Innovation in Financing Energy-Efficient and Renewable Energy Upgrades: An Evaluation of Property Assessed Clean Energy for California Residences

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Objective. We examine whether Property Assessed Clean Energy (PACE) programs, an innovative financing mechanism using municipal bonds to finance the up-front cost of household energy conservation projects, reduced conventional energy purchases by residential customers and increased energy generated through residential solar panel and fuel cell installations. *Methods.* Using data on municipal bond issuances, electricity and natural gas purchases, and self-generated energy, we use a difference-in-differences design to estimate the effect of PACE bonds issued in California between 2009 and 2017 on purchases and self-generation. *Results.* We find more residential energy self-generation in counties with PACE programs. Results are inconclusive for conventional energy purchases, suggesting a possible rebound effect. *Conclusion.* While innovative financing mechanisms facilitate access to otherwise prohibitively expensive technologies, governments must consider that behavioral responses may result in lower efficacy than desired and should consider pairing financing tools with instruments that concurrently promote reduced energy consumption.

Despite growing public concern over climate change, there has been a notable lack of federal environmental policy activity in the United States. Although scholarship and advocacy groups have made reasonable arguments promoting the development and implementation of consistent federal statutes to address this issue, none have emerged (Grubler, 2012; Vandenburgh, 2014). In particular, partisan gridlock has prevented national leaders from adopting a consistent or comprehensive energy strategy that supports shifting the United States from a fossil fuel based economy to one that is more reliant on lower carbon alternatives (Knuth, 2018; Konisky and Woods, 2012).

The absence of federal policy or successful regulatory activity (Freeman, 1997) is relevant because while the costs associated with renewable energy generation are falling, renewable sources still remain pricier than traditional energy sources. Previous energy transitions (i.e., the replacement of wood with coal during the Industrial Revolution) reveal that the pace of an energy transition is historically slow because, without intervention, it takes decades for new technologies to improve, scaleup, and realize economies of scale so prices can compete with the incumbent technology (Wilson, 2009). Climate change, however, was not a serious social and economic threat during previous energy transitions (Allen, 2012). As a result, unlike in previous transitions, scholars contend that government intervention must be employed to overcome the existing cost gap to facilitate the deployment of lower carbon technologies (Fouquet, 2010).

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Because lower carbon technologies often have high capital costs and low operating costs, there is an opportunity for the government to employ innovative financing mechanisms to help customers pay for the large up-front investment (Levi, 2013; Yue, Liu, and Liou, 2001). In fact, the U.S. government has set a precedent for inventing financing tools that enable people to make purchases in expensive capital markets. For example, the federal government created the automobile loan in the 1920s and popularized the mortgage in the 1940s, revolutionizing Americans' ability to buy cars and homes (Griffith, 2019). The federal government could create the same opportunities for customers through analogous financing innovations for solar panels and energy-efficient appliances. Yet, notwithstanding the substantial infusion of resources into energy-related activities from the American Recovery and Reinvestment Act in 2009 (Carley, Nicholson-Crotty, and Fisher, 2015), the federal government has not structurally intervened in energy efficiency or renewable energy financing as it did with other residential investments in the 20th century.

Instead, state and local governments have intervened to encourage energy-efficient innovation and renewable energy deployment (Carley, 2011). In theory, there is a wide variety of policy instruments that can be employed to address this issue (see, e.g., Stavins, 1997, for a menu of policy options). In actual fact, states have primarily implemented quantity-based and technology-based renewable energy standards, such as Renewable Portfolio Standards and vehicle emissions standards, to aid in the domestic transition to lower carbon energy alternatives (see, e.g., Carley and Miller, 2012; Konisky, 2007; Konisky and Woods, 2012; Matisoff, 2008; Woods, 2006; Yi and Feiock, 2012; Carley, 2009; Greene, Park, and Liu, 2014). In addition, states have employed traditional financing mechanisms, such as loans and leases, and have worked through the tax code with subsidies, rebates, and credits to lower the cost of adoption of energy-efficient and renewable technologies (see, e.g., Leventis et al., 2016, for an overview of energy efficiency financing products employed at the state and local levels). By contrast, local governments have, most commonly, provided property tax incentives to encourage and foster green building opportunities (Clement et al., 2005), which have, on average, positively impacted the development of energy efficiency upgrades (Shazmin, Sipan, and Sapri, 2016).

While U.S. states have primarily relied on these traditional tools, they have also adopted alternative strategies to encourage deployment of renewable energy technologies. The Property Assessed Clean Energy (PACE) program is one such alternative, and it has been implemented in several U.S. states for over a decade. PACE is an innovative financing mechanism that functions as a voluntary property tax assessment and was specifically designed to deploy green energy technologies. PACE programs finance energy efficiency upgrades and renewable energy installations on private property to both commercial and residential sectors.

PACE's financing strategy is innovative for several reasons. First, the program is enabled by the state legislature, authorized and implemented at the municipal level, and often administered by a partnership between the implementing municipality and PACE financing providers. Second, the implementing municipality uses its legal authority to issue municipal securities, which is the method by which capital is raised from the private sector. The role of the municipality is to provide the legal authority to issue debt and to assess and collect property taxes. There are no expenditures by the municipality, as the administrative costs of issuing bonds, running the program, and assessing and collecting additional taxes are bundled into the loans to property owners. Third, the bond is secured by special tax assessments that are placed on the property of individual property owners who voluntarily participate in the program. A special property tax assessment (SA) is a method of funding projects and services that directly benefit particular property owners rather than entire local jurisdictions (Hendrick and Wang, 2018). While SAs are typically levied on a group of geographically defined properties—such as a neighborhood paying for sidewalks or street lights—the PACE program is designed by single property owners. Therefore, an especially innovative feature of the program is that PACE loans are attached to the property, not the property's owner. To repay the loan, the owner pays a special assessment, which is added to their property tax bill. Should they sell their property, the balance of the loan must be paid by the new property owner, unless other arrangements are made.

PACE financing programs have two stated goals: (1) to renovate homes to increase their energy efficiency and reduce their energy bill, and (2) to increase the amount of self-generated energy by installing renewable energy generation products, such as rooftop solar, on private homes. This article examines whether these goals are being met by evaluating if the program effectively reduces residential electricity consumption from municipal utilities and if it increases residential self-generated energy production in the counties that have adopted the program. While previous studies have evaluated how PACE financing has impacted the adoption of solar energy (see, e.g., Ameli, Pisu, and Kammen, 2017; Deason and Murphy, 2018; Kirkpatrick and Bennear, 2014), the scholarship has yet to conduct a large-scale statistical analysis on the specific impacts that PACE has on energy usage (Fadrhonc et al., 2016). Thus, the literature has not evaluated whether the increase in renewable energy and energy efficiency installations from PACE programs will lead to what is known as the rebound effect, a phenomenon in which the consumption of energy actually increases because the costs associated with energy services decrease when efficient technology is installed. Our study aims to fill these knowledge gaps; thereby offering a more direct evaluation of whether PACE is meeting its goals by estimating how the program actually impacts electricity consumption.

To conduct our evaluation, we perform a statewide analysis of PACE financing in the State of California. We employ a generalized difference-in-difference (DID) design to estimate the effects of PACE financing on three factors: (1) the purchase of electricity by residential customers; (2) the purchase of natural gas by residential customers; and (3) the amount of electricity generated by households through renewable energy generation. To briefly summarize our results, we find that the program slightly increases the volume of self-generated electricity; however, our findings are inconclusive as to the program's effect on purchases of conventionally generated energy.

The manuscript proceeds as follows. First, we provide a brief background and literature review on PACE financing; next, we outline our expectations and hypotheses for our analysis; subsequently, we describe our research design and data; and we end with a discussion of our results.

PACE Background

SAs are a policy instrument used by local governments to fund property improvements and services that directly benefit particular property owners rather than entire municipalities (Hendrick and Wang, 2018). Property owners who receive the benefits are taxed an additional amount above their customary property tax bill. Originally, SAs were designed to pay for local infrastructure projects; however, in recent decades, this type of assessment has been used to provide a variety of public services, including energy upgrades and installations (McCubbins and Seljan, 2018; Kogan and McCubbins, 2009).

This article explores the PACE program, which is a contemporary and novel use of the SA financing tool (Department of Energy, 2018). Since 2008, PACE municipal bond programs have built equity in clean energy projects by easing financial constraints and financing the up-front costs of energy efficiency upgrades and renewable energy installations on private property (Ameli, Pisu, and Kammen, 2017). Some of the approved projects include solar panel installations, heating and cooling efficiency upgrades, as well as insulation, and windows and doors efficiency improvements. The program exists for both residential properties and commercial properties; however, based on data availability, our article focuses on the residential program. Although PACE is enabled through state legislation, local governments authorize and participate in implementation of the program. Often, after the state has enabled a PACE financing mechanism, the programs are administered through partnerships between municipal governments and PACE financing providers or lenders. Even if the state has enabled its subordinate jurisdictions to implement PACE financing, not all municipalities choose to do so—it is an elective program that states have authorized local governments to undertake.

Next, property owners may apply for a PACE loan to finance a specific project on their property. The decision to extend a loan to the property owner is based primarily on the eligibility of the project, the owner's record of paying property taxes on time, and whether or not they are in bankruptcy. Notably, the property owner's income, overall indebtedness, and credit score are not taken into consideration. If the application is approved, a PACE-affiliated contractor begins upgrades and/or installations in the house. Upon project completion, the contractor and owner sign and submit a certificate indicating that work has been completed. An assessment lien is recorded on the property owner's house, a municipal bond is issued, and the contractor receives payment. Typically, the municipal bond issue raises capital for multiple property owners at once, likely achieving economies of scale in administrative and transaction costs. Rather than being available on the public market, the bonds are privately placed or purchased by PACE financing providers typically doing business as limited liability corporations. Then, the property owner pays additional property tax each period until their individual loan is repaid, often over a period of 10–30 years, servicing the bond in combination with other participating property owners. If the owner sells his or her property after renovations but prior to full repayment, the obligation transfers to the new owner, if not otherwise specified.

California's PACE Financing Initiative

While SAs have long been used across the country, California has employed them extensively since the 1980s following the passage of Proposition 13—a constitutional amendment limiting local governments' ability to alter property taxes (Cervero, 1988; McCubbins and Seljan, 2018). In addition, California is a longtime leader in its energy efficiency and climate change policies (Carley et al., 2019). In fact, other states often look to California for guidance on these issues (Bachrach, 2003). On July 21, 2008, California's state legislature passed Assembly Bill (AB) 81, pioneering the first PACE financing program in the United States. Not only did PACE financing originate in California, it is also home to the nation's largest PACE program—CaliforniaFIRST. Over 5,000 residential energy conservation municipal bonds—the capital-raising mechanism of PACE programs—were issued in California between 2009 and 2017 in 34 of its 58 counties. For these reasons, we focus on California. We conduct a statewide analysis of the PACE programs that have been adopted and implemented throughout the state.

Figure 1 presents the history of California's PACE adoption rates and intensity of use from 2009 to 2017, displaying the number of counties that have ever issued (labeled

FIGURE 1

History of PACE Program

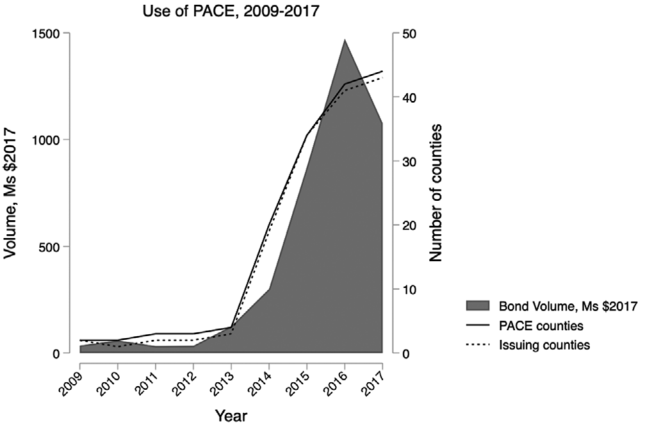
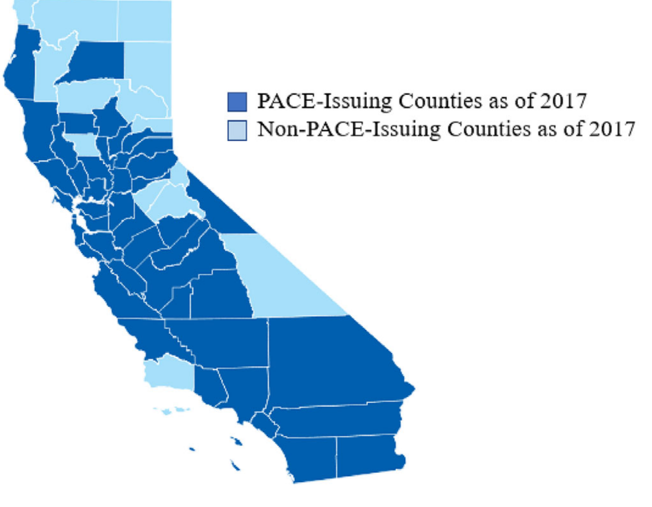


FIGURE 2

Distribution of PACE Funds



"PACE counties"), the number of counties issuing PACE bonds each year (labeled "Issuing counties"), and the total principal amount of PACE bonds issued each year (labeled "Bond Volume").

Figure 1 reveals that PACE financing has grown tremendously in California over the period. Over half of California's counties have authorized and implemented PACE financing in their jurisdictions and consistently issue PACE bonds once a program is established. Figure 2 displays the distribution of counties across the State of California that allow PACE financing as of 2017.

As climate change worsens and with other states looking to California for continued leadership in energy efficiency initiatives, it will be valuable for both scholars and practitioners to examine if the state's PACE financing programs are achieving their stated goals of reducing electricity consumption and increasing the amount of self-generated energy in private homes.

Tax Credits for Renewable Energy

There are several barriers to retrofitting residential homes with energy-efficient and renewable energy installations in the United States. Yet, the literature notes that the primary challenge preventing homeowners from investing in these upgrades is the high up-front costs of installation (Li and Yi, 2014; Shrimali and Jenner, 2013; Sichtermann, 2011). To help homeowners overcome this barrier, state and local governments have implemented various financing mechanisms (Shazmin, Sipan, and Sapri, 2016). As described in the previous section, PACE programs are an innovative financing method that local governments have implemented with the goal of alleviating the high up-front costs of energy-efficient and renewable energy upgrades to homeowners.

Although PACE financing offers an important effort to combat climate change, there is opposition to the policy. Opponents of PACE claim that the loans place fiscal insecurity on mortgages (Kirkpatrick and Bennear, 2014) because it enables homeowners to take on inappropriate levels of debt while using their homes as collateral (Sichtermann, 2011). Because homeowners voluntarily apply a PACE loan to their property tax bill, the SA has a senior lien status over any existing mortgage. Therefore, in the event of a foreclosure, the portion of the PACE assessment that is due at that time is paid out prior to any mortgage payments. For this reason, the primary opponent to PACE financing is the Federal Housing Finance Agency (FHFA), the federal agency that monitors and regulates Fannie Mae and Freddie Mac. In 2010, the FHFA issued a letter forbidding Fannie Mae and Freddie Mac from purchasing mortgages that have the senior liens assessed from the PACE program (Federal Housing Financing Agency, 2010). In 2017, the Federal Housing Agency (FHA) joined the FHFA, instituting a new policy that it would not insure any new mortgages with a PACE assessment. To combat this opposition, in 2010, California established a specific loan loss reserve program, providing first mortgage holders the opportunity to recover any losses resulting from a residential PACE loan in the event of a foreclosure. Despite the FHFA and FHA's opposition to PACE, programs have been adopted and grown across a majority of U.S. states.

By contrast, proponents of PACE financing argue that the benefits are straightforward. If implemented properly, homeowners can invest in energy-efficient and renewable energy projects leading to a reduction in energy use and thus a reduction in pollutants associated with nonrenewable forms of energy generation (Kirkpatrick and Bennear, 2014; Rose and Wei, 2019). Both scholars and practitioners have conducted evaluations as to whether PACE programs, in fact, lead to increased renewable energy generation. Specifically, several of the analyses focus on the extent to which PACE financing has impacted solar photovoltaic (PV) installations in California. The major studies that examine this relationship find, to varying degrees, that the program increases residential PV installations in specific regions of California, in the state's largest cities, as well as across the state (see, e.g., Ameli, Pisu, and Kammen, 2017; Deason and Murphy, 2018; Kirkpatrick and Bennear, 2014; O' Shaughnessy et al., 2020).

Other analyses have examined the economic co-benefits of P. Through modeling simulations, the literature has found that PACE has resulted in substantial economic gains in California, including increased gross domestic product (GDP), personal income, tax revenue, and employment (ECONorthwest, 2011; Rose and Wei, 2019). Rose and Wei

(2019) find in their analysis, however, that the increased economic activity has had partial offsetting effects, increasing natural gas and electricity consumption in their study region. Additionally, studies have found that PACE renovations have a positive effect on a home's resale value (Goodman and Zhu, 2016) and those property owners who have received financing have a relatively low delinquency rate compared to the general aggregate property tax and single-family residential property tax delinquency levels (DBRS, 2018).

Our study adds to the growing body of literature that examines the efficacy of PACE financing in three ways. First, we conduct a statewide analysis of California compared to the majority of other studies that consider regional and municipal level effects. Second, we consider a longer period (up to 2017). Lastly, and most importantly, we specifically examine the impact of PACE financing on energy consumption, both conventional and self-generated. Examining this particular relationship allows us to evaluate whether the potential carbon reductions that should result from the increased adoption of renewable and energy-efficient technologies due to PACE programs may be mitigated by the rebound effect (Wigley, 1997). The rebound effect refers to an increase in energy demand, and thus consumption, when energy prices decrease due to technological efficiency gains. Depending on the size of the increase in energy demand, any reduction in energy consumption, and thus pollutants, may be eroded (see, e.g., Greening, Greene, and Difiglio, 2000, for a summary of empirical evidence on the size of rebound effects). Therefore, it is necessary to more closely examine whether California's PACE program is not only boosting adoption of renewable and energy-efficient technologies but if it is also, on average, reducing energy use and thus the pollutants associated with non-renewable forms of energy generation that exacerbate the effects of climate change.

Expectations and Hypotheses

In general, government-funded financial incentives should encourage households to meet a goal, such as increasing the deployment of technologies (Shrimali and Jenner, 2013). Specifically, PACE programs are not only meant to help households deploy energy-efficient and renewable energy technologies but they are also expected to reduce residential conventional energy consumption and increase self-generated energy. Therefore, to begin our analysis of PACE, we generate three hypotheses that stem directly from the program's stated objectives.

First, if PACE is successful, we would expect residents in counties that authorize PACE financing to consume less electricity and natural gas than residents in counties that do not authorize PACE financing programs. We assume that the renovations and upgrades that PACE financing affords property owners would improve the energy efficiency of the county's housing stock. All else equal, increased energy-efficient housing stock should reduce the electricity consumed by each property owner. This leads to our first and second testable hypotheses:

H1: Counties in California that adopt PACE financing programs will consume less conventionally generated electricity than counties that do not adopt these programs.
H2: Counties in California that adopt PACE financing programs will consume less natural gas than counties that do not adopt these programs.

Next, PACE financing programs offer property owners the opportunity to install renewable energy generation, such as solar panels. Accordingly, we would expect residents in counties that authorize PACE financing to install more renewable energy projects and thus produce more self-generated electricity than residents in counties that do not authorize PACE programs. If all else is held constant, increasing the amount of renewable energy installations throughout a county's housing stock should increase that county's amount of self-generated electricity. Therefore, our third testable hypothesis is:

H3: Counties in California that adopt PACE financing programs will generate more self-generated energy than counties that do not adopt these programs.

However, because the PACE financing program is less than 15 years old and the increase in take-up has been an even more recent phenomenon due to early opposition from the FHFA, we acknowledge that the observable effects, or the changes in household behavior, may not be substantial at this time (Pattberg et al., 2012).

Data

To test our expectations, we use publicly available data collected primarily from the State of California. We developed our primary independent variables of interest, or treatment variables, by collecting information on all residential PACE bond issues sold between 2009 and 2017, totaling 5,029 issues, from the California Debt & Investment Advisory Commission. Specifically, we identify the county in which the debt was issued, the year in which it was sold, and the principal amount. Over one thousand of the bond issues were sold by finance or development authorities in which multiple counties participated. To retrieve county-specific information from these issues, we review the list of participating parcels from the official statements for the bond issue.[1] From these documents, we attribute the portion of the overall principal amount to the specific county in which a participating household resides. After adjusting the principal amount to 2017 dollars using the Consumer Price Index accessed from the Minneapolis Federal Reserve, we aggregate the principal amount to the county-year level to measure the amount of investment in PACE projects in individual participating counties over time.

Our three outcome variables are from the California Energy Commission. They measure the electricity and natural gas purchased by residences from utility companies from 2000 to 2017, and the amount of electricity generated by residences between 2000 and 2016. The two electricity variables are measured in gigawatt hours in the original data, which we convert to kilowatt hours. The natural gas variable is measured in therms, which we convert to kilowatt hours by multiplying by 29,301,000. We adjust all three outcome variables by population, using intercensal county population estimates from the U.S. Census Bureau. We have information for all 58 California counties for conventional electricity consumption (or purchases); between 46 and 48 counties over the period for natural gas purchases; and between 48 and 56 counties for electricity self-generation.[2]

Our control variables include the share of registered voters registered as Democrats from the Voter Registration Database maintained by the California Secretary of State's office, considering the possibility that individuals in more politically liberal counties may be more

[1]Official statements for 10 issues by multiple counties were unavailable at the time of our data collection and are thus missing from our sample.

[2]The missing counties in our data set are relatively evenly distributed between the treatment and control group, are sparsely populated, and—of the counties that have issued PACE bonds—are modest users of the program. Nine of the 21 counties that have any missing data for either self-generated electricity or natural gas purchases issue PACE bonds over the period of study, while 12 do not. In addition, their total population as a share of the total population of California ranges between 3.34 and 3.54 percent over the period, and their total dollar volume of PACE bond issues over the period is 0.34 percent of the total statewide.

TABLE 1

Summary Statistics

Variable	*N*	Mean	*SD*	Min	Max
Residential electricity purchases (kWh per capita)	1,044	3,175	1,299	587	11,912
Residential gas purchases (kWh per capita)	844	3,541	1,401	0	7,645
Residential self-generation (kWh per capita)	923	32.9	54.5	0.0027	369
Principal amount (millions $2017)	1,044	3.84	33.9	0	555
Cumulative principal amount (millions $2017)	1,044	9.27	86	0	1,835
LAZoning2001	1,044	0.016	0.13	0	1
LABuilding2011	1,044	0.0067	0.082	0	1
MarinSolar2004	1,044	0.013	0.12	0	1
MarinFIT2011	1,044	0.0067	0.082	0	1
OCWind2011	1,044	0.0067	0.082	0	1
SDMulti2004	1,044	0.013	0.12	0	1
SDMulti2011	1,044	0.0067	0.082	0	1
SFMulti2008	1,044	0.0096	0.097	0	1
SFRebates2010	1,044	0.0077	0.087	0	1
SantaClaraMulti2011	1,044	0.0067	0.082	0	1
SantaCruzMulti2004	1,044	0.013	0.12	0	1
Democratic share of registered voters	1,044	0.39	0.082	0.14	0.58

prone to prioritize efforts to combat climate change (Ansolabehere and Konisky, 2014). Finally, we employ a set of indicator variables, derived from the Database of Sate Incentives for Renewables and Energy, to control for programs adopted in California at the substate level, which may confound our results. Examples include municipal and local zoning laws and green building codes. Descriptive statistics for all our data are presented in Table 1.

Research Design

Once the State of California passed legislation enabling PACE financing in 2008, the decision by some, but not all, California counties to establish the program lends itself to a quasi-experimental research design, specifically a DID approach. Although PACE programs are not randomly assigned to California counties, if the assumptions of our research design are met, we can compare counties that have not implemented PACE programs—our control group—to counties that have adopted the program—our treatment group.

We estimate the effect of the PACE program using four treatment measures from our municipal securities data. Two of our treatment variables are binary in nature. Our first measure, the *Post-2007 indicator,* is equal to zero for all counties prior to 2008 and for those counties that never issue a PACE bond during our study period, and equal to one from 2008 to 2017 for counties that issue PACE bonds between the 2008 and 2017 period. We employ the *Post-2007 indicator* variable because households' behavior may be altered by the state's enabling legislation, even in absence of an available PACE program in their county. For example, a household may defer investment in energy saving or energy generating renovations or projects in anticipation of the availability of PACE financing in the future. Our second binary treatment variable, the *First-issue indicator*, differs from the *Post-2007* *indicator* in that PACE counties are coded as one the first year in which they issue PACE bonds. We use the *First-issue indicator* to provide comparability with our two continuous treatment variables: *Principal* and *Stock of principal,* which cannot be observed prior to the first PACE bond issue in a county. The former measures the amount, in millions of 2017 dollars, of PACE bonds issued in a particular county in a particular year, while the latter is a cumulative measure of the PACE bonds issued in prior years and the current year. The continuous variables measure the intensity of investment in PACE projects. We use the cumulative measure because energy savings and energy generation from investment in PACE projects should be persistent over time during our study period. Each of our treatment variables is lagged by one year in our analysis, allowing time for PACE projects to accumulate energy savings or energy generation.

We estimate the effect of these four treatment variables on three outcome variables: *Electricity consumed* (kWh per capita); *Natural gas consumed* (kWh per capita); and *Electricity generated* (kWh per capita).

Our basic specification is $\text{kWh}_{it} = \alpha_0 + \beta_1 (\text{Post}^{*}\text{PACE})_{(it-1)} + \beta X_{it} + \gamma_i + \delta_t + \varepsilon_{it}$

where

$$\text{kWh} = \{\text{Electricity purchases; Natural gas purchases; Electricity generation}\}$$

$$i = \text{county}$$

$$t = \text{year}$$

$$\text{PACE} = \{\text{Post 2007 indicator; First issue indicator; Principal; Stock of principal}\}$$

$$X = \text{controls}$$

$$\gamma = \text{county fixed effects}$$

$$\delta = \text{year fixed effects}$$

ε are standard errors clustered at county level.

The DID research design assumes that unmeasured confounding variation is limited in form to two types: time invariant group attributes and factors that vary over time but commonly to all groups. In combination, this means that any difference between the treatment

TABLE 2

Statistical Test of Pretreatment Parallel Trends Assumption

	Electricity Purchases (kWh per Capita)	Natural Gas Purchases (kWh per Capita)	Electricity Generation (kWh per Capita)
PACE county × *Linear time trend*, 2000–2007	−34.25	−20.91	0.20
	(23.92)	(15.08)	(0.34)
N	464	375	418

NOTE: Clustered standard errors are in parentheses.
*$p < 0.10$;
**$p < 0.05$;
***$p < 0.01$.

and control group in the observed outcome variable remains constant over time, prior to treatment. Therefore, differences between the groups posttreatment can be attributed to the policy change—in this case, the introduction of the PACE program. Next, we explore the validity of this assumption—called the common trends assumption—two ways: through graphical evidence and through regression models.

Figure 3 plots the mean residential electricity purchases, natural gas purchases, and electricity self-generation measured in per capita kilowatt hours for both PACE bond issuing and non-PACE bond issuing counties over the study period, respectively. All are suggestive of relatively parallel trends in the period prior to PACE enabling legislation, though there is some divergence, particularly in the top plot that illustrates electricity consumption.

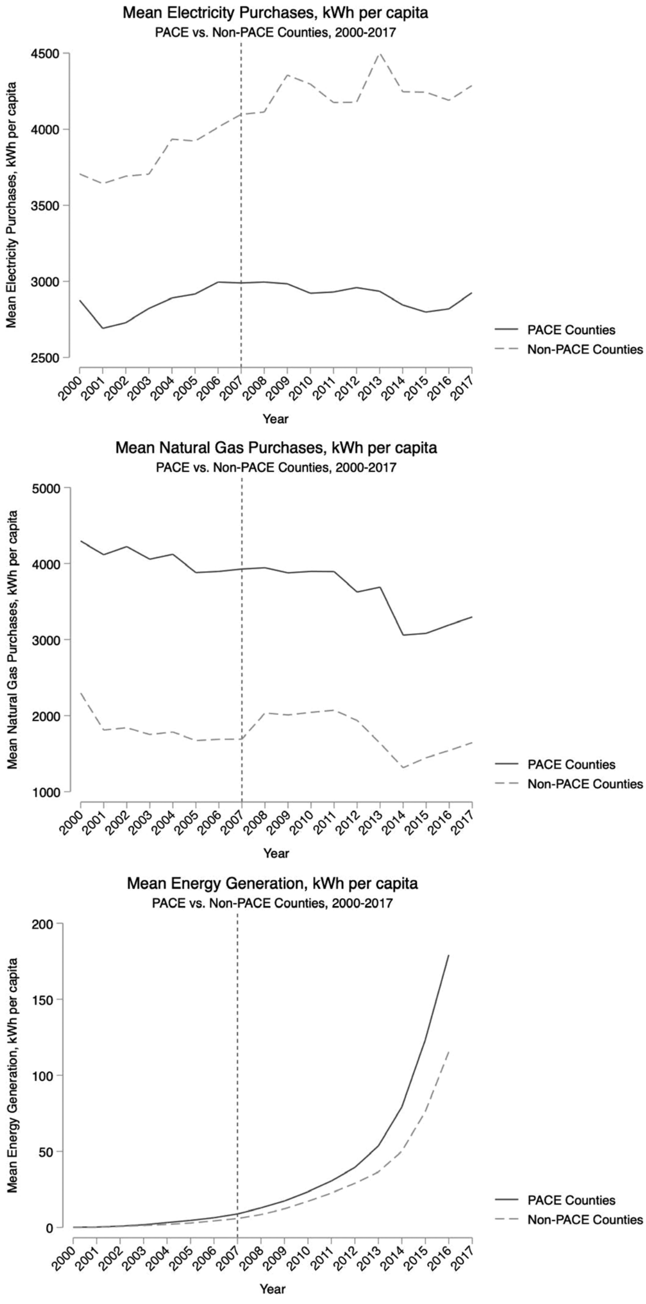
To statistically test the assumption, we use two methods. For the *Post-2007 indicator*, we use Soni et al.'s (2017) regression-based approach. In our basic specification, we simply substitute our treatment variable with a linear time trend interacted with a binary variable indicating counties that are PACE-issuing counties, while restricting the data to observations prior to 2008 when PACE was enabled by the state legislature. The parameter estimate on the interaction term is the coefficient of interest as it measures the difference in pretreatment trends between the treatment and control group. If statistically significant, it would challenge the validity of the common trends assumption. Table 2 shows the results of the regressions for the three outcomes, in which none of the parameter estimates are statistically significant, offering support to the validity of our research design.

Testing the common trends assumption with the approach used above is not feasible for the *First-issue indicator* because counties enter the treatment group at different times—that is, when they first issue a PACE bond. Therefore, to test the parallel trends assumption for the *First-issue indicator* treatment variable, we use an event study. We define indicator variables for PACE-issuing counties for each of the one to four years prior to their first PACE issue and for each of one to four years after their first PACE issue. The year prior to first issue for PACE-issuing counties and all counties that never issue a PACE bond are the comparison group against which each indicator variable is measured. Event studies in which the pretreatment indicators are statistically insignificant and which do not show a noticeable trend lend support to the DID research design. We include the same set of control variables as in our main specifications, as well as a linear time trend variable for each county. Figure 4 shows the event studies for our three outcome variables.

As revealed by Figure 4, none of the parameter estimates in the pretreatment period are statistically significant and only the event study for energy generation shows a mild trend

FIGURE 3

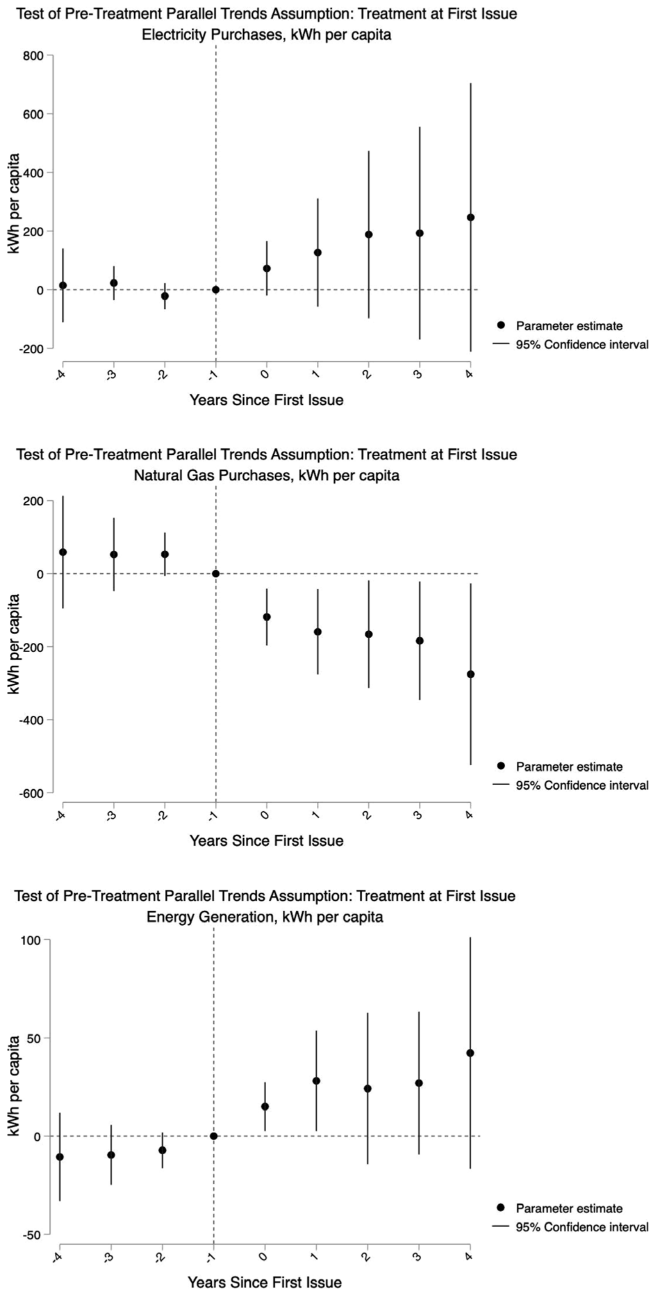
Consequences of PACE Program



in the pretreatment period. Therefore, the event studies confirm that our analysis meets the common trends assumption, lending further support to the validity of the results of our DID research design, which we will discuss in the upcoming section.

FIGURE 4

Impact of PACE Program



Results

Tables 3–5 show the results of two alternative specifications. The two specifications of each treatment-outcome variable pair differ in whether we include county fixed effects interacted with linear time trends. This interaction serves as a check on the parallel trends

TABLE 3

Results: Electricity Purchases (kWh per Capita)

Treatment Variables	*Post-2007 indicator* (1)	(2)	*First-issue indicator* (3)	(4)	*Principal* (millions, $2017) (5)	(6)	*Stock of principal* (millions, $2017) (7)	(8)
Post ×* *Treat*	−383.8 (260.1)	−195.3 (193.4)	−126.8* (66.32)	108.4 (83.61)	−0.0364 (0.116)	0.509* (0.261)	−0.0145 (0.0709)	0.259** (0.0998)
Year and county fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y
County time trends	N	Y	N	Y	N	Y	N	Y
Mean of outcome variable°	3,367	3,367	3,367	3,367	3,367	3,367	3,367	3,367
N	1,044	1,044	1,044	1,044	1,044	1,044	1,044	1,044

NOTE: Mean of outcome variable for PACE counties pre-2008 and for non-PACE counties all years. Clustered standard errors are in parentheses.
$^{*}p < 0.10$;
$^{**}p < 0.05$;
$^{***}p < 0.01$.

assumption. Table 3 shows the regression results for our first outcome variable of interest, electricity purchases, with all four of our treatment variables. The results reveal that the effect of PACE financing on electricity purchases is not robust across either specification or any of the treatment variables. Specifically, the *Post-2007 indicator* is negative and statistically insignificant in both specifications, the *First-issue indicator* is negative and marginally significant in Model 3, but changes signs and loses statistical significance once the county time trend is introduced in Model 4. Likewise, the measure of principal amount in Models 5 and 6 switches from a negative to a positive parameter estimate once the county time trend is introduced, as well as going from not statistically significant in Model 5 to marginally significant in Model 6. *Stock of principal* follows a similar pattern to *Principal.* The results for the regressions on natural gas purchases, in Table 4, are similarly inconsistent across specification, with county time trends significantly affecting the parameter estimates and their standard errors.

Finally, Table 5 shows the results for self-generated electricity. Compared to our previous findings, these results are more consistent across the models, with the sole negative parameter estimate being where *Post-2007 indicator* is the treatment variable and county time trends are included. The dollar amount variables are consistent across all four specifications. Models 6–8 provide evidence that investment in PACE projects, as measured by the principal amount and cumulative principal amount of PACE bond issues, is associated with an increase in the amount of electricity self-generated by households. The increase, however, is substantively small. Using the most conservative of the parameter estimates on the continuous treatment variables from Model 8 (0.0809, $p < 0.01$), an additional million dollars in the stock of principal increases electricity self-generation by 0.74 percent over the mean of treated counties prior to state enablement of the PACE program and nontreated counties over the period. The largest treatment effect estimate (0.156, $p < 0.01$) from Model 5 represents a 1.4 percent increase over the same mean.

TABLE 4

Results: Natural Gas Purchases (kWh per Capita)

Treatment Variables	*Post-2007 indicator* (1)	(2)	*First-issue indicator* (3)	(4)	*Principal* (millions, $2017) (5)	(6)	*Stock of principal* (millions, $2017) (7)	(8)
Post × *Treat*	−183.0	70.25	−306.8***	−85.78**	−0.760***	0.746	−0.370***	0.412**
	(151.8)	(75.27)	(80.22)	(41.22)	(0.207)	(0.618)	(0.129)	(0.177)
Year and county fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y
County time trends	N	Y	N	Y	N	Y	N	Y
Mean of outcome variable°	3,524	3,524	3,524	3,524	3,524	3,524	3,524	3,524
N	843	843	843	843	843	843	843	843

NOTE: Mean of outcome variable for PACE counties pre-2008 and for non-PACE counties all years. Clustered standard errors in parentheses.
*$p < 0.10$;
**$p < 0.05$;
***$p < 0.01$.

Taken in totality, our results reflect that we are unable to generate stable estimates for aggregate-level measures, such as total electricity and natural gas purchases, but can dependably detect how PACE bonds impact more specific metrics, including renewable electricity generated. This outcome is reasonable given the relatively low dollar amount the PACE program injects into each California county every year, suggesting that future scholarship should aim to gather data at lower levels of geographic variation to more explicitly understand if, and how, PACE programs impact electricity consumption and generation at the household level.

Conclusion

The State of California and its substate governments pioneered the use of PACE programs, an innovative policy tool that finances energy-efficient and renewable energy technologies on private residential properties. PACE programs coordinate the private capital of PACE firms and lenders, the voluntary participation of homeowners, and the legal authority of municipalities to issue debt and to assess and collect the special property taxes that secure the debt. In addition to the innovative use of special property assessments, the program is novel because local governments facilitate private behavior that could result in positive externalities (i.e., reduced consumption of carbon-based energy sources accrues benefits beyond participating homeowners, such as a reduction in overall air pollution) without a budget expenditure. To our knowledge, PACE is the only program of its kind.

We test the effectiveness of PACE financing programs by comparing California counties that have participated in the program with those that have yet to issue a PACE bond. Using a DID design, we analyze the relationship between the issuance of PACE bonds and

TABLE 5

Results: Electricity Generation (KWh per Capita)

Treatment Variables	*Post-2007 indicator* (1)	(2)	*First-issue indicator* (3)	(4)	*Principal* (millions, $2017) (5)	(6)	*Stock of principal* (millions, $2017) (7)	(8)
Post × Treat	21.42*	−17.30*	26.72**	17.12	0.156***	0.129**	0.101***	0.0809***
	(11.55)	(8.715)	(12.88)	(10.97)	(0.0563)	(0.0594)	(0.0275)	(0.0249)
Year and county fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y
County time trends	N	Y	N	Y	N	Y	N	Y
Mean of outcome variable°	10.96	10.96	10.96	10.96	10.96	10.96	10.96	10.96
N	923	923	923	923	923	923	923	923

NOTE: Mean of outcome variable for PACE counties pre-2008 and for non-PACE counties all years. Clustered standard errors are in parentheses.
*$p < 0.10$;
**$p < 0.05$;
***$p < 0.01$.

the consumption of conventionally generated electricity, natural gas, and self-generated electricity by private California residences. This analysis is the first empirical study to examine the impact of PACE financing on the consumption of conventionally generated energy and on the generation of renewable energy by homeowners.

Our estimates of the program's impact on conventional energy purchases are inconclusive due to mixed and inconsistent results across specifications. However, we find evidence suggesting that investment in PACE projects increases energy self-generated by residences, relative to counties in which PACE bonds are not issued, though the increase is modest. We find that an additional million dollars in investment, as measured by PACE bond issues, increases self-generation between 0.74 and 1.4 percent over the mean of treated counties prior to state enablement of the PACE program and nontreated counties over the period. Though our findings are statistically significant, suggesting that PACE programs are meeting their stated goal of increasing the amount of self-generated energy on private homes, these results do not suggest that the PACE program substantially alters conventional energy consumption or self-generation in California, nor are the improvements cost-effective.

While previous analyses report an increase in solar PV installations in California counties that have adopted PACE financing (Ameli, Pisu, and Kammen, 2017; Deason and Murphy, 2018; Kirkpatrick and Bennear, 2014; O' Shaughnessy et al., 2020), our findings suggest that the program may not, in fact, encourage homeowners to unequivocally substitute conventional energy with renewable energy self-generation. As a result, we cannot, with confidence, argue that California's PACE program reduces consumption of carbon-based energy sources. Thus, while the PACE program may boost solar PV installations and self-generation of low-carbon energy, it may not lead to a reduction in the pollutants that contribute to the continued and growing threat of climate change. Therefore, though PACE is an innovative financing mechanism, it may not be the most effective policy tool at reducing carbon emissions.

To help combat climate change, state and local policymakers have adopted a diverse portfolio of energy policies and financing mechanisms, including PACE programs, which aim to facilitate the transition from a fossil fuel based economy to one that is more reliant on renewable energy options. Our analysis suggests that shifting the U.S. economy away from legacy energy industries and encouraging consumers to reduce their consumption of energy is difficult. While innovative financing mechanisms, such as California's PACE program, promote the diffusion of otherwise prohibitively expensive technologies, governments must consider that expected energy savings and accompanying reductions in carbon dioxide emissions from residential renewable energy installations will likely be lower than expected because of behavioral responses such as the rebound effect (Haas, Auer, and Biermayr, 1998). Governments should thus consider pairing financing policy tools that facilitate renewable energy installations with instruments that concurrently educate and encourage residential property owners to reduce their consumption of energy to successfully reduce the pollutants that contribute to climate change.

Future research should consider conducting a parcel-level analysis in California to disentangle the impacts of PACE financing on electricity consumption and determine whether a rebound effect exists. Furthermore, 35 other states and Washington, DC have enabled PACE legislation, so scholarship should extend beyond California's PACE programs to better understand how the program operates across the United States. A larger, national data set may yield more conclusive results regarding its impacts on conventional electricity consumption as well as self-generated energy, which would in turn help policymakers determine whether they should expand or amend the PACE program to help combat climate change.

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