USC Schwarzenegger
Institute for State and Global Policy

THE IMPACT OF PACE FUNDING ON SOLAR ADOPTION

Jonathan Eyer
Research Assistant Professor in Policy Analysis and Economics

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Abstract

The Property Assessed Clean Energy (PACE) Act allows the cost of energy saving investments like solar panels to be paid via property taxes rather than with traditional loan payments. The costs of PACE financing are low to the government and may provide a more cost-effective method of inducing solar panel installations than other mechanisms like subsidies. This paper provides evidence that PACE availability results in large increases in solar panel installations. This behavior exists both in California, which was an early PACE adopter, but also in Missouri, a later PACE adopter which may be considered less amenable to green solar preferences. Importantly, the installation benefits of PACE are not permanent and there is evidence that the installations decline in the instances where PACE authority is removed.

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1 Introduction

In order to reduce greenhouse gas emissions and slow anthropogenic climate change, it is necessary to shift electricity generation from fossil fuel sources that emit carbon dioxide toward renewable sources like solar and wind power. In the case of solar power, electricity- generating photovoltaic (PV) panels are frequently placed on homes, businesses, and other privately-owned structures. Rather than an electric utility owning the solar panels and selling the electricity directly to the consumer, the panels can be purchased, financed, or leased by the property owner and their generation reduces the owner's net electricity bill. The solar panel systems are relatively expensive, generally costing tens of thousands of dollars, so the upfront cost of solar panels constitutes an important barrier to solar deployment. One strategy that has been implemented to increase the adoption of solar PV (and other energy efficiency capital improvements) is the Property Assessed Clean Energy (PACE) program, in which the responsibility for the cost of the installation is attached to the property itself via a tax assessment, rather than to the homeowner who takes out the assessment.

PACE is a financing mechanism through which property owners who wish to invest in energy or water efficiency, hazard mitigation, or renewable energy improvements can pay for the investment. Under PACE, a special tax assessment is placed on the property owner's tax bill. Like traditional financing models, this allows homeowners to make investments even if they do not have the upfront capital required for the purchase. In the case of PACE, however, the responsibility for the repayment (through the tax assessment) is tied to the property rather than the property owner, and eligibility is tied to the equity in the property and underwriting criteria are determined by state statute.

There are several mechanisms through which PACE might increase the amount of solar PV capacity that is installed. On average, interest rates from PACE assessments are similar to interest rates that homeowners would receive in traditional lending markets, but PACE may provide lower interest rates for borrowers with below average credit histories. This may result in additional PV installations because PACE is facilitating installations from a type of homeowner who would otherwise be priced out of the credit market (Bird and Hernandez (2012)). PACE may also simply increase consumer awareness about solar panels in general or about financing opportunities in general. Finally, the duration of PACE repayment is tied to the useful life of the project. In the case of solar panels, repayment can occur over 25-30 years, reducing the annual payments.

While states and municipalities began experimenting with authorizing PACE financing in the late 2000s, initial PACE programs were relatively limited in geographic range. In subsequent years, several states and many counties and municipalities (primarily in California) have begun residential PACE financing programs and similar property-assessment structures are being considered for a wide range of financing needs. Evidence from the early PACE adopters suggests that the program is indeed effective in increasing installations.

Kirkpatrick and Bennear (2014) find that the introduction of California's initial PACE programs in Palm Desert, Yucaipa, and Sonoma County more than doubled the amount of solar capacity per household that was installed each quarter. Similarly, Ameli et al. (2017) find that PACE authorization in Sonoma County increased PV installations by similar magnitudes using neighboring counties that did not institute PACE to control for changes in conditions in the solar industry that occurred concurrently to Sonoma County's PACE authorization. Deason and Murphy (2018) considers a longer sample than Kirkpatrick and Bennear (2014) and finds smaller effects suggesting that approximately 10% of all installations are attributable to PACE.

Despite the relative success of the initial PACE programs in increasing solar PV installations, there has been some opposition to PACE financing programs (Hoops (2011)). Fannie Mae and the Federal Housing Financing Agency (FHFA) raised opposition to PACE in 2010 on the basis that because liens associated with PACE assessments took priority over other liens against a property, and that PACE created risks in the home lending market. Similarly, realtor groups have opposed PACE on the grounds that, because the PACE assessments may have to be fully repaid prior to the transfer of a property's title, these programs affect the ability for a borrower to sell their home. Under the Trump Administration, there is further opposition to PACE financing in general as the Department of Housing and Urban Development has indicated that it will no longer insure mortgages with PACE liens (a reversal of HUD policy under the Obama administration).

In light of these concerns and the general progression of PACE funding, it is important to better understand the impact of PACE on solar installations. In particular, while existing studies of the efficacy of PACE were based on the early adopters of the program, PACE funding is now available to a large number of residential consumers throughout California. While PACE showed large increases in solar installations when these early programs went into effect, the benefits of PACE may not be as large in municipalities that were slower to adopt PACE (which may suggest homeowners who are less interested in solar panels regardless of the funding mechanism) or in the current solar market. This paper fills these gaps by providing estimates of the impact of PACE on solar PV installations across a wider range of municipalities than previous studies and under more mature PACE and solar PV market conditions.

Specifically, this paper identifies when PACE financing was first utilized in each incorporated and unincorporated municipality in California and uses this date to define when PACE became available in communities throughout California. It uses a fixed effects approach to control for observable and unobservable characteristics of municipalities that would influence the magnitude of solar installations in a community and estimates the change in solar PV installations within a municipality after PACE became available. Baseline results suggest an effect that is comparable with Kirkpatrick and Bennear (2014) and Ameli et al. (2017); PACE availability approximately doubles the amount of new PV that is installed in a community. Alternative specifications that provide greater confidence about identifying the causal effect of PACE (rather than time effects that merely correlate with the intro- duction of PACE) reduce this effect to around a 25% increase in new PV installations each month.

The paper also provides an analysis of how removing PACE will affect future PV installations by examining how installations in Bakersfield and unincorporated Kern County changed following the removal of PACE authorization. This is an important contribution in light of growing opposition to PACE. Moreover, if the primary mechanism through which PACE increases installations is through raising awareness of solar power in general, sub- sequent PACE programs may be unnecessary as homeowners are likely much more aware of the benefits of solar panels than they were when PACE was initially authorized. This paper provides evidence against this hypothesis. Solar panel installations fell by around a third in areas that removed PACE authorization relative to control communities, suggesting that PACE provides on going benefits and that further removal of PACE authorization will dampen solar installations.

Finally, existing research on PACE funding has focused exclusively on the effect of PACE in California by comparing solar installations in municipalities with PACE to those without PACE. Residential PACE is now available in multiple states and the impact of PACE may not generalize outside of California. This paper provides estimates of the impact of PACE on solar PV at the state and county level for California and Missouri. This provides a larger scale understanding of how PACE influences solar installations than approaches that rely on understanding municipality-level installation changes within California.

2 Data

2.1 California Distributed Generation Statistics

The primary data source for this paper is the California Distributed Generation Statistics (CDGS) Currently Interconnected Data Set which is compiled by the State of California. The Currently Interconnected Data Set provides data on 780,445 solar PV installations in California that are connected to the grid through one of California's three Investor Owned Utilities (IOU) but does not include solar panels that are connected through a Publicly Owned Utility (POU) or a Municipal Utility. This covers most of the state's population and geographic area but does not include several cities, including Los Angeles. The data set is updated periodically by CDGS and covers all installations that have been connected regardless of whether they applied for a rebate but does not include decommissioned projects or projects that are still in progress. The data used for this study was from July 31, 2018, the most recent available.

The data contain information about each solar PV system that is interconnected. Most notably, it provides the city, county, and zip code where the PV was connected as well as the date when the interconnection application was approved and the capacity of the installation in kilowatts. Following California Public Utility Commission (CPUC) order 14-11-001 in November 2014 several variables that were infrequently recorded became required. Most notably for this project, the CPUC mandated that utilities report whether a project was funded through PACE and, if it was PACE funded, which company provided the funding. While PACE funding variables are frequently missing prior to the CPUC order, each of the three IOUs reported PACE funding status on some interconnection applications prior to the order going into effect. The earliest observation for which the PACE financed variable is non-missing is in 2008, but the first observation in which PACE financing is recorded is in January 2012 (i.e., observations between 2008 and 2012 all signal "No" for PACE financing).

The most impactful data cleaning procedure removes all observations for which PACE status is unrecorded. This removes approximately 300,000 observations, most of which occurred prior to the CPUC order. In order to maximize comparability across municipalities and limit the effect of outliers, non-residential installations (approximately 3% of all applications), installations above 19.5 kw (3 standard deviations above the mean installation size, 0.4% of all applications), and installations above $12,800 / kw (0.6% of all applications with total cost data). Solar data are aggregated to the monthly and quarterly level to provide installation counts and capacity-weighted average installation prices for each municipality over time.[1]

Many small municipalities do not record solar installations in each month or quarter of the sample, so the data is balanced data by assigning each municipality that does not have any approved interconnection applications a zero for the relevant time frame. This results in a balanced panel of data on total solar capacity interconnections, total number of solar capacity interconnections, and the number of new capacities per household in each municipality.

The CDGS data is complemented with data from the 2015 5-year American Community Survey statistics. These data provide information about the number of housing units, the percentage of housing units with a mortgage, and the median income in each Census Designated Place in California. While using the 5-year estimates removes variation in community characteristics over time, it captures less populous areas than are reported in more frequent population estimates. These are merged to the CDGS data based on the name of the city or place.

2.1.1 Identification of PACE Availability

The key variable of interest in this study is whether PACE funding is available in a municipality at a given point in time. Given the relatively large number of municipalities and the opacity of the legislation authorizing PACE funding, PACE availability is calculated based on the first observed date where PV was installed using PACE funding in each regulatory region.[2] PACE is assumed to be available in the region for the rest of the sample.[3]

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[1] The term municipality here refers to both incorporated towns and cities as well as unincorporated Census designated places.

[2] Publication accessibility for city and county legislation varies and it is often difficult to ascertain when a council passed legislation to authorize PACE. This is particularly true for small municipalities.

[3] There are two cases in which PACE authorization was removed. These are discussed in Section 3.3.

In the case of incorporated areas, the definition is relatively straightforward because the decision to institute PACE corresponds to the level of aggregation in the data. If a PACE-funded solar installation is observed within an incorporated city's boundaries it must be the case that the city council has authorized PACE. In the case of installations in unincorporated places, the PACE authorization decision is made at the county-level and affects all unincorporated Census Designated Places within that county. The PACE availability dates in these regions are determined based on the first PACE-funded solar installation of an unincorporated Census Designated Place within a county, regardless of which Census Designated Place it took place in, and that date is applied to all unincorporated places within the county.

In addition to indicating whether a solar installation was financed via a PACE assessment, the CDGS data also lists the PACE administrator. The administrator provides the upfront capital to the local government that is creating the special tax assessment and in turn receives payment from the government as the assessment is repaid. Following the same process above, the first date that each of the three largest PACE administrators (Ygrene, Renovate America, and Renew Financial) are calculated for each municipality. This allows an observation to denote not only whether PACE was available, but also how many of the main PACE administrators were available to property owners in each municipality. Again, there is an implicit assumption that after a PACE lender is observed financing an assessment in a municipality that they remain in operation in that area.

Summary statistics of the CDGS data based on the monthly balanced panel are presented in Table 1. Most municipality-month observations have zero installations; approximately 30% of municipality-months have at least one new PV installation. Average installed capacity per municipality-month is 33 kW, approximately 5-6 new installations. Housing- stock normalized installations are highly variable throughout the sample, spiking when very small communities have moderate to large capacity additions. PACE is in effect for over three quarters of the municipality-month observations and there are approximately even numbers of observations that have one, two, and three of the primary finance companies in operation.

2.2 NREL Open PV

The CDGS data is supplemented with national data on solar panel installations from the NREL Open PV database. The Open PV database consolidates data on solar PV installations from government, utility, and individual sources.

The NREL data differs from the CDGS data in several key ways. Most notably, the CDGS data relates only to California while the NREL Open PV data covers the entire country. Similarly, while the CDGS only covers IOUs, the NREL data has information about installations in outside of IOU territory providing information about solar system installations across a wider range of households. On the other hand, the NREL data is driven in large part by voluntary reporting while the CDGS data is based on reporting requirements for affected utilities.

The NREL data contains installation dates and sizes for over 1 million solar PV systems in the United States. Every state is represented in the data although the number of observations is quite low in some states. There are observations dating back to the early 1980s, though they are relatively rare. Observations become much more frequent in the mid 2000s and the count of installed solar systems continues to grow until 2016 when the data quality weakens substantially. I limit the data to only installations that occurred after 2005 and before 2016 in order to maximize both the quality of the data and the external validity as it relates to PACE. After removing installations outside of this time frame and non-residential observations there are about 880,000 observations.

The NREL data is reported at the level of the ZIP code based on the installation address. The data are then mapped to counties by using the FCC's Census Block Conversion Tool. Installations are again aggregated to the monthly level so that the unit of observation is a county-month (or state-month).

3 Empirical Approach

In order to understand how the adoption of the PACE program has influenced solar PV installations, the number and size of residential solar PV installations in each municipality in California is estimated based on whether or not PACE is in effect.

The dependent variable, solar, is measured in four distinct ways. First, the total capacity of new solar installation (measured in kilowatts) measures the overall presence of solar PV capacity in a municipality. Second, the number of solar installations in a municipality conveys information about how much of the population is installing solar panels. The capacity per household is defined as the number of kilo-watt hours of capacity that are installed in a municipality divided by the number of households. This allows for a direct comparison of the effect of PACE funding on solar installations across cities of varying sizes. Finally, the installed price of solar panels, as measured in dollars per installed watt, provides information about the impact of PACE on the local market, particularly with respect to how PACE authorization might impact those who do not use PACE funding.

3.1 Fixed Effects Approach

The general structure of the model is

$$solar_{mt} = \alpha + \beta X_{mt} + \gamma PACE_{mt} + f(t) + \eta_m + e_{mt} \quad (1)$$

where $solar_{mt}$ is the amount of solar PV that is installed in municipality m at time t, $PACE_{mt}$ is an indicator variable that takes on a value of 1 if PACE lending is available in municipality m at time t, X_{mt} is a matrix of municipality characteristics that may influence solar adoption, f(t) is a flexible control for time, and e_{mt} is an idiosyncratic error term. The primary concern in the baseline regression of solar installation characteristics as a function of PACE funding is that the introduction of PACE will be endogenous. Municipalities with a large population of constituents who value solar power may implement PACE because its residents have underlying preferences for solar energy and would have installed solar panels even in the absence of PACE authorization. This could cause bias in the γ parameter because this coefficient is capturing both the impact of PACE and time-varying preferences in the community.

If the PACE adoption decision is entirely based on observable characteristics the matrix of municipality-level explanatory variables X_{mt} will address the selection process and the coefficient on $PACE_{mt}$ will be the causal impact of the introduction of the PACE pro- gram. Many municipality-level characteristics that would influence both underlying solar preferences and the adoption of PACE are unobservable (e.g., preferences for clean energy or concern about climate change), so municipality-specific fixed effects are used to control for all time-invariant characteristics of each municipality. This requires the assumption that these unobservable characteristics are not changing over time but given the relatively short length of time that PACE has been in effect this is not an overly aggressive assumption.

The generalized fixed effects framework may overstate the causal impact of the PACE program if solar installations change at a heterogenous rate across municipalities. Solar installations have generally increased over time and there are only two cases in which PACE programs went out of effect (See Section 3.3). Even with non-linear time controls, this could lead the estimated coefficient to capture the general upward trend of installations.

To address this concern, the primary estimating equation is modified to focus on time bands before and after the introduction of the PACE program in each municipality. In this case, the sample is limited to only municipalities that ever enacted PACE and a control for the length of time before the PACE program went into effect in a municipality is included.

3.2 Robustness to Data Errors

Due to the timing of CPUC order 14-11-001 and possible errors in reporting fields that were only mandatory after the order, some of the data may falsely assign early PACE adopters to an erroneously late adoption date. For example, the City of Berkeley was the first municipality in California to adopt PACE in 2008 while the first observation in the CDGS data suggests a PACE adoption date in 2015, shortly after Pacific Gas & Electric began reporting under the new requirements.

There are two strategies to address this possible bias considered in this paper. First, Ygrene was able to confirm the timing of their entry into Yolo and Sacramento Counties and the City of Chula Vista. They also confirmed that they were the first PACE financiers in those regions, so the timing of this PACE adoption is measured without error. Equation 1 is re-estimated using only the set of municipalities in which Ygrene was the first administrator.

Second, the data is limited to only those municipalities that had their first observed PACE-financed installation in 2017 or 2018. The assumption underlying this approach is that if a municipality adopted PACE prior to the implementation of order 14-11-001 that they would likely have at least one PACE-financed installation in the two years following the order. By removing all such municipalities, the data is limited to only those areas that plausibly experienced their PACE installation within the range of the heightened reporting requirements.

3.3 Removal of PACE

While PACE has generally been popular, there have been challenges to PACE in some communities. These concerns are generally based on the claim that a PACE assessment will make it more difficult to buy, sell, or refinance a home due to federal policies relating to PACE. As a result of this pressure, some municipalities have considered removing the authorization of PACE, precluding future installations from relying on this funding source. The most notable case of PACE termination occurred in Kern County, where the PACE program was removed in both the city of Bakersfield and in the unincorporated regions of the county. While the PACE program was officially repealed in June and July of 2017, projects were allowed to continue until January 2018 so that PACE-related projects that were already in development could proceed.

This provides an opportunity to understand how the effects of policies like PACE that are designed to promote adoption of cost-saving investments evolve over time. The reductions in electricity bills from solar panels generally exceed the installation costs of the equipment in the long-run so rational consumers should be installing panels even in the absence of government policy (Borenstein (2017)). Failure to adopt energy saving technologies that pay for themselves over time has been well documented and several behavioral explanations have been suggested for this paradox and policies aimed at increasing purchases of solar panels are intended to account for this failure (Gillingham and Palmer (2014)).

Similarly, one argument in favor of policy intervention in markets holds that governments can support new industries while they begin their growth, providing consumers an opportunity to learn more about the benefits of the product or providing producers an opportunity to learn efficient manufacturing processes that will make their product cost competitive against incumbent technologies (Van Benthem et al. (2008)). In the case of PACE funding, if PACE funding increases solar panel installations, these solar systems will contribute to overall knowledge about solar panels. From the consumer side, this means greater awareness of the benefits and options of installing residential solar. On the supplier side, the experience gained from installing PACE-financed panels will mean that installers learn to operate more efficiently and drive down costs for all consumers.

If the learning effect is driving the impact of PACE, there should be a relatively small reduction in solar installations after funding opportunities are removed. Solar technology and awareness advanced substantially between July 2015 when the first PACE-funded purchases took place in Bakersfield and "learning" benefits from PACE-influenced solar adoptions would likely have ameliorated.

Because there are only two municipalities that removed PACE, the problem can be presented in a standard difference-in-differences framework. Other similar municipalities that did not withdraw their PACE program authorization serve as counterfactuals to the level of solar installations in Kern County and Bakersfield. By comparing the regions that removed the PACE program to areas that were on similar trends prior to program removal the impact of the policy removal can be directly identified. The critical assumption necessary for causal inference in this case is that the treatment and control groups exhibited common trends prior to the shock (the termination of PACE).

The general estimating equation is

$$solar_{mt} = \alpha + \beta_1 Year2018_t + \beta_2 Treatment_m + \beta_3 Year2018XTreatment_{mt} + e_{mt}. \quad (2)$$

This is estimated separately for unincorporated Kern County and the City of Bakersfield. The coefficient β_1 identifies the difference in the solar installation market conditions between 2018 (when the PACE removal went into effect) and earlier years and the coefficient β_2 identifies the difference between the treatment groups (the municipalities that removed PACE authorization). The interaction term between the two estimates the causal impact of removing PACE funding opportunities on each of the four measures of solar installations. In the case of Bakersfield, the control group is the set of other cities in California that are of similar size to Bakersfield as determined by the number of housing units according to the American Communities Survey (ACS). For example, Bakersfield has 120,553 housing units so a 20,000 household band would result in Anaheim and Stockton (both of which did not remove their PACE programs) serving as control cities.[44] The number of control cities in the treatment group can be increased or decreased by increasing or decreasing the band of cities that are considered "comparable" to Bakersfield.

Unincorporated areas in neighboring counties serve as the counterfactual for the unincorporated regions of Kern County, specifically, San Bernadino, Kings, and Tulare Counties. While Kern County also borders Los Angeles, Ventura, Santa Barbara, and San Luis Obispo counties, these areas are generally higher income and more urban than Kern County.

3.4 Competition Among PACE Administrators

PACE administrators facilitate the process of establishing the special assessment districts for homeowners wishing to use PACE financing for approved projects. The specific PACE

[4] The solar installation data is received from investor-owned utilities and not municipal utilities. Anaheim, which is primarily served by a municipal utility, is removed from the control set because there are relatively few solar installations reported in that data.

administrator or administrators who are authorized to implement PACE financing in a particular jurisdiction are typically set by statute and new PACE administrators can not enter a municipality without statutory authority. While early in the PACE process most municipalities with PACE were served by a single administrator there has been increasing competition over time and there are multiple PACE administrators in many places.

As PACE rates and terms are generally set by statute and are competitive with other methods of financing the upfront solar panel investment, the impact of additional PACE administrators in a municipality should be relatively small if the primary reason that PACE influences solar adoption is access to capital. The assumption here is that homeowners who are interested in getting solar systems for their homes but who are unable to afford the system with conventional lending structures would be able to finance their home with PACE even if there was a single administrator in the municipality.

I explore this effect by replacing the dummy variable for whether or not PACE is in effect with the number of PACE operators who are active in a municipality.

3.5 National Evidence

The previous methodological structure has focused on variation in solar installations based on PACE status in California. This might raise concern that California is uniquely responsive to PACE due to attributes that are unique to California (e.g., utility structures, income, environmental preferences). While this would not affect the implications surrounding PACE in California it would cast doubt on how well these interpretations could be extended to other states which have not yet implemented residential PACE programs.

In order to investigate the national impact, I use the NREL Open PV data to show how solar panel installations changed in states and counties with residential PACE programs relative to neighboring states and counties that did not authorize PACE. During the time period covered by the NREL data, there are three states that authorized residential PACE: California, Florida, and Missouri. Because the NREL data is relatively sparse in Florida and Alabama (which would serve as one of Florida's controls), I focus only on California and Missouri.[5] [5] At the state-level, it is relatively straight-forward to identify when PACE authorization went into effect and each of these states are matched to their applicable authorization date. Neighboring states serve as a counterfactual for each of the PACE states (e.g., Arizona, Nevada, and Oregon provide the counterfactual for California). This results in a straight- forward differences-in-differences framework for each of the three states.

The estimating equation is

$$solar_{mt} = \alpha + \beta_1 PostTreatment_t + \beta_2 TreatmentState_s + \beta_3 PostXTreatment_{st} + e_{st} \qquad (3)$$

[5] Commercial PACE authorization is far more prevalent than residential PACE.

which I estimate separately for each of three residential PACE states.

The state-level estimation may still be susceptible to bias because states are large geo- graphic areas and important heterogeneity may be masked by this aggregation. For example, while California and Oregon share a border, the majority of California's population lives further south where solar radiance is higher and solar panels provide a more compelling investment. In this case, Oregon would be a poor comparison to California.

County-level solar installations can provide closer comparisons between treated and control regions. Each border county in a PACE state is matched with the counties that it borders that are in other states. For example, Modoc County in Northeastern California is matched with Klamath and Lake Counties in Oregon and with Washoe County in Nevada. Under the assumption that solar radiance, income, and population density are spatially correlated this minimizes the difference between the PACE-treated county and the control counties.[6] A dummy variable is constructed for each neighboring county group to control for these unobservable spatially-varying characteristics (e.g., Modoc, Klamath, Lake, and Washoe Counties would share a dummy variable).

The estimating equation becomes

$$solar_{ckt} = \alpha + \beta_1 PostTreatment_t + \beta_2 TreatmentState_c + \beta_3 PostXTreatment_{ct} + \eta_k + e_{ckt} \quad (4)$$

where k corresponds to the set of dummy variables identifying each group of neighboring counties. Note that a control county can be in multiple neighboring county groups if it neighbors more than one county in the state with PACE authorization.

4 Results

Primary estimation results from the baseline specification in Equation 1 are presented in Table 2. Each of the four dependent variables are estimated three times. First, municipality-specific observable characteristics from the ACS are used to control for other attributes that might influence solar adoptions and costs. Second, municipality fixed effects are used to capture all observable and unobservable characteristics of a municipality that could influence adoptions. Finally, municipality-specific time trends are used to allow the underlying (unrelated to PACE) trend in solar installations in each county.

PACE availability increases total new solar capacity in each municipality by 40-60 kw per month. For perspective, this suggests an increase in installed capacity of over 100% relative to the sample average. The implication is similar for total number of installations. The introduction of PACE availability increased the number of solar PV systems that were connected to the grid by 5-

[6] In the case of California, this approach removes many of the large population centers which do not fall along state borders. In Missouri, however, several population centers remain in the data.

10 installations per month, again an increase of over 100% compared to the sample average. These large percentage increases mask important heterogeneity. The estimated coefficients are average effects of PACE across all regions and include both small communities where 5 additional installations would be an incredible per- centage shift as well as large cities where 5 additional installations would be a more modest increase. When installations are explicitly normalized with respect to municipality size, the effects decline. The introduction of PACE increases new solar capacity per housing unit by less than 10 kw per house. While the municipality-specific time trend structure suggests that PACE increases capacity per housing unit by about 150% of the sample average, the two alternative controls are more modest.

The evidence that PACE has an influence on installation costs is mixed at best. In one of the three specifications, there is evidence that PACE increased installation costs around 5 cents per watt, about 1% of the sample average. There are several possible explanations for why PACE availability could increase installation costs. The most direct pathway is through increased demand for installation. As shown in the overall capacity regressions, PACE shifts the local demand for solar panels and solar panel installation. In the short run, this may bid up installation prices until additional solar installation companies can enter the market. On the other hand, the type of consumer who uses a PACE assessment may be fundamentally different from the consumers who would install solar panels without PACE. For example, a homeowner who is spurred by PACE financing may choose higher efficiency panels, resulting in higher costs.

While flexible time trends are intended to abrogate this issue, one concern surrounding the baseline results is that the relatively long-time horizon of the data may cause long-run changes in solar industry conditions (e.g., declining input costs) to falsely assign temporal effects to the availability of PACE. Table 3 shows the impact of the PACE program when the dataset is restricted to only two months before and after PACE went into effect in a municipality. In this framework, there is still a statistically significant impact of PACE availability on total installed solar capacity and the number of solar applications that are approved. The coefficients are smaller: between 25% and 50% of the baseline estimates in most cases. Using the preferred and most conservative estimates which rely on municipality-specific fixed effects rather than observable municipality characteristics, these results suggest that introducing PACE increases newly installed solar capacity by 20%-50% of the average level of installed capacity. There is no statistically significant evidence that PACE is affecting the normalized installed capacity per housing unit or the price of installed capacity in these regressions, though restricting the sample size necessarily decreases the statistical precision of the estimated coefficients.

The effect persists as well even when the sample is limited to reduce the likelihood that a municipality that adopted PACE prior to CPUC order 14-11-001 is incorrectly treated as a non-adopter. In the first robustness check, the sample is limited to only the regions that the financier Ygrene attested that they were the first PACE lender. The introduction of PACE availability in these regions has a statistically significant impact on total installed capacity and the number of installations, as well as on installed capacity per housing unit and installation price when the time trends were allowed to vary by municipality. The coefficients themselves are substantially higher than in the baseline and time band regression results; they correspond to an increase of around 200%-300% of installed capacity based on the sample average installed capacity in Yolo County, Sacramento County, and Chula Vista. As an alternative to the Ygrene-specific robustness check, the sample is also limited to only municipalities for which the first observed PACE-funded installation occurred after 2016. This provides further evidence of an impact of PACE on total installed capacity and the number of installations that take place in a municipality.

4.1 PACE Removal

Table 6 shows the impact of the removal of PACE on solar installations in the City of Bakersfield and unincorporated regions of Kern County. The removal of PACE availability in Bakersfield resulted in a substantial reduction in solar installations. Installed capacity in Bakersfield declined over 800 kw after PACE was terminated in January 2018. For perspective, this is around a 33% reduction in monthly capacity additions. The impacts are similarly large for the number of installations and the amount of new capacity per municipality. Figure 2 shows this graphically. Prior to the removal of the PACE program in Bakersfield, Bakersfield and Stockton had similar trajectories in new solar installations even though they had differing levels of installations. While they both experienced a reduction in installations at the beginning of 2018, the reduction was much larger in Bakersfield where PACE authorization was removed. Interestingly, there is a clear and substantial price effect as well, providing further evidence that PACE may have an impact on average solar installation costs in a municipality. After the removal of PACE from Bakersfield, the cost per watt of installed capacity fell by around $0.17.

Similarly, when examining Kern County there is additional evidence that the removal of PACE authorization reduced the amount of solar capacity and the number of solar systems that were being connected to the grid. Again, the price of solar installations per watt fell after PACE authorization was removed. It is notable, however, that in Kern County while the total installed capacity per month declined by about 22 kw after PACE was removed, there is weakly statistically significant evidence of a small increase in the amount of solar that was installed per housing unit.

4.2 Competition Among PACE Administrators

Table 7 shows the differential impact of multiple PACE administrators. Additional PACE administrators in a municipality are associated with additional increases in monthly in- stalled capacity and the number of monthly installations. In each of these cases, the addition of the second, third, and fourth PACE administrators results in large solar panel installation increases relative to when there is only a single PACE administrator in the municipality. When newly installed capacity is normalized by the number of households in a municipality, however, there is no statistically significant impact of marginal administrators. Similarly, in only one of the three specifications is there evidence that marginal increases in PACE administrators are associated with further increases in installation prices.

While the evidence is mixed across the three capacity-related dependent variables, this evidence is broadly consistent with the impact of PACE varying based on the number of administrators in a municipality. There are several potential explanations for this. First, one potential explanation is that there is competition among PACE administrators and that having more than one PACE administrator in a municipality results in greater competition which in turn results in more installations. If this was the dominant path, though, one would expect that installation prices would decline as competition increased.[7] Further, repayment rates are generally set by statute and administrators will be unable to compete on rates.

An alternative explanation for this behavior is that PACE administrators spur home-owners interest in solar panels through advertising and awareness. For example, if each PACE administrator sets an advertising budget to inform homeowners about the possibility of PACE financing for solar panels, exposure to this advertising would necessarily increase as the number of administrators in a region increase.

4.3 National Evidence

Table 8 shows the effect of the legislation authorizing PACE in California (Columns 1-3) and Missouri (4-6). In California and Missouri, there is an increase in total installed capacity per month and the number of installations per month relative to their neighboring states. In California, the impact is around 6.4 mW of installed capacity each month. For reference, the average monthly solar panel installation in California in this dataset is around 9.5 mW. In Missouri the effect is relatively larger; the impact of PACE on total installations is around 100% of the average monthly installed capacity in Missouri. In Missouri, there is also an impact when installations are normalized by the state's population, but this is not evident in California.

Figures 3 and 4 show installed capacity per capacity in California and Missouri and their neighboring states in the 24 months before and after PACE legislation was passed. In California, both California and Arizona exhibit relatively similar trends prior to the authorization of PACE and installed capacity per capita begins to increase rapidly around 6 months following the legislation. Notably, Arizona closes the gap between California and both states diverge from Nevada and Oregon. The fact that Arizona – which did not authorize residential PACE – increases as fast or more quickly than California raises concerns about

[7] If competition were the driver of increases in installations on the part of consumers, prices would have to decline in order to cause the observed increases in quantity.

whether PACE is the mechanism driving the increase in California installations.

The impact of PACE is more obvious in Missouri. Prior to the passage of residential PACE legislation, Missouri and its neighboring states were installing solar systems at roughly the same rate although there may have been an upward trend in Missouri and Arkansas prior to the PACE legislation. Following the authorization of PACE, installations in Missouri converged substantially from installations in the neighboring states and installations were an order of magnitude higher than the neighboring states 24 months after Missouri authorized PACE.

Table 9 shows the impact of PACE legislation on county-level solar installations. Installed capacity per capita, which is arguably the most persuasive outcome measure are positive and statistically significant in both Missouri and California. In each case, the point estimate suggests that solar installations per capita increased about 0.0001 kW per person in areas that received PACE (about 1 kW per 10,000 people).

In Missouri this corresponds to about 25% of the average monthly level of installations per capita and around 13% in California. The relatively smaller magnitudes reflect the precision of the control counties relative to the geographically aggregated models. There are several potential explanations for why the impact is larger in Missouri than in California. First, Missouri homeowners may simply be more responsive to PACE than Californians and the solar industry and PACE administrators had developed significantly by the time that the Missouri legislature authorized PACE. Another possible explanation lies in the restriction of the sample to only border counties. This restriction removes a large portion of California's urban population centers (e.g., Los Angeles, San Francisco, San Diego) while a larger portion of Missouri's urban population lives in a border county.

5 Conclusion

The statistical evidence suggests that the PACE program did in fact increase solar installations, though it also resulted in a small increase in the average price of solar PV installations. These estimates can be used to predict how solar installations would be different in the absence of PACE.

Using the most conservative estimates of the impact of PACE from Table 3, each municipality that had PACE availability would have experienced 4.48 less kW of installation per month if PACE had not been in effect. Because there are many communities that had no solar installations in a given month when PACE was in effect, the counterfactual level of solar PV installations in each month is calculated as the maximum of either zero or the modeled quantity of solar PV minus 4.48. Figure 2 shows the predicted monthly amount of PV capacity that would not have been installed in the absence of the PACE program beginning in 2016. The result is a net change in installed PV of around 3 mW per month, or about 83 mW between 2016 and the end of the data in mid-2018, about 4.5% of the total capacity that was installed over that time frame.

Note that these predicted values are smaller than the overall percentage difference from the reduced form econometric models. This difference comes from the fact that the econometric results are based on the average impact of PACE across all municipalities while in the construction of the counterfactuals installation quantities, the smaller municipalities are essentially removed from the sample by the restriction that predicted installations be non-negative. If the baseline regressions were run without these small communities, the average treatment effect of PACE would be higher.

Similarly, predicted overall consumer expenditure can be predicted using a simple back- of-the-envelope calculation. Using the low-end predicted price impact from the primary regression results suggests that PACE increased installation costs about 5 cents per watt. In the absence of PACE, there would have been about 83 mW less installation which would have reduced total expenditure on solar PV by around $380 million due to the lower amount of installed capacity. In addition to the change in expenditure due to lower levels of installation, there would also have been lower expenditure on the solar systems that were installed (in the absence of PACE) because PACE is associated with an increase in price per kW so expenditure on all systems would be lower in the absence of PACE by approximately $86 million.

There is also additional evidence suggesting that PACE increased solar PV installations from state-level data. These effects were generally larger in Missouri than in California which could be driven by either the later PACE adoption in Missouri or by the inclusion of large population centers. While less comprehensive data on installation costs in the national data make it difficult to provide direct expenditure comparisons to the California results, the model suggests the average-sized California border county would have around 75 kW of additional installations per month due to PACE. In Missouri, the effect was around 22 kW of additional monthly installation per border county per month.

It is also worth considering the impacts of PACE that were not explicitly considered in this paper. Much of the increase in solar PV installations has been driven by falling panel costs. Manufacturers and installers are able to lower their costs as they gain more experience with PV production (Van Benthem et al. (2008)). In this case, PACE programs would not only increase local PV installations but also increase PV installations in non-PACE regions because consumers in those municipalities would have access to lower cost solar panels. Similarly, the presence of products that are viewed as "environmentally friendly" can influence others in a like-minded community to purchase the product as well (Sexton and Sexton (2014)). In this case, installations that were influenced by PACE could cause consumers to have greater preferences for solar panels even outside of the PACE jurisdictions. This equilibrium effects are not included in the above discussion and would suggest that these estimates of the effect of PACE are underestimates of the total impact.

The bulk of the evidence presented in this paper suggests that PACE had substantial effects on the amount of solar PV that was installed in participating areas. Moreover, evidence from Bakersfield and Kern County indicate that the benefits of PACE are long- lasting and that the removal of PACE will slow installations and weaken efforts to slow climate change. Evidence from state-level implementations also indicate the large potential benefits from further residential PACE authorization. While California is in some ways an abnormal market for solar installations, the large impact of PACE authorization in Missouri suggests that PACE can grow solar installations throughout the country, not only in relatively environmentally friendly places like California.

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6 Tables

Table 1: Summary Statistics for Monthly Panel

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Total Capacity (kw)	274,571	14.452	82.059	0.000	0.000	0.657	5,756.614
Number of Installations	274,571	2.712	14.851	0	0	1	1,061
Capacity per House	219,382	0.003	0.027	0.000	0.000	0.001	3.240
Cost per Watt	24,755	4.387	2.461	0.000	3.879	5.069	288.015
Housing Units (Thousands)	219,382	12.182	54.585	0.005	0.526	10.867	1,436.543
Percent Mortgage	219,382	36.047	15.771	0.000	25.562	46.716	100.000
Median Income (Thousands)	179,078	34.946	16.592	2.499	23.586	41.011	104.112
Pace In Effect	274,571	0.139	0.346	0	0	0	1
Number of PACE Operators	274,571	0.235	0.698	0	0	0	3

Table 2: Baseline Regression - Monthly

	Dependent variable:											
	Capacity			Number of Installs			Capacity per House			Cost per Watt		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Units (Thousands)	0.332			0.069			-0.00001^{**}			0.0005^{***}		
	(0.266)			(0.055)			(0.00000)			(0.0001)		
Percent Mortgage	0.412^{***}			0.072^{***}			0.00004			-0.002^{***}		
	(0.070)			(0.012)			(0.00003)			(0.001)		
	(0.058)			(0.010)			(0.00001)					
Median Income (Thousands)	-0.109^{*}			-0.017^{*}			−0.00001			0.002^{***}		
										(0.001)		
PACE in Effect	77.020^{***}	44.452^{***}	37.164^{***}	14.094^{***}	8.109^{***}	6.206^{***}	0.004^{***}	0.006^{***}	0.007^{***}	0.051^{*}	0.069^{***}	0.065^{***}
			(4.652)			(0.870)			(0.001)			
	(8.908)	(5.449)	(3.670)	(1.655)	(1.017)	(0.633)	(0.001)	(0.002)	(0.001)	(0.029)	(0.022)	(0.020)
Constant			-54.010^{***}			-10.334^{***}			-0.013^{***}			9.512^{***}
												(0.336)
Time FE	X	X		X	X		X	X		X	X	
Municipality FE		X	X		X	X		X	X		X	X
[illegible]			X			X			X			X

Note: *p<0.1; **p<0.05; ***p<0.01

Table 3: 2 Month Band - Monthly

	Dependent variable:											
	Capacity			Number of Installs			Capacity per House			Cost per Watt		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Units (Thousands)	1.100			0.220			-0.00002^{**}			0.0002		
	(0.909)			(0.181)			(0.00001)			(0.0002)		
Percent Mortgage	0.914^{***}			0.148^{***}			0.0001			−0.003		
	(0.306)			(0.055)			(0.0001)			(0.002)		
Median Income (Thousands)	-0.778^{***}			-0.142^{***}			-0.0001^{**}			0.003^{**}		
	(0.282)			(0.048)			(0.00004)			(0.002)		
PACE in Effect	24.222^{***}	5.683	3.712^{**}	4.579^{***}	0.994	0.734^{***}	0.0001	0.0004	−0.0001	−0.009	−0.037	0.044
	(4.677)	(4.038)	(1.461)	(0.875)	(0.727)	(0.268)	(0.001)	(0.002)	(0.001)	(0.038)	(0.078)	(0.053)
Constant			−56.349			−2.689			−0.123			2.037
			(359.045)			(63.018)			(0.224)			(4.159)
Time FE	X	X		X	X		X	X		X	X	
Municipality FE		X	X		X	X		X	X		X	X
Municipality Time Trend			X			X			X			X
Observations	2,891	4,492	4,492	2,891	4,492	4,492	2,891	3,556	3,556	1,318	1,497	1,497
R^2	0.186	0.974	0.972	0.218	0.974	0.973	0.033	0.488	0.485	0.051	0.585	0.560
Adjusted R^2	0.163	0.965	0.963	0.196	0.966	0.964	0.006	0.310	0.324	0.019	0.245	0.235
Note:										*p<0.1; **p<0.05; ***p<0.01		

Table 4: Ygrene Regions - Monthly

	Dependent variable:											
	Capacity			Number of Installs			Capacity per House			Cost per Watt		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Units (Thousands)	0.328			0.073			−0.00000			0.005^{*}		
	(0.358)			(0.081)			(0.00000)			(0.002)		
Percent Mortgage	−0.279			−0.054			0.0001			0.002		
	(0.559)			(0.117)			(0.00005)			(0.010)		
Median Income (Thousands)	1.138^{**}			0.190^{*}			0.00002			−0.006		
	(0.473)			(0.100)			(0.00003)			(0.006)		
PACE in Effect	165.782^{***}	120.734^{***}	58.852^{***}	32.593^{**}	23.110^{**}	10.213^{***}	0.005^{**}	0.005^{**}	0.005^{***}	0.477	0.902	0.044
	(60.300)	(44.384)	(20.238)	(12.792)	(9.194)	(3.797)	(0.002)	(0.002)	(0.001)	(0.661)	(0.665)	(0.053)
Constant			-77.047^{***}			-15.720^{***}			-0.009^{***}			2.037
			(24.070)			(5.021)			(0.002)			(4.159)
Time FE	X	X		X	X		X	X		X	X	
Municipality FE		X	X		X	X		X	X		X	X
Municipality Time Trend			X			X			X			X
Observations	6,183	8,473	8,473	6,183	8,473	8,473	6,183	6,870	6,870	564	612	1,497
R^2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Note: *p<0.1; **p<0.05; ***p<0.01

Table 5: Post 2017 - Monthly

	Dependent variable:											
	Capacity			Number of Installs			Capacity per House			Cost per Watt		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Units (Thousands)	0.263			0.053			−0.0001**			0.012***		
	(0.214)			(0.040)			(0.00003)			(0.003)		
Percent Mortgage	0.160***			0.026***			−0.0001			−0.008		
	(0.057)			(0.009)			(0.0001)			(0.006)		
	(0.041)			(0.006)								
Median Income (Thousands)	−0.027			−0.006			0.00001			0.008**		
							(0.00003)			(0.110) (0.003)		
PACE in Effect	1.927	3.374	4.570***	0.335	0.526	0.591***	0.002	0.003	0.003**	−0.017	−0.070	−0.021
	(4.757)	(2.646)	(3.856) (0.988)	(0.798)	(0.454)	(0.639)	(0.005)	(0.003)	(0.002)		(0.107)	(0.048)
						(0.207)			(0.001)			
Constant			−22.819***			−3.970***			−0.013***			7.295***
												(1.177)
Time FE	X	X		X	X		X	X		X	X	
Municipality FE		X	X		X	X		X	X		X	X
Municipality Time Trend			X			X			X			X

Note: *p<0.1; **p<0.05; ***p<0.01

Table 6: PACE Removal - Monthly

	Dependent variable:							
	Capacity	Number of Installs	Capacity per House	Cost per Watt	Capacity	Number of Installs	Capacity per House	Cost per Watt
	Bakersfield				Kern Unincorporated			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatment Group	1,696.200***	209.750***	12.818***	−0.412***	101.853**	20.583***	−1.210**	−
		0.211** (0.000)	(0.000)		(0.000)	(0.000)	(40.429)	(7.154)
		(0.468)	(0.088)					
Post Period	−267.229***	−52.411***	−2.640***	0.376***	−16.673	−3.405	−1.811***	−
		0.035*** (0.000)		(0.000)	(0.000)	(0.000)	(11.493)	(2.248)
		(0.220)	(0.007)					
Treatment X Post	−817.081***	−104.464***	−6.355***	−0.177***	−22.975**	−4.869**	0.433*	−
		0.319*** (0.000)		(0.000)	(0.000)	(0.000)	(11.493)	(2.248)
		(0.220)	(0.007)					
Constant	790.447***	142.125***	7.809***	4.207***	60.584	10.833	6.854***	
		4.574*** (0.000)	(0.000)	(0.000)	(0.000)	(40.429)	(7.154)	(0.468)
		(0.088)						
Observations	62	62	62	48	93	93	93	67
R^2	0.852	0.801	0.828	0.432	0.528	0.578	0.078	0.160
Adjusted R^2	0.845	0.790	0.820	0.394	0.512	0.564	0.047	0.120

Note: *p<0.1; **p<0.05; ***p<0.01

Table 7: Operator Count Regression - Monthly

	Dependent variable:											
	Capacity			Number of Installs			Capacity per House			Cost per Watt		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Units (Thousands)	0.320			0.067			−0.00001**			0.001**		
	(0.260)			(0.054)			(0.00000)			*		
										(0.0001)		
Percent Mortgage	0.339**			0.059**			0.00003			−0.002** / (0.001)		
	*			*			(0.00003)					
	(0.068)			(0.012)								
	(0.054)			(0.010)			(0.00001)					
Median Income (Thousands)	−0.051			−0.007			−0.00001			0.002**		
										*		
										(0.001)		
PACE in Effect	18.198*	14.710***	9.648**	3.841**	2.966***	1.752**	0.003**	0.003***	0.005***	0.052	0.062***	0.059**
										(0.013)	(0.011)	*
	(10.000)	(4.659)	(4.149)	(1.647)	(0.781)	(0.709)	(0.001)	(0.001)	(0.002)	(0.032)	(0.023)	(0.021)
			(4.025)			(0.769)			(0.001)			
Number of Administrators	49.726**	27.360**	17.244**	8.667***	4.731***	2.791**	0.001	0.002	0.001	−0.001	0.020*	0.010
	*	*	*	(1.771)	(1.010)	*	(0.001)	(0.002)	(0.001)			(0.011)
	(10.270)	(5.826)	(4.197)			(0.708)						
Constant			−50.980**			−9.844**			−0.013***			9.728**
			*			*						*
												(0.385)
Time FE	X	X		X	X		X	X		X	X	
[illegible]		[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]

Note: *p<0.1; **p<0.05; ***p<0.01

Table 8: State-level PACE Implementation Regressions

	Dependent variable:					
	Capacity California	Capacity per Capita California	Number Installs California	Capacity Missouri	Capacity per Capita Missouri	Number Installs Missouri
	(1)	(2)	(3)	(4)	(5)	(6)
PACE in Effect	6,410.083***	0.0001	1,185.060***	125.814***	0.00002***	15.425***
	(647.187)	(0.0001)	(101.940)	(17.008)	(0.00000)	(2.756)
Observations	184	184	184	171	171	171
R^2	0.902	0.716	0.919	0.614	0.610	0.550
Adjusted R^2	0.865	0.610	0.888	0.434	0.429	0.340

Note: * p<0.1; ** p<0.05; *** p<0.01

Table 9: County-level PACE Implementation Regressions

	Dependent variable:					
	Capacity California	Capacity per Capita California	Number Installs California	Capacity Missouri	Capacity per Capita Missouri	Number Installs Missouri
	(1)	(2)	(3)	(4)	(5)	(6)
PACE in Effect	40.581	0.0001***	12.320	11.694***	0.0001**	0.841
	(82.626)	(0.00004)	(11.588)	(3.789)	(0.00004)	(1.244)
Observations	2,954	2,954	2,954	595	595	595
R^2	0.514	0.577	0.546	0.397	0.417	0.222
Adjusted R^2	0.495	0.562	0.529	0.284	0.308	0.076

Note: *p<0.1; **p<0.05; ***p<0.01

7 Figures

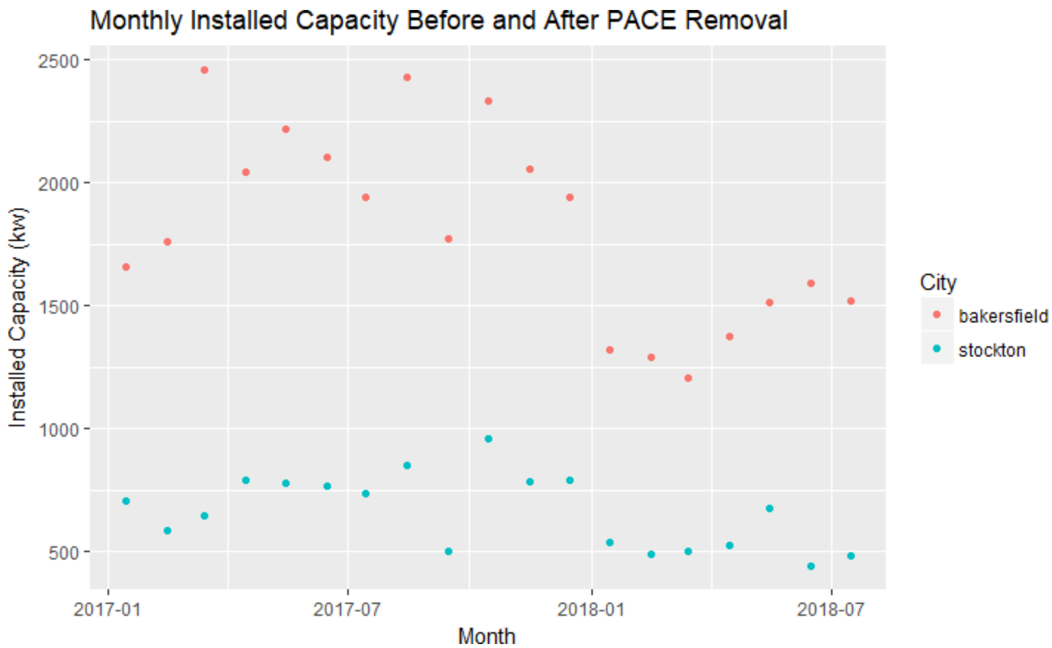

Figure 1: Comparison of Monthly Installed Capacity in Bakersfield and Stockton Municipalities

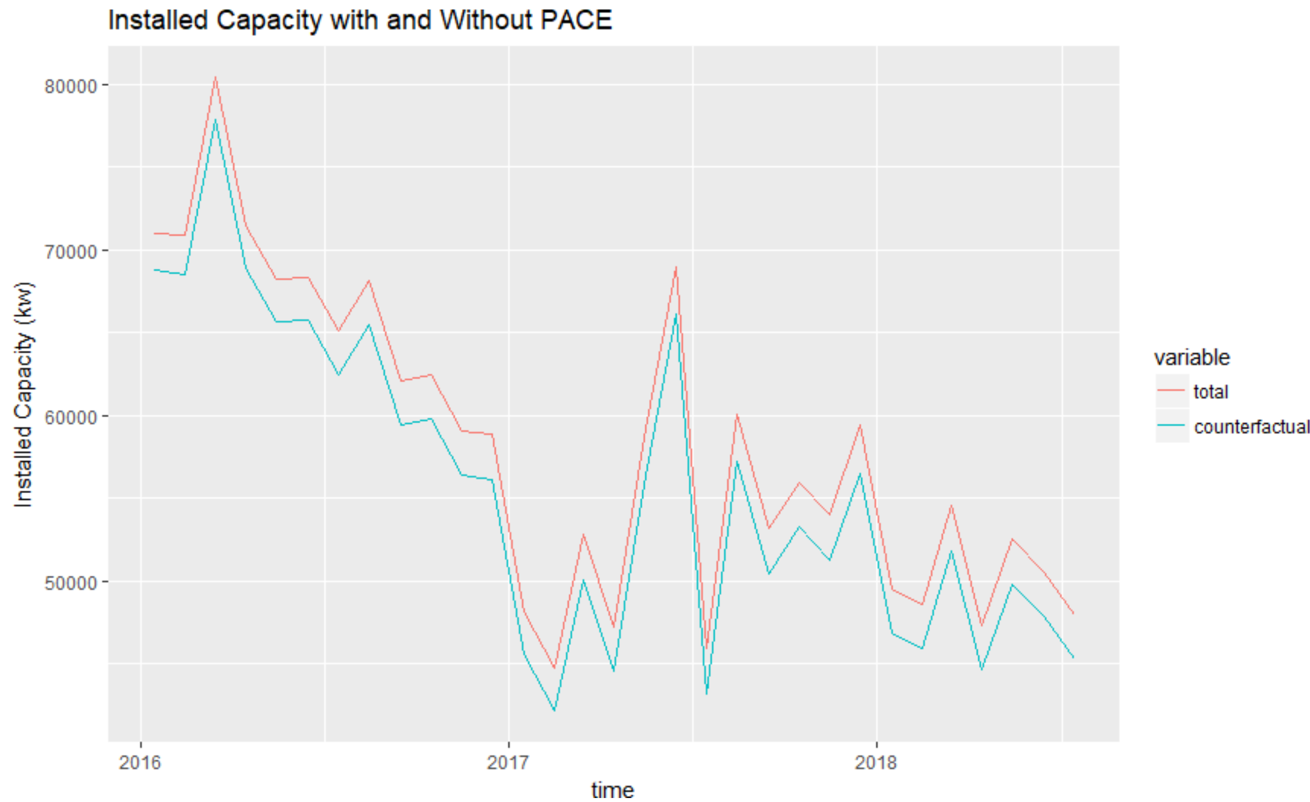

Figure 2: Comparison of Monthly Installed Capacity in California With and Without PACE

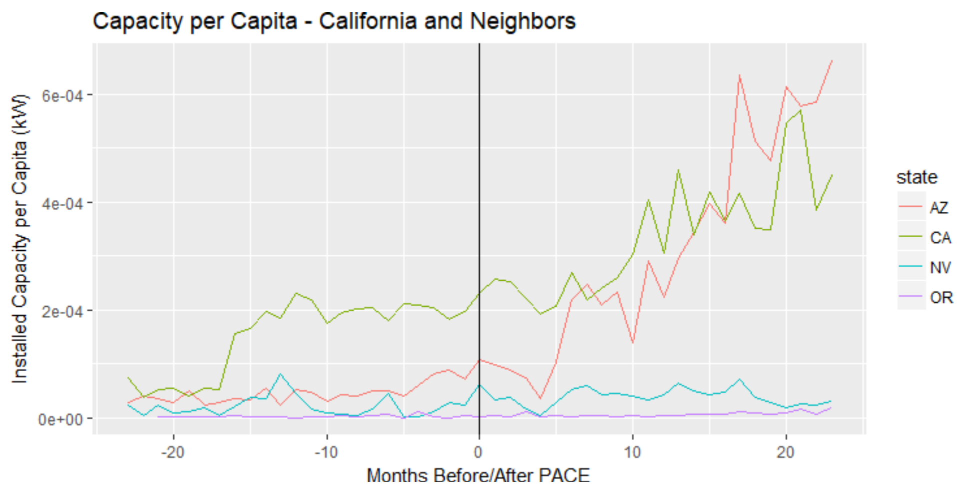

Figure 3: Comparison of Monthly Installed Capacity per Capita in California and Neighboring States

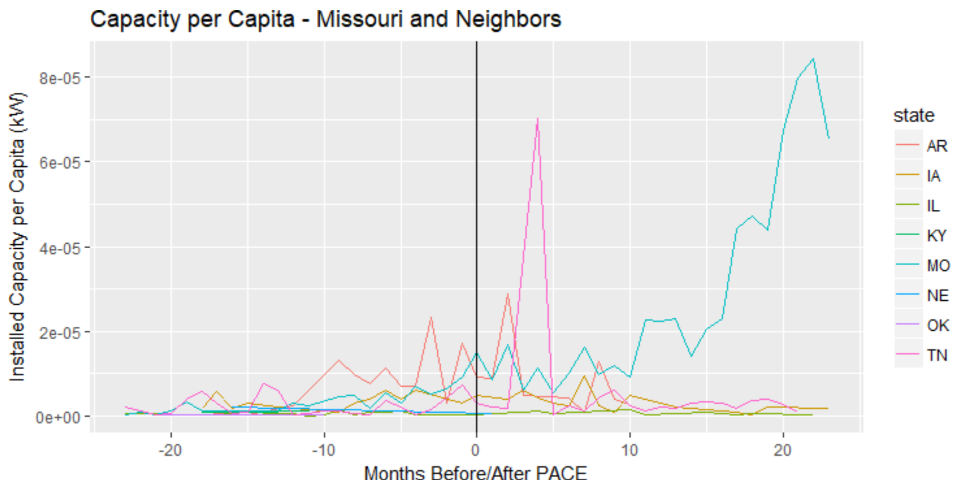

Figure 4: Comparison of Monthly Installed Capacity per Capita in Missouri and Neighboring States