, and the District of Columbia were calculated based on the average size of installations by year and information on the rebate structure based on installation size. Figure 3 shows that the average rebate for the different states has been decreasing since its peak in 2008. The average rebate in 2008 was \$2.12 per watt, falling to an average of \$0.88 per watt in 2013.



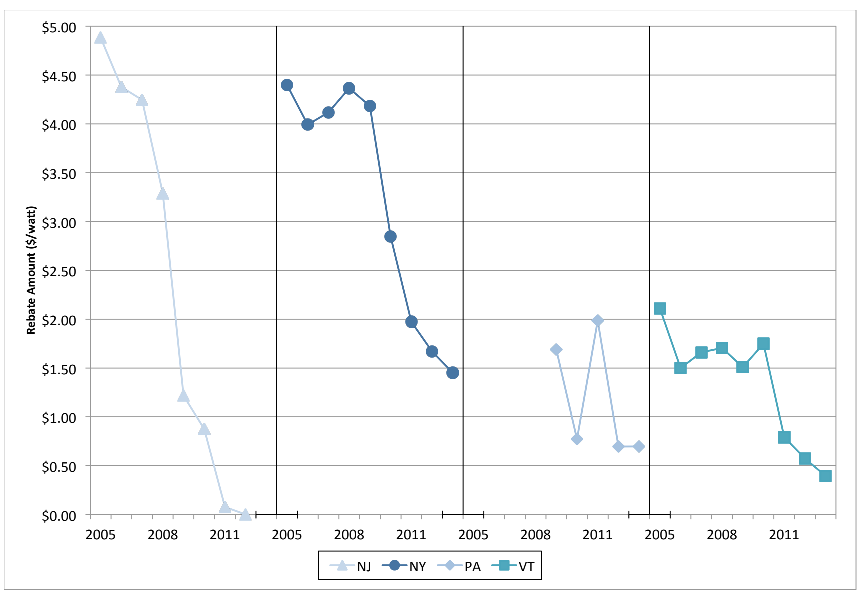


Figure 3: Changes in rebate rates over time, 2005-2013

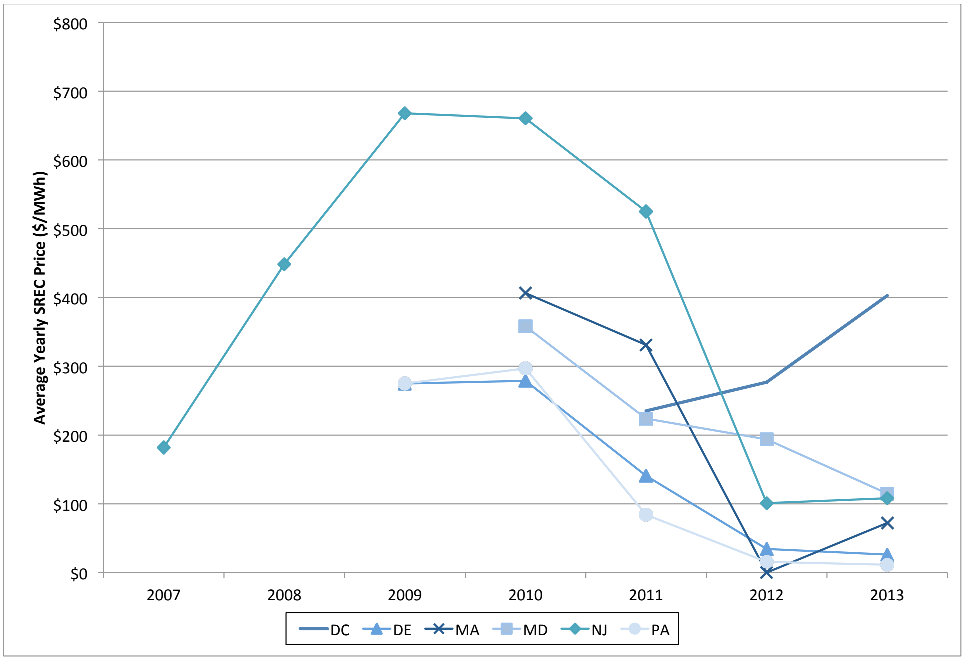


Figure 4: SREC prices in states with active SREC markets, 2005-2013

The price of SRECs are measured as the average yearly price of SRECs in a state. These prices were obtained from Flett Exchange, a leading trader of SRECs in New England. Figure 4 shows the trend in SREC prices for the states with active SREC markets. A common trend among SREC markets is high prices at inception of the market, and prices trending downward toward the end of our sample period, suggesting increasing supply of credits relative to demand. Data on SACP rates, which is the amount LSEs have to pay if they do not have sufficient SRECs, were obtained from DSIRE.

Commercial electricity prices were obtained from the Energy Information Administration (U.S. Energy Information Administration 2015). We use state-level wholesale electricity prices because this is the rate that is relevant to potential adopters of commercial solar PV. Solar insolation measures the intensity of sunlight and is expressed in kilowatt-hours per square meter per day. Data on solar insolation are collected from the National Renewable

Energy Laboratory (2015). As a control variable for the size of the market we include the number of businesses in a county. We obtain data on businesses from the U.S. Census Bureau (2016b). Only businesses with more than 10 employees are considered, under the assumption that larger businesses are a better measure of the economic activity in a county.

We also control for demographic characteristics likely to affect adoption of solar PV, including income, unemployment and population density. Household income acts as a proxy for the revenue of businesses in an area and their ability to finance large solar projects, while unemployment is a measure of the strength of the local economy. Data on income and unemployment are obtained from the U.S. Bureau of Labor Statistics (2015). Population density has been found to be negatively related to changes in residential PV capacity (Crago and Chernyakhovskiy 2017). It is not clear how population density will affect commercial PV capacity. It is possible that a highly dense area will have less available space for large solar projects. However, it is also possible that more dense areas will have a greater number of businesses that can choose to put up a solar installation. Population density combines population data from the American Community Survey and land area from the Census Tiger/Line database (U.S. Census Bureau 2016a,c).

Prior literature in residential solar PV adoption also suggests that pro-environmental preferences are an important driver of solar PV adoption. Therefore, we include measures of this in our empirical model. To capture environmental preferences, we use the percent of voters who voted for a Democratic House of Representatives candidate. Democratic party affiliation has been linked to support for renewable energy, and solar PV in particular (Dastrup et al. 2012; Crago and Chernyakhovskiy 2017). Voting data are obtained from the U.S. Federal Election Committee (2016). Since representatives are voted for every other year we interpolated the value for odd numbered years. Another measure of environmental attitudes and preferences for solar technology is the lagged count of new commercial installations, which are obtained from DSIRE (2015).

A detailed summary of the variables in our study is provided in Appendix Table A.1.

4 Estimation and Empirical Results

The model we estimate is given by:

$$lnY_{it} = \alpha_0 + \beta P_{it} + \delta D_{it} + \gamma M_{it} + \eta E_{it} + \xi C_{it-1} + \kappa_t + t + e_{it} \tag{1}$$

where i denotes county i, t gives the year and e_{it} is the error term. The dependent variable is the log of Y, the amount in kilowatts of PV capacity added in year t. The explanatory variables include vectors of policy incentives P_{it}, demographic characteristics D_{it}, market factors M_{it}, and an indicator of environmental preferences, E_{it}.[1] We include year fixed effects, κ_t, to account for changes in market conditions and federal policy over time. The time trend, t, captures decreasing cost of solar installation, as well as other unobserved trends that are common across counties. Finally, the lagged count of annual commercial installations, C_{it-1}, serves as a control for changes in preferences and solar market trends that vary by county over time. These include changes in preferences for solar technologies that are not captured by demographic or environmental preference variables.

We estimate Equation 1 using a Tobit estimator. The Tobit estimator allows us to address the non-linear nature of our data. Out of all county-year capacity additions of commercial solar PV systems, 66% of observations are zero. This means that we have a mass point at zero. Note that our data is not censored, since zero values do not denote censored or missing values, but are true values of the dependent variable. For non-zero values, the data is continuous. Cameron and Trivedi (2010) and Wooldridge (2016) argue that a Tobit model is appropriate for this type of corner solution outcome. Results of estimation using a Tobit estimator versus an OLS estimator are shown in Appendix Table A.2. The results show a sharp difference in the significance and magnitude of coefficients, confirming the need to use a non-linear estimator.

A key issue in our estimation is the possible endogeneity of policy variables, particularly

[1]Note that some variables do not vary over time or vary only at the state level (See Appendix Table A.1).

the SREC price. Policy variables can be endogenous if there are omitted variables that are correlated with policy variables. We mitigate the omitted variables problem by including a broad set of controls that capture key factors affecting changes in PV capacity, including year fixed effects and a time trend to capture unobserved variables that vary over time, and the lagged count of new solar installations to account for other unobserved variables that vary by time and county. We address the possible endogeneity of the SREC price using instrumental variables, which we describe in the next paragraph.

We first estimate Equation 1 using a pooled Tobit estimator. The pooled estimator assumes that that regressors are exogenous. The SREC price is determined in the SREC market depending on supply and demand of SRECs. Since contemporaneous PV capacity may affect the supply of SRECs, the SREC price could be endogenous. To account for possible endogeneity of the SREC price, we instrument the SREC price with the Solar Alternative Compliance Payment (SACP), which is the dollar amount that LSEs have to pay the state government if they do not have sufficient credits to meet the solar power generation mandate. The first stage regression of the SREC price on the SACP and other covariates show that the SACP is highly significant, and is therefore a good candidate for an instrument (See Appendix Table A.3). While we cannot test that our instrument meets the exclusion restriction, we know that SACP rates are typically set well in advance by state administrators, and unlike the SREC price, is not determined by supply and demand of solar generation credits in a given time period. Thus, it is likely to meet the exclusion restriction. To account for possible county-specific effects, we also estimate the model using a random effects Tobit estimator.[2] The RE Tobit model also assumes that regressors are exogenous. We cannot simultaneously include county-specific effects and instrumental variables in our estimation. Since the IV Tobit and RE Tobit estimators have their own advantages (and limitations) we present results from both estimators. Table 1 presents the estimated beta coefficients for Pooled Tobit, IV Tobit and RE Tobit estimators.

[2]Note that a fixed-effects Tobit estimator yields biased estimates so we do not use that particular estimator.

Table 1 shows that electricity price, insolation, number of businesses, and time trend (which captures changes in installation costs) are significant across the different estimators. Whereas the number of businesses is primarily a control variable for the size of the market, the other three non-policy variables are key determinants of financial returns from a solar PV installation. Insolation and price of electricity jointly determine the total value of electricity output from the solar PV installation, while the time trend represents the cost of installation. It is notable that demographic characteristics like population and income are not significant across estimators, which is in contrast with previous studies (Crago and Chernyakhovskiy 2017; Kwan 2012) in the residential solar market that find these demographic characteristics to be strong drivers of growth in PV capacity. Unemployment has a negative and significant effect, which is expected since low unemployment signals a strong local economy and greater ability on the part of businesses to invest in solar PV.

The share of Democratic party votes (an indicator of pro-environmental preference) is only significant in the RE Tobit, while the lagged count of commercial PV installations is only (weakly) significant in the pooled Tobit. The lack of broad significance of environmental preference indicators contrasts with findings in the residential solar market that pro-environmental preferences are key drivers of solar capacity growth.

In terms of policy variables, the rebate, sales tax waiver, SREC price, and RPS trend are significant across estimators. The policy variables that are not significant are loan programs, PBI, and net metering. The presence of net metering is critical to financial returns of a commercial solar installation. Thus, its lack of broad significance is unexpected. It is likely that the effect of net metering may not be identifiable in our regressions because almost all states have allowed net metering since 2003.

4.1 Marginal Effects

In addition to information about which variables significantly affect growth in solar PV capacity, the magnitude of the effect of a change in these variables on new capacity is

Table 1: Regression results across Tobit estimators: beta coefficients

	Pooled Tobit	IV Tobit	RE Tobit
Time Trend	1.484***	1.588***	1.605***
	(0.231)	(0.234)	(0.262)
Electricity Price	0.916***	1.008***	0.849***
	(0.159)	(0.171)	(0.195)
Lagged Count of New PV Installations	0.0389*	0.0310	-0.00951
	(0.0212)	(0.0217)	(0.0227)
Insolation	9.561***	9.361***	9.822***
	(1.668)	(1.664)	(2.742)
ln(Business)	4.189***	4.168***	4.452***
	(0.388)	(0.388)	(0.699)
ln(Population)	-0.789**	-0.790**	-0.690
	(0.312)	(0.312)	(0.561)
Income	-0.000106***	-0.000107***	-0.0000942
	(0.0000280)	(0.0000280)	(0.0000576)
Unemployment	-0.875***	-0.930***	-0.623**
	(0.200)	(0.202)	(0.304)
Democrats	0.00429	0.0226	0.132**
	(0.0393)	(0.0400)	(0.0642)
Loan Program	0.909	0.562	1.972
	(0.898)	(0.903)	(1.345)
Sales Tax Waiver	1.094***	1.010***	1.010***
	(0.120)	(0.130)	(0.164)
Rebate	2.465***	2.390***	2.881***
	(0.247)	(0.255)	(0.263)
PBI	1.131	1.472	2.637**
	(0.901)	(0.905)	(1.076)
SREC Price	0.00713***	0.0130***	0.00509**
	(0.00182)	(0.00343)	(0.00198)
Net Metering	4.575**	4.634**	0.704
	(2.024)	(2.027)	(2.165)
RPS Trend	1.057***	0.960***	0.814***
	(0.172)	(0.181)	(0.170)
Constant	-110.4***	-111.0***	-119.9***
	(8.400)	(8.360)	(13.19)
Log-Likelihood	-3898.9	-19271.6	-3814.4
Observations	2700	2700	2700

Standard errors in parentheses. Year fixed effects are included in regressions.
Standard errors for the RE estimator are bootstrapped standard errors, clustered at the county level.
For the Pooled Tobit and IV Tobit, standard errors are cluster-robust.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

Table 2: Effect of non-policy variables on new solar PV capacity: marginal effects

	Pooled Tobit	IV Tobit	RE Tobit
Time Trend	0.571***	0.580***	0.623***
	(0.0887)	(0.0899)	(0.0965)
Electricity Price	0.353***	0.384***	0.329***
	(0.0611)	(0.0651)	(0.0761)
Insolation	3.682***	3.688***	3.813***
	(0.647)	(0.647)	(1.091)

Standard errors in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

Table 3: Effect of Rebate on new solar PV capacity: marginal effects

	Pooled Tobit	IV Tobit	RE Tobit
Rebate ($/kW-Capacity)			
0.1	0.768***	0.756***	0.881***
	(0.0617)	(0.0649)	(0.0638)
0.5	0.817***	0.803***	0.946***
	(0.0709)	(0.0741)	(0.0740)
1	0.880***	0.863***	1.029***
	(0.0829)	(0.0861)	(0.0874)
2	1.010***	0.987***	1.200***
	(0.108)	(0.111)	(0.116)
3	1.144***	1.116***	1.377***
	(0.135)	(0.138)	(0.147)

Standard errors in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

Table 4: Effect of SREC Price on new solar PV capacity: marginal effects

	Pooled Tobit	IV Tobit	RE Tobit
SREC Price ($/MWh)			
50	0.00274***	0.00144	0.00197**
	(0.000693)	(0.00131)	(0.000746)
100	0.00279***	0.00146	0.00200**
	(0.000721)	(0.00134)	(0.000767)
250	0.00296***	0.00150	0.00208**
	(0.000805)	(0.00142)	(0.000830)
400	0.00312***	0.00155	0.00216**
	(0.000889)	(0.00151)	(0.000892)

Standard errors in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

Table 5: Effect of Sales Tax Waiver on new solar PV capacity: marginal effects

	Pooled Tobit	IV Tobit	RE Tobit
Sales Tax (%)			
5	0.503***	0.509***	0.457***
	(0.0642)	(0.0694)	(0.0857)
6	0.530***	0.536***	0.479***
	(0.0702)	(0.0759)	(0.0929)
7	0.557***	0.563***	0.501***
	(0.0761)	(0.0823)	(0.100)
8	0.584***	0.590***	0.523***
	(0.0819)	(0.0886)	(0.107)

Standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

Table 6: Effect of RPS Trend on new solar PV capacity: marginal effects

	Pooled Tobit	IV Tobit	RE Tobit
RPS Year			
1	0.339***	0.294***	0.277***
	(0.0434)	(0.0499)	(0.0504)
5	0.445***	0.367***	0.336***
	(0.0798)	(0.0812)	(0.0765)
10	0.580***	0.460***	0.411***
	(0.126)	(0.121)	(0.109)

Standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

also of interest. In this section, we discuss marginal effects of variables that are significant across estimators. The estimated marginal effects can be interpreted as semi-elasticities (proportional change in PV capacity for a one unit change in the independent variable). [3] In the discussion below, we focus on the result of the IV Tobit model since it addresses the endogeneity of SREC price. The estimates from Pooled Tobit and RE Tobit estimators are shown in the tables for comparison. Table 2 shows that a one dollar increase in wholesale commercial electricity rate increases capacity by 38%. A one unit change in insolation will increase capacity by 368%. The difference in insolation of the sunniest county and least sunniest county in our sample is 1, so all else equal the sunniest county will have over three times more solar PV than the least sunny county. The marginal effect of the time trend shows that each additional year sees an increase in capacity of 58%. This increase is likely related to decreasing solar installation costs over time.

For policy variables, it is more informative to present marginal effects at different levels of the incentive. Table 3 shows that a one dollar increase in the rebate offered increases new PV capacity by 75%-111%, depending on the prevailing rebate rate. The marginal effect is larger as the rebate rate increases. This is because the total rebate to be received is larger the greater the rebate rate is. The marginal effect of SREC price is roughly the same across SREC values with a $100 increase in the SREC price leading to a roughly 15% increase in solar capacity added (Table 4). Table 5 shows that if the sales tax is at 5%, increasing the sales tax waiver from 5% to 6% will increase new capacity by 50%. Similar to the rebate, if the initial waiver rate is high, the marginal effect is also larger. If the sales tax is at 7%, increasing the sales tax waiver from 7% to 8% will increase added capacity by 59%. The effect of one additional year of having a RPS policy ranges from a 29% increase in capacity in the early years of the RPS to 46% when the RPS policy has been in place for 10 years (Table 6).

[3] Note that marginal effects are average partial effects, which give the average of partial effects across the different values of the independent variables, while holding the covariate of interest at a constant value, usually the mean.

5 Conclusion

We find strong evidence that factors that directly effect payback and returns on investment have the most impact on capacity growth in the commercial solar PV market. These include electricity price and solar insolation. Among policy variables, rebates, sales tax waivers, SREC price and years the RPS is in effect are significant. Measures of income, pro-environmental attitudes, and familiarity with solar technology are not significant, suggesting that financial factors are the main drivers of commercial PV growth. This is likely because commercial solar installations are usually installed by businesses or organizations, and financial viability is of paramount concern to these entities. It is possible that households participating in community solar projects are partly motivated by pro-environmental preferences. However, the role of these preferences are likely to be smaller for community solar participants compared to installers of residential PV because some of the "green" benefits of solar PV are not available to the former. For example, participants in community solar projects do not benefit from the green "halo effect" that comes from having solar panels visible in their homes.

The significance of the time trend and RPS trend suggests that continued lower cost of solar panels as well as increasing experience of installers will continue to spur the growth of the commercial PV market. However, sustaining current levels of annual PV capacity additions will depend on continued provision of policy incentives.

The commercial solar market's reliance on incentives raises the question of the cost of financing incentive programs. Many states have steadily decreased or even eliminated rebates over time due to cost concerns. States can continue to incentivize growth in commercial PV capacity by improving the effectiveness of existing incentives. For example, states can put in place mechanisms to reduce the uncertainly related to SREC prices, given that the volatility in SREC prices may be dampening its effect on encouraging new installations (Bauner and Crago 2015). Steps in this direction can stimulate growth in the commercial segment without imposing additional financial burden on public funds or ratepayers.

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Appendix A

Table A.1: Summary statistics

Variable	Varies By*	Max	Min	Median	Mean	Std Deviation
Dependent Variable						
Added Capacity (kW/year)	C,Y	75716	10	193	1591	4867
Solar Market Policies						
Net Metering (b)	S,Y	1	0	1	0.91	0.28
Net Metering (b)	S,Y	5	0	4	3.32	2.03
Loan (b)	S,Y	1	0	0	0.46	0.5
Performance-Based Incentive (b)	S,Y	1	0	0	0.12	0.32
Sales Tax Rate (%)	S,Y	7	0	0	1.69	2.74
Rebate (dollars/watt)	S,Y	4.88	0	0.36	1.1	1.49
SREC Price (dollars/MWh/year)	S,Y	668	0	0	51	128.17
RPS Trend (Number of years)	S,Y	11	0	2	2.89	2.86
Instruments						
SACP ($/MWh/year)	S,Y	711	0	0	104	209.33
Controls						
Electricity Price (cents/kWh)	C,Y	17.11	5.53	11.61	11.55	3.23
Insolation (kWh/m2/day)	C	5.01	4.08	4.47	4.48	0.2
Number of Businesses	C,Y	166050	42	2805	8592	15115
Population Density	C,Y	72006	2.77	140	1138	5304
Income ($)	C,Y	121632	17275	36037	38348	11528
Unemployment (%)	C,Y	17.1	2	7	6.77	2.21
Democratic votes (%)	S,Y	97.34	30.16	56.35	56.61	0.09

*S denotes state, C denotes county, and Y denotes year. (b) denotes binary variables.

Table A.2: Tobit versus OLS: beta coefficients

	Pooled Tobit	OLS
Time Trend	1.484***	0.310***
	(0.231)	(0.0914)
Electricity Price	0.916***	0.0131
	(0.159)	(0.0712)
Lagged Count of PV Installations	0.0389*	0.0896***
	(0.0212)	(0.0167)
Insolation	9.561***	2.939**
	(1.668)	(1.080)
ln(Business)	4.189***	1.075***
	(0.388)	(0.232)
ln(Population)	-0.789**	0.0825
	(0.312)	(0.179)
Income	-0.000106***	-0.0000305
	(0.0000280)	(0.0000275)
Unemployment	-0.875***	-0.260**
	(0.200)	(0.0972)
Democrats	0.00429	0.00886
	(0.0393)	(0.0179)
Loan Program	0.909	-0.680
	(0.898)	(0.491)
Sales Tax Waiver	1.094***	0.467***
	(0.120)	(0.0759)
Rebate	2.465***	0.697***
	(0.247)	(0.137)
PBI	1.131	2.078**
	(0.901)	(0.648)
SREC Price	0.00713***	0.00572***
	(0.00182)	(0.00110)
Net Metering	4.575**	-0.171
	(2.024)	(0.486)
RPS Trend	1.057***	0.585***
	(0.172)	(0.0939)
Constant	-110.4***	-30.13***
	(8.400)	(5.117)
Log-Likelihood	-3898.9	-8036.9
Observations	2700	2700

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

Table A.3: First stage IV regression

SACP	0.453***
	(0.0116)
F(23, 2676)	253.23
Observations	2700

Standard error in parentheses. Only the coefficient on SACP is shown.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$