Going Solar: Property-Assessed Clean Energy in California

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Over the past two decades, the price per watt of rooftop solar photovoltaics (PV) has fallen substantially. Federal, state and local governments have employed numerous policy measures to promote the adoption of clean energy. Property-assessed clean energy (PACE) is a financing mechanism which allows homeowners to finance energy efficiency and renewable energy projects through a property assessment. Since 2011, the number of residential PACE programs has expanded dramatically. This paper uses difference-in-differences to estimate the impact of PACE programs on the adoption of residential solar in California. This analysis finds that the launch of PACE in a given city leads to an increase of 0.5 installations per 1,000 households per quarter. These results are not statistically significant but consistent with previous studies.

Every year since 1998[1], more and more households make the decision to install rooftop solar photovoltiacs (PV) in their homes. California has become the nation's leader in solar generation and ranks fourth in solar capacity per capita[2]. As of 2016, 4,885,000 Californians power their homes with solar (Perea 2017) and 9.96 percent of California's electricity generation came from solar (EIA 2017). Over half of all residential solar capacity was installed in 2015 and 2016 alone, shown in figure 1. In tandem, the price per watt of solar PV has declined by half over the last five years. This decline is attributable to a combination of policy improvements in technology and firm innovation (Bollinger and Gillingham 2014).

There are many reasons why solar energy has become so popular beyond price. A major factor is due to growing public and social consciousness towards climate change (Bollinger and Gillingham 2012). Governments have also implemented policies such as financial incentives (Solangi et al. 2011) and performance incentives (Darghouth et al. 2010) which have been largely successful at promoting renewable energy. The most notable is the Federal Investment Tax Credit (ITC) which offers a 30 percent rebate which has been largely successful at accelerating the rate of installations (Mai et al. 2016).

In 2006, Governor Arnold Schwarzenegger launched the California Solar Initia-

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[1]With the exception of 2017, where total installations were down. This study goes as far as the end of 2016

[2]In 2016, California generated 466 watts per capita from solar. It follows, in order, Nevada, Utah and Hawaii

tive with the goal of installing 3,000 MW of additional solar capacity by 2016. In 2011, this goal was expanded to 12,000 MW by 2020 (Go Solar California 2011). In the early years, CSI offered cash incentives on solar PV installations of up to $2.50 per watt. Combined with the ITC, cash rebates could cover up to 50 percent of the total cost[3]. Research finds that in the absence of the CSI, predicted installations would have been 58 percent lower (Hughes and Podolefsky 2016). Today, the median installed price has fallen under $4 per watt and total cash incentives are well below $1 per watt in most states. Falling cash incentives is also partly a response to the feedback from falling system costs (Barbose and Darghouth 2016).

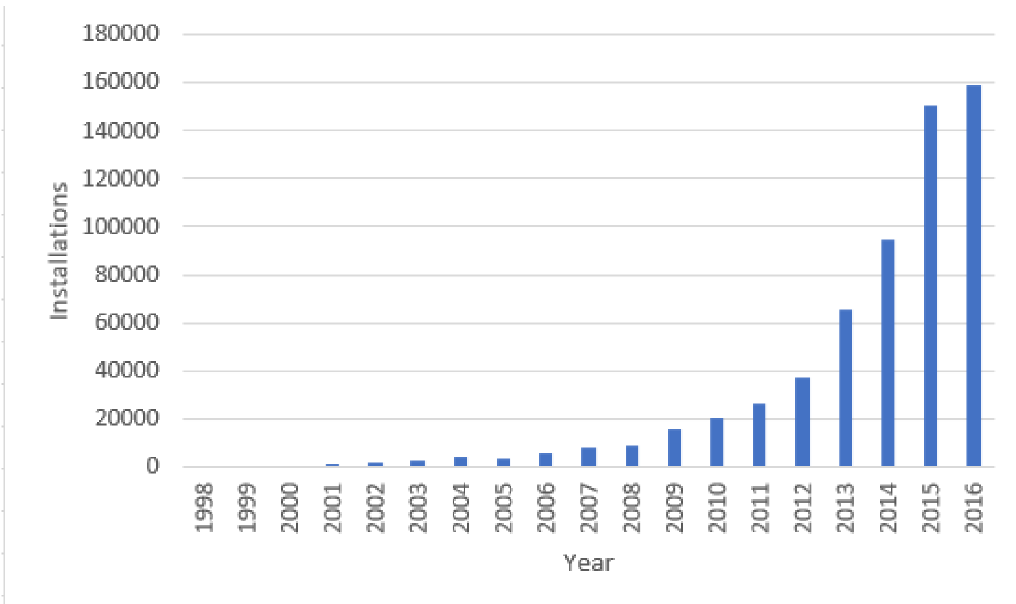

Figure 1. Cumulative Installations by Year

As the levelized cost of solar PV continues to fall, cash incentives are being phased out as part of a deliberate long-term signal to the energy industry (Barbose and Darghouth 2016). Many states including California have launched ambitious renewable portfolio standards (RPS)[4] which have helped states cut carbon emissions (Yin and Powers 2010). One long term goal is grid-parity, where the levelized cost of generating from solar is less than or equal to the cost of purchasing from the grid. As the market for solar continues to develop, policymakers look to new ways to incentive renewable energy and combat climate change.

[3]At the time, the median install price was $9.00 per watt
[4]Governor Brown signed legislation in April 2011 setting a goal of 33% RPS by 2020

I. Background

A. PACE Overview

PACE is an innovative financing mechanism that promotes solar adoption and is an alternative to direct subsidies (Burr 2014). The idea of PACE is similar to municipal bonds used to finance public infrastructure projects such as sidewalks. Projects undergo voluntary assessments and are repaid through property taxes (PACENation 2016). The state of California sees PACE as a crucial instrument to meeting their renewable energy goals (Deason and Murphy 2018). PACE is available in both residential and commercial forms. This paper will focus solely on residential programs.

State legislation must be passed which authorizes local governments to establish "special assessment districts" which allows the establishment of PACE. Local governments then partner with a PACE provider to establish the program over a specified geography[5]. Most PACE programs today are public-private partnerships and rely on private capital for funding. This makes PACE popular with policymakers as there is little to no cost to the taxpayer (Department of Energy). Property owners start by choosing to undergo a property assessment. If eligible, PACE covers 100 percent of upfront costs to energy efficiency upgrades such as rooftop solar, HVAC improvements, or water conservation projects. The improvement is repaid over a set term, typically 10 to 20 years (PACENation 2016). PACE bonds are often resold on the secondary market for additional funding.

The PACE assessment is filed as a lien on the property with a local municipality and PACE is repaid with an addition to the homeowner's property tax bill. Unlike a traditional loan, this project is affixed to the property and not the owner. This means owner's ability to repay the loan is assessed by the value of their home rather than credit score. Another consequence is that the PACE loan will be transferred if the home is sold, which decreases uncertainty over breaking even on an investment. Another significant advantage of the PACE payment structure is that it allows consumers to see immediate net-positive cash flow from energy savings (Renovate America 2017). The expansion of residential PACE financing in California is shown in figure 2.

B. PACE History

The first PACE program launched in Berkeley California in 2007. By 2010, there were 7 active PACE programs in the U.S., with 5 being in California (Kirkpatrick and Bennear 2014). Soon, concerns grew over the adverse impact PACE had on mortgages since PACE loans were structured in a way to be considered senior to the first mortgage.[6] This posed potential risk to the mortgage

[5] Most common are cities and unincorporated areas of a county. Also seen are sections of or the entire county

[6] There were additional concerns over consumer protection as income verification was not required

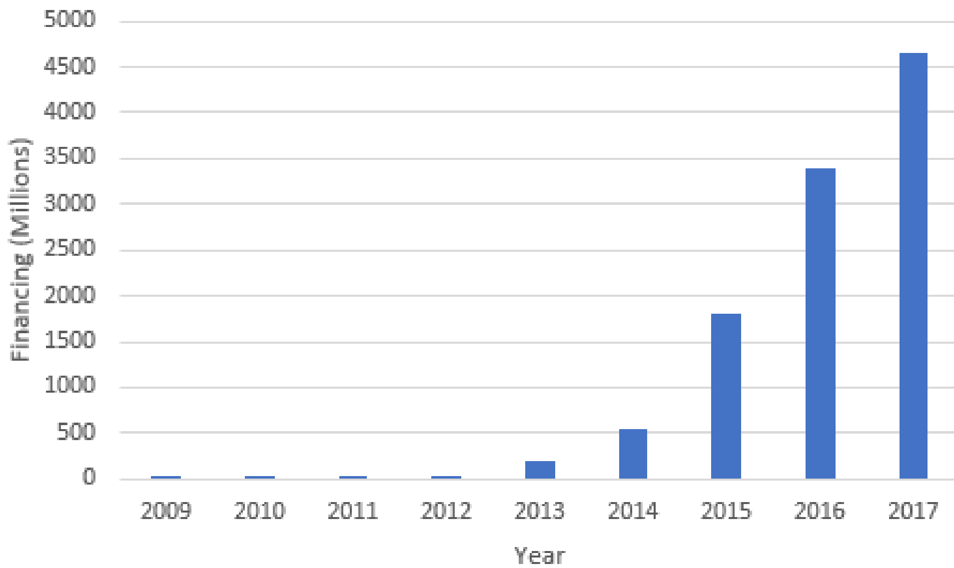

Figure 2. Cumulative Residential Financing

Note: Figure includes all PACE projects. Renewable energy upgrades account for 37 percent of total
source: PaceNation

holder's ability to recover the value of the mortgage in case of default or forced sale. In that event, the outstanding PACE obligation would be paid before other liens. (Kaatz and Anders 2014).

This caught the concern of the Federal Housing Finance Agency (FHFA) who on July 6, 2010 issued a determination that PACE posed "significant safety and soundness concerns" to mortgages and the entities that underwrite them.[7] Later that year, Fannie Mae and Freddie Mac issued letters to lenders stating they would no longer back mortgages with outstanding PACE assessments. Property owners would be required to pay off the PACE assessment in full before selling or refinancing their home. This decision had the effect of stalling active PACE programs at the time (Kaatz and Anders 2014).[8]

This FHFA ruling created vast uncertainty around PACE and an extended legal fight. Even with PACE in legal limbo, PACE programs began to restart, and new programs were created. Current PACE programs look to address FHFA concerns in different ways. PACE providers implemented stricter underwriting standards and often require property owners to sign a written disclosure acknowledging

[7]Since 2008, the FHFA became the conservator of Fannie Mac and Freddie Mae which underwrote a majority of these mortgages. The FHFA also feared risks to secondary markets as well

[8]Commercial programs were not affected due to a difference in structure

FHFA concerns (Kaatz and Anders 2014).

PACE got a boost when the White House launched the Clean Energy Savings for All initiative in July 2016 (The White House 2016). This included revised rule making from the FHFA and the release of *Best Practices Guidelines for Residential PACE Financing* by the Department of Energy (Office of Energy Efficiency and Renewable Energy 2016). The key requirements in the FHFA guidance are for the PACE assessment to be subordinate to FHFA single-family first mortgages and the assessment to transfers to the next property owner, including the case of forced sale.

The California PACE Loss Reserve program is an initiative launched by Governor Brown in 2013 to help assist with FHFA concerns. The program received $10,000,000 to pay back first mortgage holders in case of default or forced sale. No claims have been paid out yet (Lacey 2014). The California Alternative Energy and Advanced Transportation Financing Authority (CAEATFA), which manages PACE Loss Reserve, would also work with partners and lenders to support PACE. California has passed additional bills in 2016 and 2017 to increase consumer protections.

California Home Energy Renovation Opportunity (HERO) is the largest and most widely available residential PACE provider in California. By April 2016, California HERO was available to over 85 percent of California communities (Hales 2016). Data from the CAEATFA shows that HERO has funded over 70 percent of outstanding PACE improvements, amounting to 1.1 billion dollars in 2016. This resulted in 89,361,397 kWh of energy savings annually from all projects. Solar energy upgrades accounts for a third of the total portfolio (CAEATFA 2016). A comparison of different PACE programs can be found on table 1.

C. Contribution

When evaluating the effectiveness of PACE as a policy, there are two main considerations. The first is the impact of PACE on mortgage defaults and the housing market while the second is the effectiveness of PACE as an incentive for clean energy (Fadrhonc et al. 2016). This paper will focus on the latter question, namely does having an active PACE program increase the adoption of solar PV that otherwise would not have happened. Substantial research has been done to look at the impact of other incentives on solar PV. This paper does not address the impact of third-party owned (TPO) systems. TPO financing, such as power purchasing agreements or solar leasing, is an alternative to PACE and have risen in popularity over the years.

This paper closely follows the methodology of Kirkpatrick and Bennear, who conduct a policy evaluation of 3 of the earliest PACE programs (Kirkpatrick and Bennear 2014). Their study ranged from 2008 to 2010 and is restricted to cities

Table 1—PACE Comparison

Program	HERO	E3	Ygrene Works	Figtree	CSCDA Open PACE
Launched	2014	2014	201	2011	2015
Administrator	Renovate America	Energy Efficiency Equity	Ygrene Energy Fund	Figtree Financing	Varies
Government Entity	Western Riverside Council of Governments	California Municipal Finance Authority	California Housing Finance Authority	California Enterprise Development Authority	California Statewide Communities Development Authority
Jurisdiction	298+	Around 50	165	160	100 - 340
Interest	6.75-8.35	2.95-7.98	6.5-8.49	Market Rate	Varies
Term	5-20	5-30	5-30	5-30	5-30
Max/Min	Min: 5,000 Max: 15%	Min: 5,000 Max: 20%	Min: 2,500 Max: 100%	Min: 5,000 Max: 20%	Mine: Varies Max: 15%
Energy Audit	Contractor may provide but not required	If desired	Recommended	Encouraged	Recommended

source: City of West Hollywood. Information is as of February, 2016

Note: Max/Min reported as dollars or percent of property value
CSCDA contains multiple PACE programs including Spruce, Alliance NRG, PACE funding group and California First

with populations of 20,000 or more[9]. This paper studies the period of 2011 and 2016 and includes all incorporated cities in California. Kirkpatrick and Bennear use data from the California Solar Initiative, which is included in the Open PV database used in this paper.

Ameli, Pisu and Kammen take a spatial approach with a regression discontinuity design to study the impact of the Sonoma County Energy Independence program which is available at the county level (Ameli, Pisu and Kammen 2017). Here, the authors compare the impact of PACE on solar installations for cities in Sonoma County compared to cities in neighboring counties without PACE. The authors employ a pseudo-Poisson maximum likelihood (PPML) estimator which is used in this paper.

Deason and Murphy conduct a comprehensive study on PACE in California from 2010 to 2015. They also follow the methodology of Kirkpatrick and Bennear. The authors use the Open PV database as well and there is a large overlap in the time frame studied. A major difference is in the units of observations used [10]. Due to similarities in the data and method, results of the impact of PACE

[9]This is because of the ACS 3-year sample used, which is available only for cities with population greater than 20,000

[10]Deason and Murphy look at kilo-watts per owner-occupied household installed in incorporated cities

are similar.

Previous studies have confirmed a positive impact of PACE solar installations. The PACE programs in Yucipa, Sonoma and Palm Desert had a 108 percent increase (Kirkpatrick and Bennear 2014), a 74 percent increase for Sonoma, (Ameli, Pisu and Kammen 2017) and a 7 percent increase for all of California (Deason and Murphy 2018). An analysis done by Lawrence Berkeley National Laboratory (LBNL) looks at the impact of PACE on mortgage performances and energy savings (Fadrhonc et al. 2016). This research is still in progress but crucial to understanding the complete economic impact of PACE.

Ameli, Pisu and Kammen conclude that PACE is a cost effective mechanism at promoting solar PV and should be more widely adopted. This paper looks at PACE on a larger scale. Our analysis spans from 2011 to 2016 and encompasses all of California. Additionally, all residential PACE programs are analyzed in a more mature solar market.

II. Data

A. Solar Data

The data used for solar installations comes from the National Renewable Energy Laboratory (NREL) Open PV Project. Open PV compiles all available project level data on solar installations from utilities, state agencies and incentive programs. The data set contains over a million entries, spanning from 1998 to the end of 2016. LBNL believes this data set contains 83 percent of all PV systems installed through 2016 (Barbose and Darghouth 2016). Data is self-reported by installers and customers. While this database contains a wide range of variables, the ones of interest to this analysis are location, project type, county, installation date and system size.

The sub sample used contains 605,596 observations from the state of California. All duplicates, non-residential installations and installations that fall outside the time frame were removed. Reporting of location and county were standardized and corrected for spelling. There are possibilities of errors with the reported system size but are uncorrected due to the large sample size.

This data is then converted to panel form. Number of installations and kilowatts installed in a given location are summed for each quarter which defines the unit of observation. [11]. The panel is then balanced by recording 0 for places with no observation in that quarter. 9,297 zeroes were filled in across 758 locations. The final data set includes 1,106 unique locations over 24 quarters, resulting in 26,544 observations. Around 35 percent of total observations are zeroes, discussed more in section III.C

on a monthly basis. This study includes unincorporated areas and is on a quarterly basis

[11]Note that the data represents only new installations that occurred in a location and quarter

Some clarification should be made on the nature of the location variable. Location is divided into two categories, incorporated cities (including towns) and unincorporated places. There are 482 cities in California and no definitive number of unincorporated places. The only locations that are used in the study are those that appear as a location entry for a project in the Open PV database after cleaning. The data is limited by the fact that it does not capture all possible locations in California, only those where a solar PV installation was observed at any point.

All 482 cities are accounted for, leaving a total of 624 unincorporated places. These unincorporated places are not under the jurisdiction of a municipal government but are administered by the county. Unincorporated places are classified to conform as closely with the Census geographic boundaries as possible.[12] While the locations included are not comprehensive in terms of area coverage, they should be comprehensive in terms of population. According to the 2010 census, around 82.5 percent of Californians live in incorporated cities (Census 2010). Adding the observed unincorporated areas, this should account for most of California's population.

To control for population, total kilo-watts are divided by the number of owner-occupied households for each location. This metric is appropriate since households are the agent making the adoption decision rather than individuals. Renters have little incentive to invest in homes they don't own, even if they are allowed to. Owners who don't occupy the unit have less incentives to install solar PV since they won't realize the energy savings. The data for owner-occupied households comes from the 2012-2016 American Communities Survey.[13] For locations where the 2012-2016 ACS estimates for households was zero, the 2011-2015 estimate was used. The household-weighted spatial distribution of observations is displayed in figure 3.

Some locations that appeared in the Open PV data did not appear in the ACS. 923 out of 1106 locations were successfully matched and had non-zero values for households. This leaves a total sample size of 22,152

B. Pace Programs

Some of the PACE programs such as the Sonoma County Energy Independence Program (SCEIP) and Place County mPower are government run and the data is publicly available. The rest of the data is generously provided by the PACE administrators.[14] Both the jurisdiction and start dates of the PACE programs are available. Jurisdictions include both specific cities and the unincorporated regions of a county. The unincorporated area of Riverside County was excluded

[12]The Census uses Census-Designated-Place when referring to unincorporated areas. Some undesignated places are lost as a result

[13]The 2011-2015 sample could have also been used. Since more observations lie in 2016 compared to 2011, the 2012-2016 sample was chosen

[14]special thanks to Mr. Jeff Deason of LBNL for the helping obtain this data

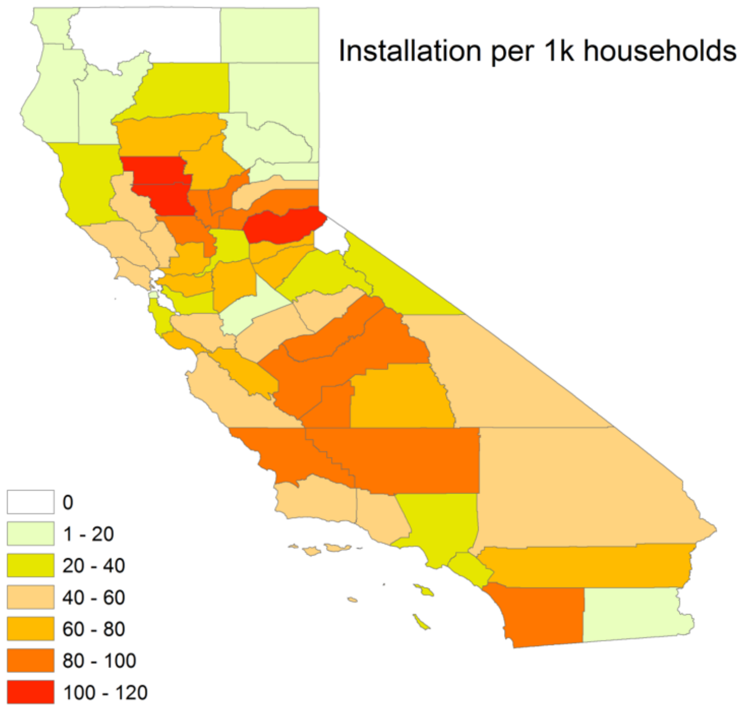

Figure 3. Cumulative Installations by County

Note: Some counties display no installations. These counties are sparsely populated.

from the final sample because of ambiguity with geographical boundaries. It was impractical to separate the regions of Western and Eastern Riverside.

The oldest PACE program was SCEIP which was available for the entire time period studied. Other regional programs in Riverside, Placer, San Bernardino and Sacramento counties launched between 2011 and 2014. February 2014 was when (HERO) began statewide. Other statewide programs such as Ygrene and CaliforniaFirst launched in later periods. CaliforniaFirst later partnered with other PACE providers to form the California Statewide Communities Development Authority (CSCDA) Open PACE program. All residential programs in CSCDA would become available once adopted, increasing competition and consumer choice.

The policy treatment is then defined as if the location had any active PACE programs in that quarter. For the time period covered, once a PACE program launched it remains active in all subsequent quarters. 23.6 percent of the final sample is considered as treatment. 383 locations had no treatment in any period. PACE coverage by year, defined as percentage of households with PACE available, is shown in figure 4. The spatial distribution of HERO coverage is shown in figure 5.

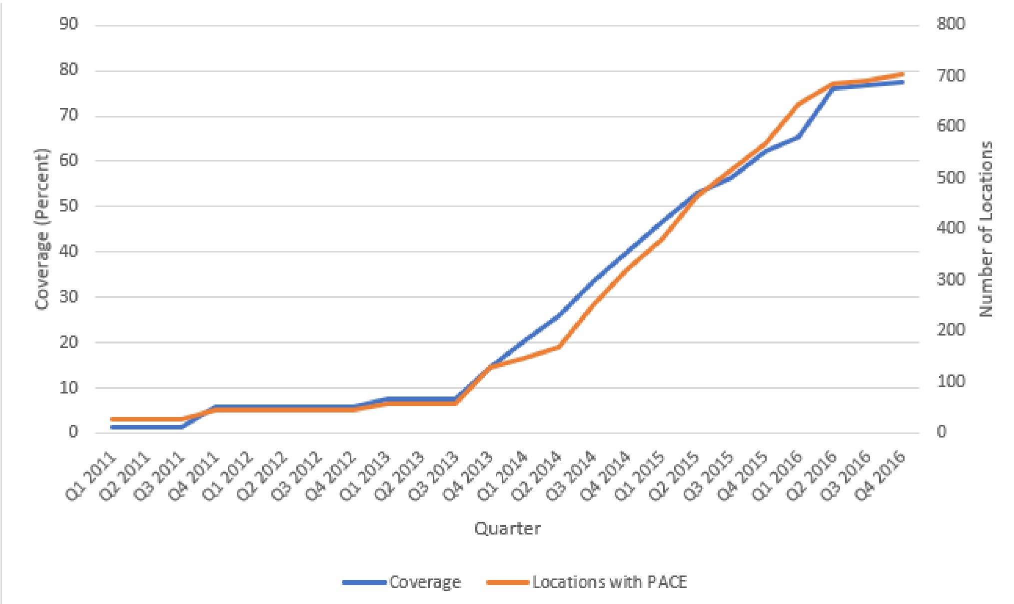

Figure 4. Yearly Expansion of PACE

C. Controls

Factors that affect a household's propensity to adopt solar PV are controlled for. These variables include housing prices, residential base-tier power price, incentive rate and political affiliation.

A housing price index is obtained through the Federal Housing Finance Agency on a yearly basis for every county. The source is appraisal value and sales price for mortgages guaranteed by the FHFA. Data is re-indexed to have 2011 be the base year.

The time period studied starts in the post housing crisis recovery and counties experience differential trends in housing prices, illustrated in table 2. We see that housing prices fell drastically in Mono County, appreciated noticeably in Monterey County and remained relatively unchanged in Nevada County.

Base-tier power price data comes from the US Energy Information Administration (EIA) and is available for every utility service territory in the Open PV data set on a yearly basis.

The largest incentive program in the state is the California Solar Initiative. The three main IOUs in California, Southern California Edison, San Diego Gas

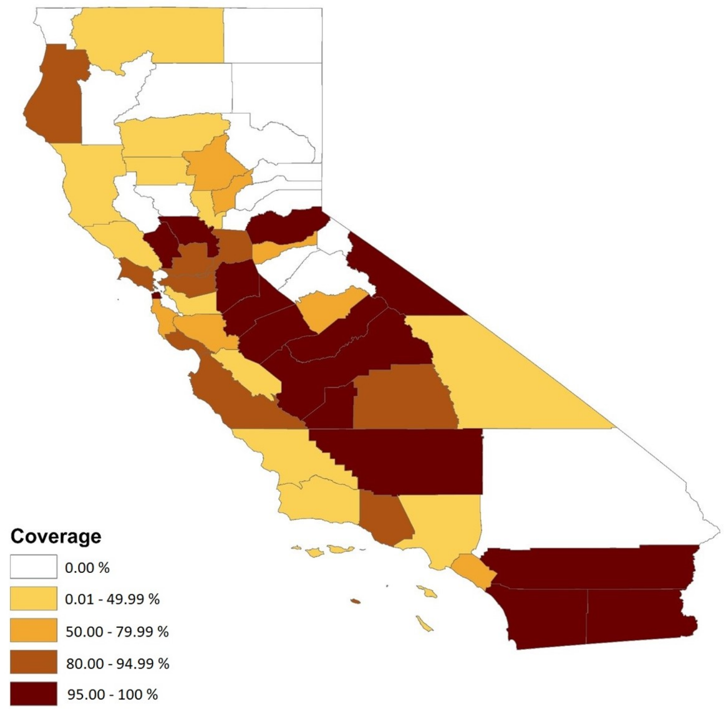

FIGURE 5. HERO COVERAGE BY COUNTY

and Electric and Pacific Gas and Electric, are responsible for distributing cash rebates to qualified systems. Over 90 percent of observations are within the three main IOUs. The rebate levels are scheduled to decline after a certain capacity has been reached, allowing different incentive rates for each IOU. Total rebates per quarter paid to residential systems per IOU is obtained from the CSI directly. The incentive rate is then calculated by dividing total rebates paid by total kilowatts installed, per IOU and quarter. Locations that fall outside the three IOUs have a value of 0 for incentive rate. There is a rebate/grant variable included in the Open PV data set but it was found to be very noisy.

Data is available for political affiliation for every incorporated city on a yearly basis from the California Secretary of State. All unincorporated areas in a county are treated as one unit. Political affiliation is calculated by the percent total voters who are registered as Democrats and percent who are registered as Republicans.

Variables that do not experience differential trends over time such as solar radiation are not included. A comparison between PACE and non-PACE cities are shown in table 3. Cites with PACE have significantly higher watts installed and population (although standard deviations are quite large). PACE cities tend

Table 2—Selective Housing Prices

Period	Mono	Monterey	Nevada
Q1 2011	770,833	246,250	225,342
Q2 2011	488,888	263,333	229,279
Q3 2011	477,778	260,667	219,122
Q4 2011	364,880	270,444	225,317
Q1 2012	513,889	286,663	217,000
Q2 2012	544,444	288,000	226,303

Note: Data is reported in nominal dollars for current sales. This data is not used in the model because it was not complete for the sample.
source: California Association of Realtors

to be younger and lean Democratic. While the median income for non-PACE cities is higher, median home price for PACE locations is higher. This may be explained by the fact that PACE is concentrated in urban areas, which display the characteristics of having higher housing prices, being more populated and leaning Democratic. Figure 5 shows the coastal and urban counties have higher coverage of HERO.

III. Methodology

The key to measuring the causal effect of PACE on solar PV is a comparison of installations in places with PACE and those without. This is done with the difference-in-difference method with the presence of PACE being the treatment. Controlling for other factors, installations that occur in PACE locations are attributed to the program. Figure 6 shows the percent of installations that occurred in PACE locations.

A. *Assumptions*

The key assumption for difference-in-differences is that trends pre-PACE are the same in treatment and control locations. Because PACE is an opt-in program, there is a potential problem of selection. The process of how PACE is adopted is unobserved. An issue of endogeniety would arise if only locations with characteristics favorable to adoption adopt PACE. Table 3 shows that key variables such as median income and education are similar in PACE and non-PACE cities.

Table 3—Q4 2016 Descriptive statistics

Variable	**Unit**	**PACE**	**non-PACE**
Watts	kilo-Watts per OOH	119.68 (1,011.44)	55.35 (131.89)
Frequency	Installations per 1k OOH	11.41 (33.38)	7.01 (12.95)
Population	People	44,760 (18,644)	22,058 (42,776)
Median Income	Dollars	65,329 (31,349)	67,828 (41,183)
Over $200,000	Percent of households	7.37 (9.74)	8.31 (12.34)
Median Age	Years	40.22 (9.67)	41.87 (10.25)
Bachelors	Percent of population over 25	27.62 (19.29)	27.34 (21.43)
Graduate	Percent of population over 25	10.37 (9.85)	10.66 (11.22)
Housing Prices	Sales Price	482,283 (278,026)	456,693 (230,883)
Ownership Rate	Percent of homes	61.49 (16.45)	62.04 (19.68)
Retail Price	Dollar/kilo-Watt Hour	18.70 (2.23)	17.97 (2.24)
Democrat	Percent of registered voters	40.70 (10.74)	38.14 (11.53)
Republican	Percent of registered voters	31.29 (11.35)	33.60 (13.08)
n	Number of Locations	597	329

Note: Cells contain averages across all locations. Standard deviation reported in parenthesis

source: Data on demographic and socio-economic variables comes from the 2012-2016 ACS

The fact that median income is higher in non-PACE locations suggests PACE is not only available in wealthy areas which are more likely to observe high levels of installations. This lowers the concern that some unobserved factor affects both the adoption of PACE and watts installed.

Another violation of the parallel trends assumption would be if places who adopt PACE see an uptick in installations before PACE goes into effect. A visual check of this assumption is performed in figure 7. Only California HERO as the treatment is considered for simplicity's sake.

Figure 7 plots the average number of installations per 1,000 owner-occupied households. The treatment group consists of all cities who have HERO by the end of 2016. Treatment start dates are normalized so that $t = 0$ represents the first

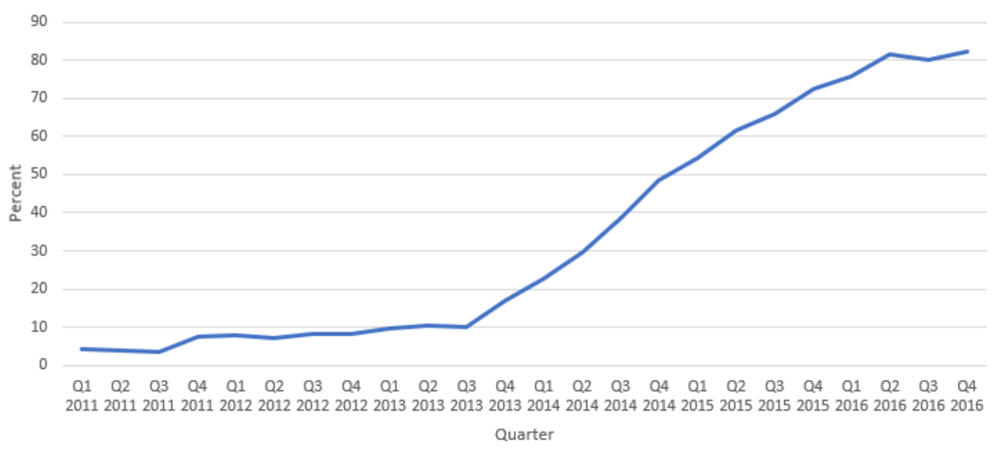

Figure 6. Installations in PACE Locations

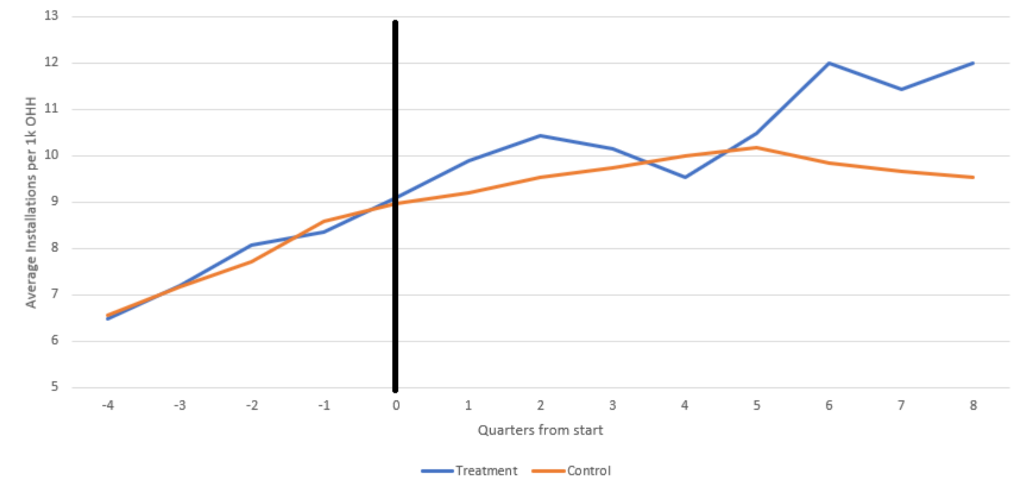

Figure 7. Normalized Treatment Effect

quarter HERO became available in a specific location, with $t = -4$ representing one year before HERO launched. The control group consists of a weighted average of locations with no PACE in any period. The time is scaled so in every period, the proportion of treatment and control locations coming from a specific quarter-year pair are the same. For example, at $t = 0$ 14 percent of the treatment group consists of programs that started in Q3 2014. This means that 14 percent of the control group consists of no-PACE cities in Q3 2014. Figure 7 shows that treatment and control groups don't perfectly follow the same trends in the year before PACE launches. However, there is no clear divergence in trends either. The visual inspection provides evidence that the parallel trends assumption is not notably violated.

An assumption is made in this model that the treatment effect of PACE is homogeneous. Certain city-specific factors may affect the rate of adoption, but the effect of PACE should be the same for all locations. There is no reason to believe that this is the case. Because PACE is an opt-in program, terms are the same for all locations. The sample of locations is also large enough to average out any heterogeneous effects.

Two other assumptions about PACE are made based off the work of Deason and Murphy. The effect of multiple PACE programs is assumed to be the same as the effect of one PACE program. This means that only the first PACE program to be launched is considered a treatment. Deason and Murphy theorize multiple PACE programs can increase information and reduce costs through competition. They find the impact of multiple PACE programs to be 40% as large as single PACE program but is not statistically significant. Due to limitations in data, multiple PACE is not considered. The authors also found no significant effect of lagged PACE variables, which are not included in this model.

If a homeowner chooses to install a TPO system, then they are choosing to not participate in PACE. TPO systems account for over a third of all installations. Removing TPO systems would lead to selection bias so they are left in the data set. Since legislation is needed to enable TPO systems, their presence is regionally concentrated. The adoption of TPOs could have a potential effect on the impact of PACE which is not measured.

Another issue with measuring the impact of PACE is the potential substitution effect. Since PACE can be used to finance all forms of energy efficiency upgrades, some homeowners may choose other projects over solar panels (Fadrhonc et al. 2016). In California, a large portion of energy costs go towards air conditioning and homeowners may choose to upgrade their HVAC system instead if they see greater potential savings. This decreases the incentive to install solar PV which could lead to PACE reducing the rate of solar adoption. Since project level data is not available, this issue is not addressed.

B. Model and Sample

Our model uses fixed-effects at the location level to address unobserved heterogeneity between places. An example would be a concentration of high tech industries in an area which could make adoption easier for residents. The concern would be if shocks lead to changes in solar PV installations only for treatment cities over a period of time. Given the spatial separation of treatment cities, this is unlikely to be a problem.

The dependent variables used in this model are watts installed per owner-occupied households (WOHH). The model is given by:

$$WOOH_{it} = \beta_0 + \alpha_i + \delta_t + \gamma X_{it} + \beta Z_{it} + \epsilon_{it} \quad (1)$$

Here, α_i represents location level fixed effects and δ_t represents quarter-year time fixed effects. X_{it} consists of time-variant control variables and Z_{it} is a binary variable representing the presence of PACE in location i at time t. Equation 1 is run again with quantity of installations per owner-occupied household as the dependent variable.

The control variables included in X_{it} are housing prices, power prices, incentive rates and political affiliation.

As shown in table 1, the maximum value of the PACE loan is dependent on the value of the property. This in turn impacts the system size and kilo-watts installed. For most providers, eligibility is dependent on the property's loan to value ratio. Household wealth is a major determinant in solar adoption and housing prices are an indirect measure of wealth. Square footage and ownership rates are not considered.

One of the largest incentives for solar PV adoption is energy savings. Power prices vary across California depending on geography due to differences in regulations and costs of generation and transmission. There should be a positive relationship between electricity prices and kilo-watts installed. Likewise, higher cash grants incentives the adoption of solar PV (Crago and Chernyakhovskiyb 2017). There are numerous state and local incentive programs besides the CSI, but it is by far the largest with a budget of over $3 billion. The CSI is assumed to be the incentive program with the largest effect on the decision to adopt.

Political affiliation captures two forces. The first is any underlying political process that may influence the adoption of PACE or other clean energy policy. Voters tend to elect candidates from their own party. Political affiliation in a city is expected to be highly correlated with the political makeup of a local government. Polling and research has consistently shown differences in support for environmental policies based on partisan affiliation[15]. Democrats tend express greater concern about the environment (Dunlap 1975) and would in theory be more likely to adopt solar PV [16].

Demographic data, especially income, is theoretically important but not included. Data was not available on a consistent basis across geography and time. Kirkpatrick and Bennear use the 3-year ACS estimates which is no longer published. The 5-year ACS is collected as an average over 5 years and provide useful estimates for each location but cannot capture between location trends.

[15]The 2017 Center for Climate Change Communication Survey 97 percent of self identified liberal Democrats think climate change is happening. 37 percent of self-identified conservative Republicans believe the same. There is a similar difference in percent of voters who are worried about climate change.

[16]The Climate Change Communications Survey found that 92 percent of Democrats say citizens should do more or much more to combat climate change. 62 percent of independents and 45 percent of Republicans responded the same way.

The yearly estimates are only available for cities with populations of 65,000 or more which would exclude too much of the sample. Kirkpatrick and Bennear find the impact of PACE drops by just .01 when demographic controls are excluded (Kirkpatrick and Bennear 2014). Other studies have also found results to be robust to the inclusion of such demographic variables (Gillingham and Tsvetanov 2017). The variation in variables that are not picked up by the time trends such as education is expected to be small.

C. Poisson Model

A common issue in the solar PV literature is the prevalence of zeroes in the data set. Figure 8 shows the distribution of installations as a count. In this sample, 35 percent of all observations are zeroes and the data is highly skewed towards zero. The zeroes observed are true zeroes, where no household in a location and quarter made the decision to adopt solar PV. As the total number of installations rises every year, the fraction of zeroes observed falls. This is shown in figure 9.

A large number of zeroes introduces non-linearity into the model which could bias linear regression results. Removing those zeroes would lead to selection bias (Ameli, Pisu and Kammen 2017). A Poisson pseudo-maximum likelihood estimator is one way of dealing with skewed data with excess zeroes and is common in trade literature (Santos Silva and Tenreyro 2006). The PPML estimator does not require the data to follow the Poisson distribution (Gourieroux and Trognon 1984) to be consistent and does not suffer from problems arising from heteroskedasticity as traditional log-linear models do. The fixed effects Poisson model is shown to be robust and able to capture unobserved heterogeneity (Wooldridge 2005).

$$WOHH_{it} = exp(\beta_0 + \alpha_i + \delta_t + \gamma X_{it} + \beta Z_{it} + \mu_{it}) \quad (2)$$

The equation estimated is similar to that of Ameli et al. and include time and location fixed effects. Here, the control variables used in X_{it} are the same as in equation 1.

IV. Results and discussion

A. Full Sample

A comparison of watts installed in PACE and non-PACE locations every quarter is shown in figure 10. In the first three quarters of 2011, the only active PACE program was in Sonoma County and the small sample explains why the average is significantly higher. Between 2012 and 2014, we see PACE and non-PACE locations follow similar trends. As shown in figure 5, the number of PACE locations expands dramatically in Q1 2014 with the launch of California HERO. After 2014, with the exception of two quarters, the PACE group has on average higher

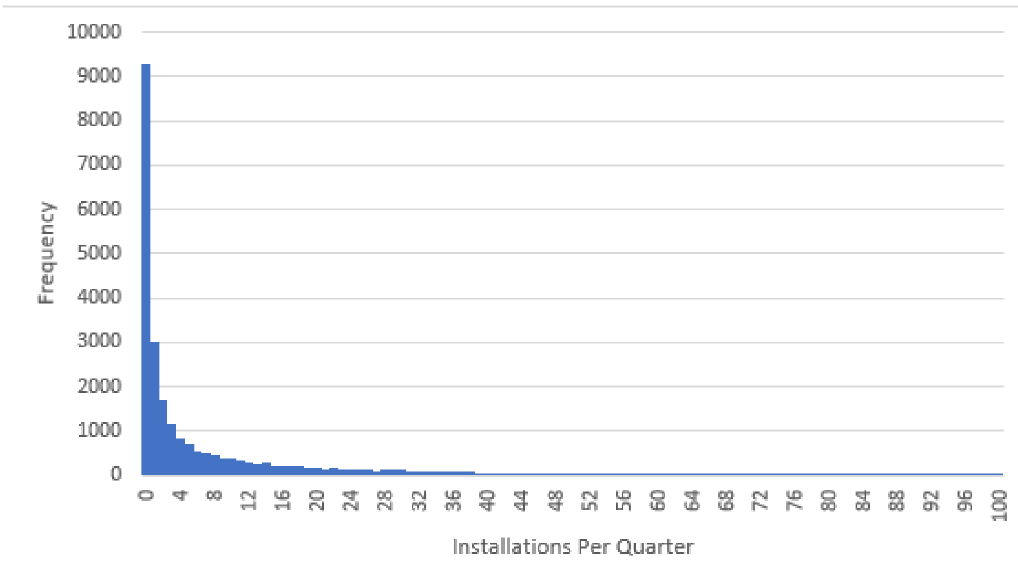

Figure 8. Distribution of Observations

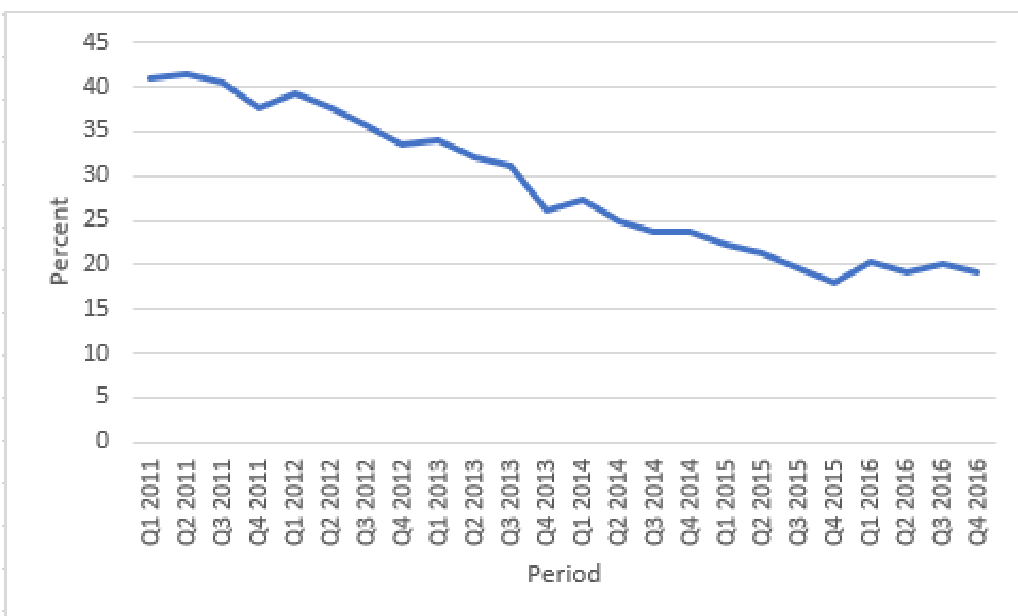

Figure 9. Percent of Observations which are Zeroes

levels of WOOH installed. There is a large upward swing in installations at the end of 2016, in part due to a large block of PACE programs starting. Figure 10 provides evidence that the impact of PACE on installations is positive.

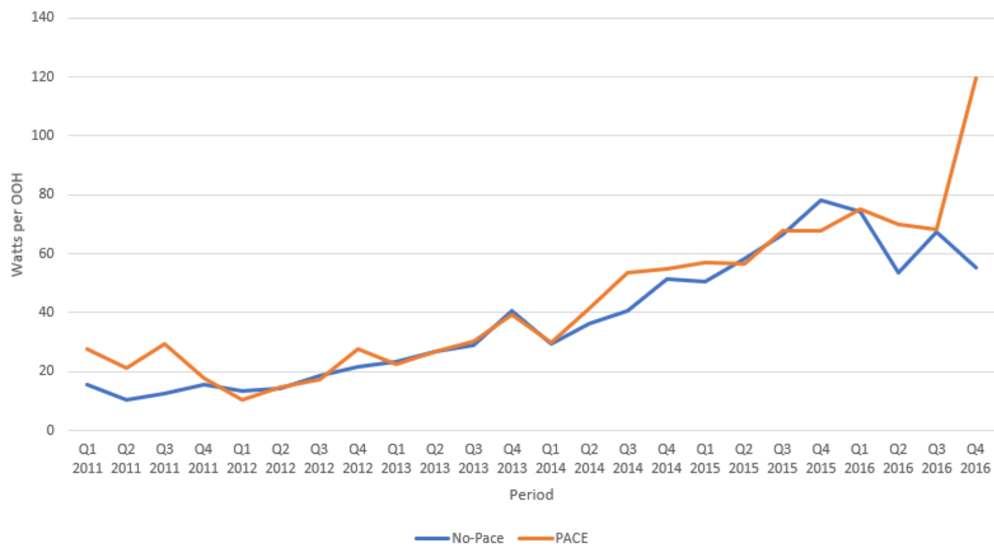

Figure 10. PACE and non-PACE

Table 4 displays the results from the linear model run on the full sample. Without any control variables, PACE leads to an increase of 8.47 WOOH installed. Once all control variables are factored in, the impact of PACE becomes 1.93 WOOH. None of the PACE variables are statistically significant at the 5 percent level. After adding the control variables, the impact of PACE drop by over 75 percent. Bennear and Kirkpatrick found an over 50 percent decrease after adding in controls. 1.93 watts corresponds to a 5 percent increase in watts or about .5 installations per every 1,000 households.

This can be compared to the findings in New York where a dollar increase in rebate per watt led to an increase in 5 adoptions per 1,000 households (Yoo 2017). Similarly, a study of the Northeast solar market finds that an additional dollar in rebates results in a 50 percent increase in installations, an order of magnitude larger in effect than PACE (Crago and Chernyakhovskiyb 2017). Both these results apply statewide rather than just treatment cities. The upside of PACE compared to these policies is the absence of direct subsidies and near zero cost to the taxpayer.

Base-tier power price is found to have a size able positive impact on installations and is significant at the 1 percent level. Due to the time-dependence of solar energy, an increase in solar PV supply to the grid creates issues with intermittency. California utilities and policymakers have proposed different ways to

Table 4—Full Sample Linear Model

Variable	1	2	3	4
PACE	8.4689 (5.2553)	6.7880 (4.5371)	1.8780 (4.7583)	1.9256 (4.7047)
Power Price		9.2027** (1.8403)	9.5736** (2.3999)	11.3752** (2.6425)
Housing Price		0.7597** (.1728)	.7601 (0.6990)	0.5821 (0.6889)
CSI Incentive Rate		0.0001 (0.0018)	.0007 (0.0012)	.0005 (0.0012)
Percent Democrat				-6.5886** (2.1453)
Percent Republican				-7.6023** (1.9077)
Location FE	Yes	Yes	Yes	Yes
Time FE	Yes	No	Yes	Yes
Constant	91.6004 (24.3412)	-198.3844** (40.6154)	-181.2878 (103.1824)	323.6368* (130.1227)
Clusters	923	923	923	923
Observations	22,152	22,152	22,152	22,152
Adj-R^2	.1332	.1341	.1346	.1353

Note: Huber/White robust standard errors in parenthesis
Standard errors are clustered at the place level
* P <= .05
** P <= .01

structure energy rates such as time of use tariffs. Changes in rate design including net-metering could have a large impact on the incentives to adopt solar PV. Technological improvements in energy storage could potentially have a significant impact on solar PV.

Both the incentive rate and housing prices have a positive effect on PV adoption. Neither are significant in the full samples. More research on the relationship between PACE and housing markets will help better understand the relationship of PACE and housing prices. Research has shown in some counties of California, solar PV increases local housing prices (Dastrup and Kahn 2011). A more complete set of controls would include more time-variant variable such as home ownership and other measures of wealth.

Both of the political variables are significant at the 1 percent level. However, both estimates fall within 1 standard deviation of each other and the economic significance is unclear. The coefficient for percent Democrat is less negative than that for percent Republican.

The results of the Poisson model are displayed on table 5. All coefficients are exponentiated and interpreted as an increase in 1 unit of the regressor increases

Table 5—Full Sample Poisson Model

Variable	1	2
PACE	1.034 (0.0913)	0.994 (0.0887)
Power Price	1.104** (0.0409)	1.158** (0.0429)
Housing Price	1.014 (0.0109)	1.008 (0.0107)
CSI Incentive Rate	1.000** (0.0001)	1.000**) (0.0001)
Percent Democrat		0.8612** (1.0454)
Percent Republican		.8712** (1.0358)
Location FE	Yes	Yes
Time FE	Yes	Yes
Clusters	923	923
Observations	22,152	22,152

Note: Coefficients and standard errors are exponentiated
Robust standard errors in parenthesis
Standard errors are clustered at the place level
* P <= .05
** P <= .01

WOHH by 1. The main finding is that the impact of PACE is substantially lower under the Poisson specification. Results are not significant and the p-value is higher compared to the linear model. The impact of both incentive rate and housing prices increases dramatically to the levels of power price. Percent Republican and Democrat have virtually the same impact in this model.

The difference in results of the Poisson model could imply that the excess zeroes do pose an issue and bias linear regression results. A 2-stage hurdle model used by Gillingham and Tsvetanov could also be employed. The first stage is a probit model of the probability of adoption and the second stage is a truncated Poisson conditional on the first stage (Gillingham and Tsvetanov 2017).

These results for the impact of PACE are consistent with Deason and Murphy who find an increase in 0.6 WOHH per month, or 1.8 per quarter. Their result was a 7 percent increase in watts compared to 5 percent in this study. Part of this is because 2016 had a record number of total watts installed. These results are much lower than, but not inconsistent with, Kirkpatrick and Bennear and Ameli et al.

V. Conclusion and policy implications

PACE financing is just one of many tools available to policymakers. This paper finds that PACE has a positive impact at increasing solar PV adoption. Although the impact of PACE is not as large as other incentive programs, PACE can be structured to have no cost to the taxpayer. These findings are consistent with economic theory and previous work. This study can be improved with access to better data, most importantly household wealth.

It is important to note that only 37 percent of the total PACE portfolio goes towards solar. PACE is most likely a better tool at promoting energy efficiency than these results alone imply. Energy prices is shown to be a very important factor in solar PV adoption. Policymakers should make sure to structure rates in a way that aligns with their climate goals.

An area worth examining is the distributional impact of PACE as a policy. Wealthier households are more likely to be able to finance solar PV directly or have access to loans with superior terms. The benefits of most other incentive programs tend to favor the wealthy who are more likely to adopt anyways.

PACE is shown to have a positive impact on PV installations and should be considered in other states. Issues relating to consumer protections and risks to mortgages should be examined. Third party owned systems, which have come to dominate the California market, should be weighed as an alternative to PACE.

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