

**CLOSING THE "ENERGY-EFFICIENCY GAP":  
AN EMPIRICAL ANALYSIS OF  
PROPERTY ASSESSED CLEAN ENERGY**

**BY**

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## **ABSTRACT**

Until federal regulators halted operations, a handful of municipal PACE programs across the US offered property-secured loans from city or county funds to homeowners for residential clean energy investments. These loans, repaid through property tax assessments, addressed multiple non-price “market barriers” to residential investments commonly identified in the literature on the “energy-efficiency gap” – information barriers, transferability of investment, and cognitive failures common to high up-front cost investments. To elucidate the magnitude of the “energy-efficiency gap”, this analysis uses difference-in-differences models as well as a synthetic counterfactual to estimate the effect on residential photovoltaic installation rates of three California PACE programs operating between 2008 and 2010. When applied statewide, results predict an increase in installations by approximately 25 homes per year for an average-size Californian city, or 14,170 installations per year statewide.

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## I. INTRODUCTION

Policy approaches to encourage diffused clean energy development are generally justified in two ways: first, clean energy development, such as residential photovoltaics, reduce the incidence of negative externalities from traditional power generation. Environmentally damaging particulate matter or mercury from coal-fired plants, climate change inducing carbon from fossil fuel plants, or public risks from nuclear plants all contribute to additional costs not reflected in the market price. Therefore, increases in diffused clean energy development which lead to decreases in traditional energy production are subsidized or encouraged as a means of addressing this externality. Second, according to many theorists, diffused clean energy development investments at the household or firm level are positive net present value (NPV), but various *market barriers* exist that preclude homeowners and decision-makers from realizing these gains. These barriers are frequently referred to as the “energy-efficiency gap” or the “energy paradox” [1].

The first justification may well provide a basis for increased subsidies (or taxes), although one faces the argument of why these subsidies (taxes) are more cost-effective than alternative means of lowering pollution externalities from fossil fuel production. The second justification, however, is more controversial. Beginning with an assumption of irrational customer behavior forgoing positive NPV investments inevitably leads to the conclusion that something could be done in the public sphere to encourage the “right” decision. Alternatively, starting from the opposite vantage point and assuming that customers are rational leads to the inevitable conclusion that there are *legitimate* unobserved costs that customers face which weigh heavily against investment. Interference in these rational decisions may only result in inefficient decisions. The question that must be asked is “what are these barriers” and “how do people react when they are removed?” The implementation of Property Assessed Clean Energy financing in a handful of California cities provides a quasi-natural experiment in addressing some of the less tangible barriers theorized by economists.

Property Assessed Clean Energy, or “PACE” is a novel form of financing for energy efficiency or clean energy generation investments where a property owner obtains a loan from their local municipality, and the loan is repaid through a property tax assessment rather than a traditional loan payment. The PACE moniker covers a wide variety of programs across the US – some for commercial projects only, some for residential only, some mixed; some apply only to solar, wind, or geothermal, and some apply for efficiency improvements such as attic insulation and window retrofits. The identifying common threads are:

- **Capital is loaned by a municipal lender who secures the loan by creating a “special assessment district” which effectively serves as a primary lien on the property, and**
- **The assessment for repayment is attached to the property and transfers to a new owner along with other traditional property tax assessments.**

If a borrower fails to make payments on a property tax assessment, the municipality may seize and sell the property for the balance due. If a borrower chooses to sell their property, the PACE assessment, as well as the improvements, transfer to the new owner. Proponents of PACE claim that making it easier for homeowners or businesses to invest in efficiency or clean energy generation projects will decrease dependence on non-renewable forms of energy generation, and will keep a larger portion of energy spending in the local economy. Opponents of PACE programs point to the fiscal insecurity it places on mortgages –a PACE loan is primary to a mortgage, meaning that a mortgage holder may recover a lower percentage of a mortgage’s value in the event of a default. In California, the average installation price and potential loss for a foreclosing mortgage holder is approximately \$37,899 [2].

In theoretical terms, PACE addresses three elements of the energy-efficiency gap: high up-front costs that lead to potentially irrational behavior in consumers, lack of transferability due to illiquidity of investment, and high information transaction costs, where the homeowner’s ability to communicate the potential benefits to a lender comes at a high cost. These elements will be discussed in detail in Section III of this paper. To understand how PACE addresses these elements of the energy-efficiency gap, one must fully understand the effect of PACE programs and the extent to which PACE programs directly encourage adoption of the diffused renewable energy systems. It is not sufficient to simply add up the number and value of PACE loans performed as a potentially large number of these investments may have been made even absent the existence of a PACE [3].

**This analysis seeks to isolate the effects of PACE programs while controlling for trends in residential photovoltaic installations (RPV) and other characteristics at the city level that are found to influence RPV levels.** Furthermore, this analysis seeks to isolate the effect of PACE programs on “market barriers” that contribute to the energy-efficiency gap independent of any direct price of capital effect. Due to large differences in consumer behavior at the residential and commercial level and regulatory intervention in the residential mortgage market, this analysis will concentrate only on residential PACE programs. To control for other intervening state-level policies, this analysis is limited only to California, though a handful of municipalities in other states have implemented PACE programs. In Section II, I introduce the three residential PACE programs studied and provide background on the current state of PACE programs in the US. In Section III, I

frame PACE programs within the literature on the energy-efficiency gap, the idea that consumers, despite facing positive net present values for energy investments in their homes, are affected by market barriers which result in a less-than-optimum uptake rate. In Sections IV and V, I present the data and methodology used for empirical analysis, followed by Section VI, where results are presented. Section VII discusses the results in terms of the energy-efficiency gap, and Section VIII concludes with a set of policy recommendations based upon the findings.

## **II. PACE PROGRAMS STUDIED**

### **Background**

Across the United States, there are a large number of PACE programs at various stages of implementation. By 2010, California, Oregon, Nevada, Colorado, New Mexico, Oklahoma, Texas, Louisiana, Minnesota, Wisconsin, Illinois, Ohio, New York, Vermont, Maryland, Virginia, North Carolina, Florida, and Hawaii had all passed state laws enabling the creation of PACE assessment districts by municipal entities. In many cases, these bills unanimously passed in the legislative houses [4]. Though many states had approved the concept of PACE, only a handful of cities had active programs as of 2010. These programs active in 2010 are shown in Table II.1.

TABLE II.1: PACE PROGRAMS ACTIVE AS OF 2010

Municipality	State	Program Name	Start Date	Loan Terms	Program Requirements		
					Energy Efficiency Audit	Energy Efficiency Investment	Credit-based
Berkeley	CA	BerkeleyFIRST	Pilot - 2008	7.75% over 20 years	No	Voluntary	No
Palm Desert	CA	Palm Desert EIP	August 2008	7% over 20 years	No	Voluntary	No
Sonoma County	CA	Sonoma County EIP	March 2009	7% over 20 years	Yes after July 2011	10% minimum investment, after July 2011	No
Yucaipa	CA	Yucaipa EIP	August 2009	7% over 20 years	No	Voluntary	No
Placer County	CA	mPOWER Placer	May 2009	7% over 20 years	Yes	Voluntary	No
Boulder County	CO	ClimateSmart Loan Program	2009	Not to exceed 4.5% (income qualified) or 7.75% (open) over 15 years	Yes	No	Partial
Babylon	NY	Long Island Green Homes	2008	3% over 10 Years	Yes	Voluntary	No

Sources: (Long Island Green Homes 2012), (Boulder County ClimateSmart Loan Program 2011), (City of Palm Desert 2011), (Farrell 2010), [5]

PACE was first proposed in the Association of Monterey Bay Area Governments (AMBAG) Regional Energy Plan of 2006 as “On Tax-Bill Financing”[6]. The idea was first implemented in Berkeley, California, in 2008 as the “Berkeley FIRST” program; however, this program was a limited trial run and full roll-out was not achieved. On July 21, 2008, California enacted AB811, which authorized local municipalities to create special assessment districts necessary for PACE programs to exist [7]. The first fully-implemented PACE program in the US was the Palm Desert, California “Energy Independence Program” (PDEIP), which was officially approved on August 28, 2008 [8]. In January, 2009, Sonoma County, California, approved the Sonoma County Energy Independence Program (SCEIP), which began operations in March, 2009 [9]. Yucaipa, California followed in August 2009 with the Yucaipa Energy Independence Program (YEIP) [5].

PDEIP has loaned over \$5 million [3], while SCEIP completed loans totaling \$18.7 million for 584 projects within its first year of operation [10], and nearly \$50 million over 2,664 residential projects through 2012 [10]. Loan information for YEIP was not publicly available.



This analysis is limited to the Palm Desert, Sonoma County and Yucaipa EIP programs. The reason for this is twofold: first, by focusing on three mature programs with significant test periods, I reduce standard errors in econometric techniques and provide better evidence. Second, by staying within the State of California, I am able to control for differences in statewide programs and incentives that would be significant roadblocks for national evaluations. The BerkeleyFIRST program had caps on participation. Therefore, it is omitted from study and control. The Placer County mPOWER program has little public information available on its implementation and is omitted from study and control.

### ***Palm Desert, California "Energy Independence Program"***

On July 24<sup>th</sup>, 2008, following the signing of AB811, the city council of Palm Desert adopted Resolution 08-75 which "declare(d) its intention to finance distributed generation renewable energy sources and energy efficiency improvements through the use of contractual assessments" and required the City Clerk to draw up a "directors report" including plans for implementation of a PACE program. This report was delivered on August 28<sup>th</sup>, 2008 and opened to public comment. After minor changes, the city council established the first residential PACE program in California [8].

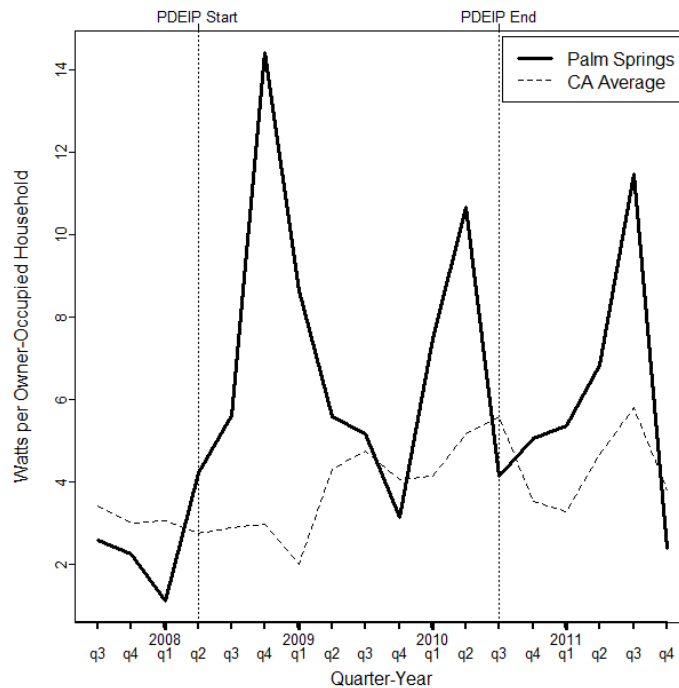
Funding for PDEIP initially consisted of \$2.5 million from the city's General Fund [11] and an additional \$2.5 million from the city's Redevelopment Agency [12]. The council also adopted a maximum interest rate of 7% for the initial \$5 million, and gave authorization for the city to issue additional bonds in the municipal bond market; PACE loan interest rate terms for funding acquired through bonding were capped at 10%, while the city was limited to issuing bonds paying a maximum of 12%, though current bond rates available to the city were priced at approximately 8%. The city's investment portfolio averages a return of 3.75%, far below the interest rate charged on PACE loans made under the PDEIP program, even once adjusted for risk. A marketing budget of \$160,000 was included in the Directors Report, adopted under Resolution 08-89 [8]. In February of 2010, an additional \$6 million in funding was announced by the city [12].

Palm Desert's "Directors Report" also established the requirements for approval for a PACE loan. Under the PDEIP's "solar system" track, PV installations are required to be rated by the California Energy Commission and bids for installation must be reviewed by the program director. Installation prices that are higher than a normal rate (determined by the city) are required to obtain additional bids, eliminating the possibility of fraudulently inflated installations. Participation is limited to residents within Palm Desert city limits who are current on property tax

assessments and do not have a history of delinquency on payments. A property’s value-to-lien ratio, comprised of the property’s assessed value against the total of existing special assessments on the property (i.e. assessments for streets, lighting, parks, schools, etc.) plus the EIP assessment, may not be lower than 10:1 [11]. Applicants need not submit credit checks, mortgage balance reviews, or income verification.

Anecdotal reports from city employees highlight “lines around the block” for applicants wishing to participate in the PACE roll-out [13]. Figure II-1 shows the Palm Desert time trend for RPV installations in Watts per Owner-Occupied Household (W/OOH) in comparison to the statewide mean Watts per Owner-Occupied Household. Monthly installations jumped from .738 W/OOH in the second quarter of 2008 to 2.58 W/OOH in the third quarter of 2008. A significant drop may be observed in the final quarter of 2009. This corresponds to the period between the initial funding and the February 2010 new funding. Though no applicants were turned away, a waiting list was created in this period anticipating additional funding; customers who did not wish to be on a “waiting list” may have delayed RPV installation.

FIGURE II-1: PALM DESERT WATTS INSTALLED PER OWNER-OCCUPIED HOUSEHOLD



### ***Sonoma County, California “Energy Independence Program”***

SCEIP was initially proposed in August of 2008, and was approved by the county council in January 2009 [14], with the first applications accepted in March 2009 [9]. The 60-day rollout from January to March of 2009 allowed local solar installation companies and industry groups to advertise the program to potential customers [15].

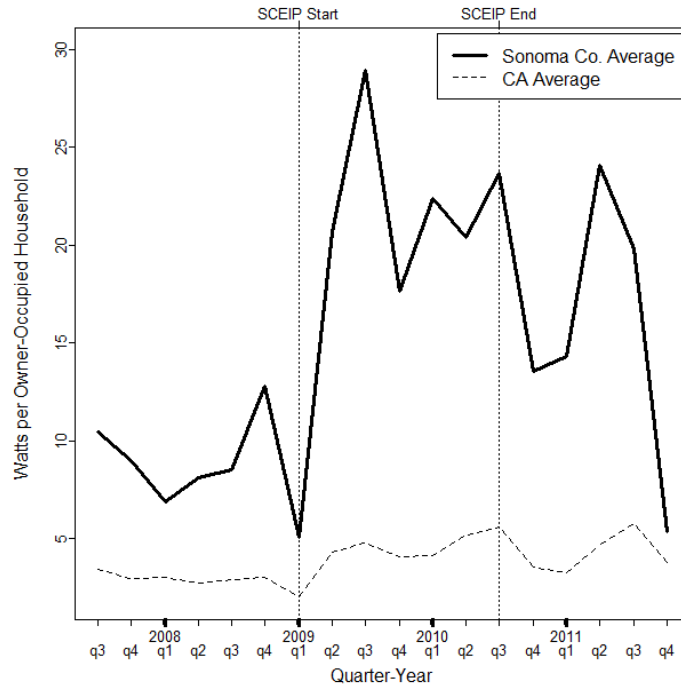
The maximum interest rate for PACE loans under SCEIP is 7% and participation is limited to county residents who would owe less than 110% of their property value inclusive of PACE loans and other loans or mortgages and are current on their property taxes and mortgage.<sup>2</sup> Loans are limited to 70% of property value for those who own their property outright [9]. No credit check or income minimums are required for participation. Effective July 1<sup>st</sup>, 2011, SCEIP participation requires that participants dedicate a minimum of 10% of the loan amount to energy efficiency improvements such as improved insulation or efficient windows unless the home rates extremely high on an energy assessment [16].

Proponents of SCEIP have released studies showing significant correlation between green jobs and SCEIP program, and touting anecdotal evidence from local solar installation firms and customers. Even without a PACE program, Sonoma County exhibited a higher-than-normal average W/OOH (Figure II-2).

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<sup>2</sup> Some additional restrictions apply for homeowners who have filed for bankruptcy within the previous 3 years.

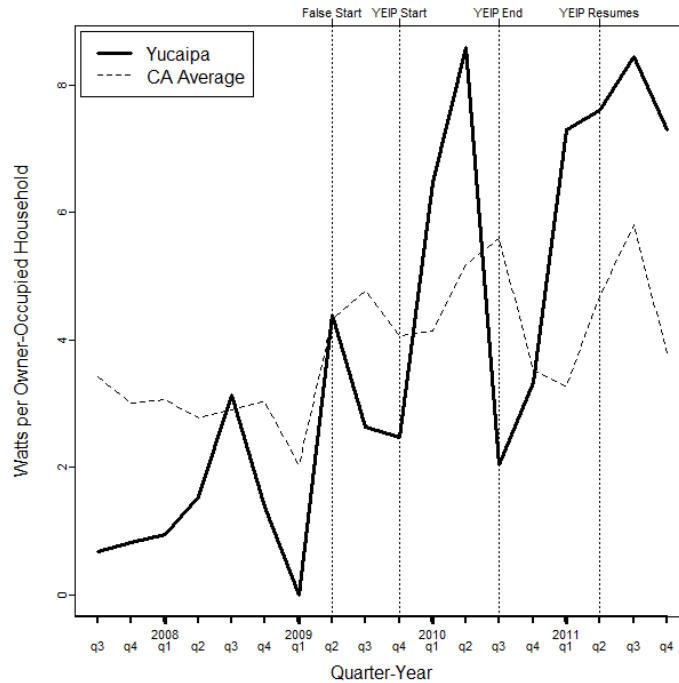
FIGURE II-2: SONOMA COUNTY WATTS INSTALLED PER OWNER-OCCUPIED HOUSEHOLD



***Yucaipa, California “Energy Independence Program”***

Quietly launched in September of 2009, Yucaipa Energy Independence Program (YEIP) is similar in terms and conditions to that of Palm Desert’s EIP. YEIP’s guidelines share structure and wording with PDEIP’s, but include financing for water conservation efforts as well as electricity conservation and RPV. The program was initially slated to begin in July of 2009, however, city staff were not immediately ready to implement the program. Full advertising began in September of 2009 and continued through December of 2009 [17]. Figure II-3 shows the quarterly W/OOH installation amounts versus the state average. While there is significant volatility in W/OOH installations even after the September 2009 program start date, there is a general upward trend in the data and most quarters following the implementation date have higher W/OOH installations relative to the state average.

FIGURE II-3: YUCAIPA WATTS INSTALLED PER OWNER-OCCUPIED HOUSEHOLD



### Next-Best Sources of Financing

A cost-comparison baseline is necessary to compare the financing options available to potential PACE applicants. For homeowners without access to a PACE program, the closest source of financing is the 30-year fixed rate mortgage via a refinance. The 7% interest rates charged by all three EIP programs were *higher* than 30-year fixed rate mortgages for a comparable metropolitan area during all but four months of the study period (Figure II-4: Alternative Financing Options) [18]<sup>3</sup>. Home equity lines of credit (HELOCs) are commonly used for home improvement projects similar to RPV installation. Unlike PACE loans, HELOCs are variable interest rate and are tied to US prime interest rate. Common HELOC terms are a set percentage above prime, and many have overall caps on the total interest rate. During the study period, a 2% above prime HELOC would be at or less-than a PACE loan. Generally, HELOCs do not have extended time periods for repayment, and are not secured against the property in the same manner as PACE loans. Therefore, they are not entirely comparable to PACE loans in operation or price. 2% above prime HELOC rates are shown in Figure II-4: Alternative Financing Options. Home equity and refinanced loans for RPV

<sup>3</sup> Mortgage data for the San Bernardino/Riverside County Area was not available for 2007-2010. The nearest comparable area with available mortgage rate history, the Sacramento Metropolitan area, was substituted.

installations enjoy the added benefit of tax deduction for interest paid. PACE loans also enjoy the same deduction as property tax assessments are non-taxable.

Other alternatives for financing include FHA Energy Efficient Mortgages which calculate energy savings or RPV into an applicant's estimated monthly expenses, allowing for a larger loan for any given income and credit rating but leaving the available interest rate unaffected. In the Sacramento area, the Sacramento Metropolitan Utilities District (SMUD) offers a 10-year secured energy investment loan at 8.75% interest. Additional points and fees may apply for refinancing, and loans obtained through mortgage refinance require minimum credit ratings.

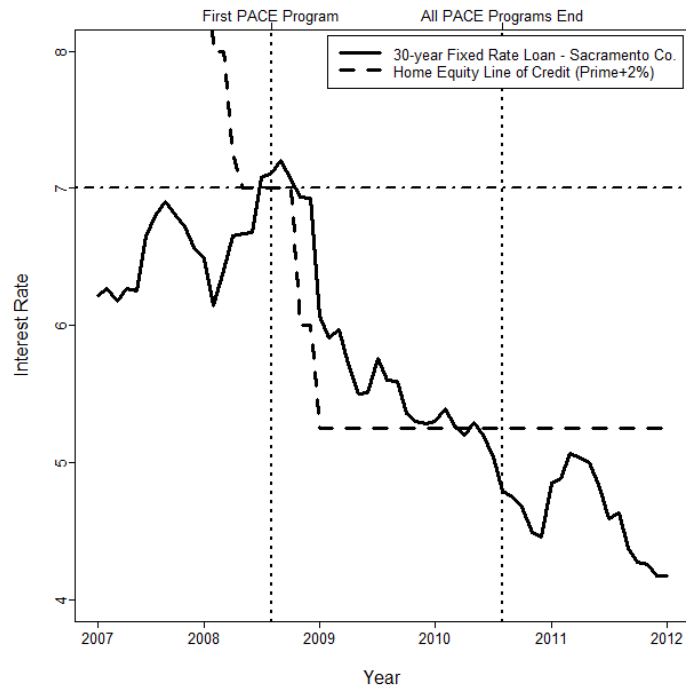
In a case study on the pilot-only BerkeleyFIRST PACE program, surveys found that, while 66% of participants who used a BerkeleyFIRST PACE loan identified "reasonable interest rate" as a reason for using their loan, 90% identified "ease of obtaining financing" as a their reason for choosing BerkeleyFIRST. Of the initial applicants who applied for a BerkeleyFIRST PACE loan but then withdrew, nearly 60% installed RPV using a "different funding scheme"[3].

When compared to existing financing methods, none of the study EIPs exhibit superior financial terms. Because the effect of PACE is not directly attributable to a lowering of costs or a subsidizing of interest, the main driver of any change in consumer behavior cannot be a change in pure price.<sup>4</sup>

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<sup>4</sup> I thank Dr. Richard Newell for motivating this question.

FIGURE II-4: ALTERNATIVE FINANCING OPTIONS



### Acceleration

An attractive aspect of PACE financing is the transferability of the PACE assessment to a new homebuyer, relieving the installing homeowner of responsibility following a sale. Although recent empirical evidence shows the capitalization of RPV into home prices [19] [20], it is likely that the perceived costs of communicating the asset value of an installed PV system is higher than the actual costs of communicating a monthly generation benefit from an installed PV system. The benefits of the transferability of a PACE loan are lost when acceleration, the requirement that a PACE lien be repaid in full when a home transfers ownership, is mandated by the PACE program.

PDEIP, SCEIP, and YEIP all have no acceleration requirements. However, federal regulators responsible for overseeing federal mortgage purchases have required acceleration for PACE loans originated after July 6<sup>th</sup>, 2010.

### Federal Housing Finance Agency Concerns

In July of 2010, the Federal Housing Finance Agency (FHFA), the federal agency tasked with monitoring and regulating the mortgage-buying Government Sponsored Entities (GSEs) Fannie Mae and Freddie Mac, issued a letter essentially forbidding the GSEs from purchasing mortgages that carry the senior liens and assessments instrumental to PACE programs [21] [22]. Because

mortgages that are unable to be re-sold to Fannie Mae and Freddie Mac are less desirable to mortgage underwriters, new PACE borrowers face an effective penalty in their mortgage interest rates, rendering residential PACE programs undesirable by most loan seekers. Although previous concerns were elucidated in FHFA letters in May 2010, the July 2010 letter was not anticipated by PACE program operators, and the general public was unlikely to have been aware of coming changes to either PACE program.

### ***Reactions to FHFA Letter***

The FHFA letter of July 2010 placed the PDEIP program on hiatus for two months, after which new guidelines required that PACE loan applicants obtain a signed approval from their mortgage-holder prior to PACE loan approval. Reports from Palm Desert employees estimate a drop of about 75% in PACE applications following the program's FHFA-fomented hiatus [13]. Figure II-1 shows this drop following 3<sup>rd</sup> quarter of 2010. SCEIP has also continued operation in a similar manner, following FHFA guidelines in requiring mortgage-holder approval for participation. Both EIPs have maintained or expanded commercial PACE programs as FHFA-regulated GSEs do not operate in the commercial lending arena. YEIP placed its nascent program on hiatus in July of 2010, and restarted the program on August 8<sup>th</sup>, 2011 with similar requirements for mortgage-holder approval for participation.

From an empirical standpoint, the additional conditions required by the GSEs for obtaining a PACE loan after July of 2010 represent a distinctly different type of treatment that is not directly comparable to pre-July 2010 treatment.

### ***Current Political Climate***

Following the FHFA letter, a number of political coalitions formed to reverse the decision. Sonoma County filed suit to reverse the FHFA decision. The suit resulted in a requirement that the FHFA initiate formal rulemaking procedures for guidelines on PACE regulation. Public comments began in Winter of 2012 and are ongoing as of March 2012.

A variety of bills were introduced in the 112<sup>th</sup> Congress to remove restrictions imposed by FHFA. HR2599, introduced by Republican Nan Hayworth of New York and co-sponsored by a bipartisan group of 51 Congresspersons would:

**“...prevent Fannie Mae, Freddie Mac, and other Federal residential and commercial mortgage lending regulators from adopting policies that contravene established State and local property assessed clean energy laws.”**



PACE loan programs have bipartisan support due mainly to the local and voluntary nature of the programs – they require no “command-and-control”, use markets, and do not force any individual or municipality to participate, a feature attractive to right-leaning political coalitions. They encourage externality-reducing green energy development, a feature attractive to left-leaning political coalitions.

### III. THEORETICAL UNDERPINNINGS OF PACE AND THE ENERGY-EFFICIENCY GAP

#### **PACE, Residential Photovoltaics, and the Energy-Efficiency Gap**

In the existing literature, the energy-efficiency gap pertains mainly to investments in home energy efficiency that lower future costs but have high up-front costs in both monetary and convenience terms. While all three PACE programs presented here may be used for efficiency-only investments in upgraded insulation, dual-pane windows, and other energy-saving repairs, this analysis looks only at PACE effects on RPV installations. Installation of RPVs exhibit many characteristics identical to energy efficiency investments.

- **RPV installations hedge against future energy costs by reducing the total amount of electricity purchased from a utility.**
- **RPV installations require research on effectiveness, potential benefits, costs, taxes, installers, and other search costs.**
- **RPV installations require installation on the homeowner’s property and involve multiple contractor visits for estimates and installation, intrusion in a home’s privacy for a short period of time during installation, and some level of future maintenance which may include operational learning costs.**
- **RPV installations may have uncertain future benefits. Likewise, energy-efficiency investments have uncertain payoffs, with some suggesting that actual savings are only 50% to 80% of predicted savings [23], and some suggesting that actual savings may be statistically similar to predicted savings [24]. Similarly RPV installations may vary in output, or information on predicted output may not be available to homeowners, increasing uncertainty.**
- **RPV installations are fixed to the property and cannot be moved with the installing homeowner.**

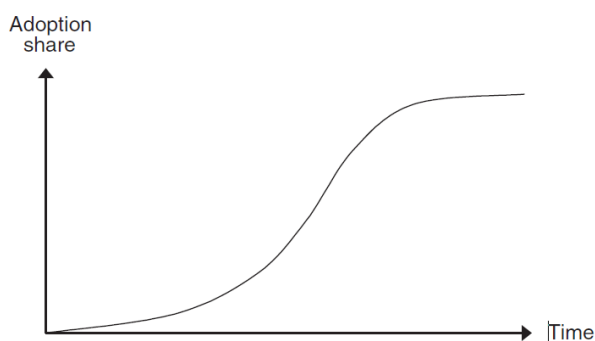
Not all homeowners are ensured a positive NPV from an investment in solar; likewise, not all homeowners are ensured a positive NPV from an investment in energy efficiency. For RPV, studies have indicated that (i) the average California homeowner, with tax incentives, has a positive NPV for RPV installation [25], or (ii) the average NPV for RPV installation is generally negative, but rises with increased expectations of energy prices [26], or (iii) homeowners facing top-tier energy rates and whose homes are situated with good afternoon sun exposure will have high positive NPV from RPV investments. An analysis of the distribution of energy use and solar potential performed by the United States Association for Energy Economics determined that 15% (1.8 million) of all homes in California, would benefit from replacing some or all of their electricity consumption with RPV.

These 15% of homes represent 30% of all residential energy use in California [27]. The NPV of energy efficiency investment depends heavily on each individual's heterogeneous energy use characteristics and geographic variables [28].

These features make RPV similar, in conceptual terms, to investments in energy efficiency and allow for homeowner decisions on RPV installations to be framed within the energy-efficiency gap. Diffusion of energy efficiency and RPV technologies may both be explained using the "diffusion s-curve".

The diffusion s-curve is frequently referred to as an illustration of the rate of diffusion of a new energy saving technology. The assumption in the s-curve is that individual consumers display heterogeneous preferences and NPV's for a new technology, and that over time, as the technology price declines and other intangibles such as search and information costs are eliminated, a growing portion of potential consumers will recognize a positive investment and will purchase or install the new technology. The diffusion s-curve, then, may be thought of as a distribution of consumer hurdle rates, comprised of all observed and unobserved costs which are, in turn, related to "differences in the characteristics of adopters and potential adopters" of a new technology [29]. The curve from Jaffe, Newell and Stavins [29] is reproduced here as Figure III-1:

FIGURE III-1: DIFFUSION OF TECHNOLOGY (JAFJE, NEWELL AND STAVINS, 2004)



### **Financing Features and PACE**

If the study EIPs are not significantly competitive in a pure price of capital market, then what features drive participation? Four key elements of PACE will form the foundation of discussion on the effects of these programs and how PACE may address the energy-efficiency gap.

First, PACE loans eliminate high up-front investment costs or "first-cost barriers." When faced with a significant investment cost, even when paired with a positive NPV, residential consumers do not behave in a manner consistent with expected utility maximization. As I will discuss in the coming

section, a high up-front cost barrier, while a natural feature of any market, creates ripples of behavioral failures and interacts with other market barriers or failures to distort decision-making processes. The first-cost barrier is the first domino that initiates potentially irrational behavior in decision-making.

Second, PACE loans are transferable through property sales. Property assessments are assumed by new owners who acquire both the generation and the repayment burden for a RPV system.

Third, PACE loans help to address information asymmetries. Social network learning may occur between neighbors where information on system payback, installation experiences, and general satisfaction can help reduce future uncertainty. Because installation costs amount to more than 60% of a RPV system, social network learning may be especially relevant in tract-style housing where neighbors reside in identical houses under identical solar conditions, raising the expectations that a neighbor's benefits from RPV may be a reliable estimate for other installations in the same neighborhood.

Finally, PACE loans also address an information asymmetry between borrower and lender. Obtaining a loan specifically for RPV from a PACE program does not require difficult and potentially costly communication of benefits to an uninformed loan officer who may be skeptical about RPV systems.

### **The Energy-Efficiency Gap**

Many individual consumer decisions on the installation of RPV mirror those studied in the literature as the energy-efficiency gap. A brief description of these decisions is given here.

The energy-efficiency gap is defined as the perceived gap in uptake of existing energy efficient technology despite the existence of positive net present values (NPV) of these technologies. Jaffe and Stavins delineate two factors that inhibit "efficient" diffusion of NPV+ technology: "(i) potential market failures: information problems, principal-agent slippage, and unobserved costs, and (ii) explanations that do not represent market failures: private information costs, high discount rates, and heterogeneity among potential adopters" [30]. The latter category is frequently referred to as "market barriers." The separation of factors into market failures and market barriers raises the question of the appropriateness of government intervention in removing market barriers [1] [30] [31], and highlights the difficulty and importance of disentangling the two. Policies that address market *failures* are economically justified. Policies that seek to reduce market *barriers*, however, are not [32].

If it is assumed that homeowners are rational, then the energy-efficiency gap is best explained by researcher's failure to assess the costs facing individual decision makers, and attempts to alter market behavior by altering market barriers may be *diversions* from the optimum, possibly reducing overall welfare [33] [34]. Conversely, if some exogenous "rational" discount rate is applied, perhaps a social time preference or an average return on investment, then failure to invest in a NPV+ energy efficiency technology is a "behavioral failure" or the result of market barriers. "To be useful, such explanations must advance beyond the tautological assertion that if the observed rate of diffusion is less than the calculated optimal rate, there must be some unobserved adoption costs that would modify our calculations of what is optimal"[1].

A variety of market barriers are identified and debated in the literature. In most analyses, these barriers are expressed through an inflated individual discount rate resulting in a high "hurdle rate," or the rate of return on an investment which must be exceeded for the investment to take place [35]. These high hurdle rates are empirically observable and are confirmed by studies on RPV [36], commercial adoption [37], and residential energy-efficiency [35]. A variety of contributors to high hurdle rates have been proposed. In many cases, further examination of the causes of these high hurdle rates have revealed an additional category of failures not accounted for by Jaffe and Stavins, specifically, in many cases, high discount rates may actually be driven by irrational behavior at the individual level spurred by certain natural properties of the energy efficiency market. The existence of these "cognitive failures," highlighted in the literature on behavioral economics, removes some aspects of high discount rates from the category of market barriers; the key difference between cognitive failure-driven high discount rates and the market barrier high discount rates cited by Jaffe and Stavins is that there exists no general rule for appropriateness of public policy interventions in cognitive failures. Discussion here is limited to contributors that are related to or may be addressed by PACE programs.

**Cognitive Failures:** The energy market is inherently uncertain in both expected future energy prices and in expected future benefits from RPV and consumers are, in effect, making a choice between two uncertain streams [38]. High up-front costs inflate the "endowment effect" by magnifying the potential gap between costs and possible gains. Both high up-front costs and uncertainty over multiple streams (RPV payback and future energy prices) are natural properties of the energy and PV market. In facing a combination of these conditions, multiple cognitive failures identified in the literature contribute to the high discount rates in a manner not consistent with rational utility maximization.

Prospect theory establishes the existence of an endowment effect, where possible losses due to uncertain results (in PV generation or unexpectedly-low energy prices) are inflated versus possible gains [39]. The additional weight placed on potential losses in comparison to potential gains reveals non-rational behavior on the part of consumers [40]. High up-front costs further inflate the endowment effect by magnifying the potential loss, distorting an individual decision-maker's internal hurdle rate.

“Ambiguity aversion” behavior amplifies cognitive failures by pushing consumers facing uncertainty and low levels of knowledge towards reduced, and thus simpler, choice sets [40]. The presence of high up-front costs further exacerbates these cognitive failures, though high up-front costs themselves are not a market barrier but rather a natural part of the market.

These cognitive failures co-exist with rationally higher hurdle rates that account for uncertainty, making them difficult to disentangle or measure. While some amount of a decision-maker's higher hurdle rates are rational market barriers, some fraction of these hurdle rates are actually the result of irrational cognitive failures. Shogren and Taylor propose that the cognitive failure-driven fraction of a decision-maker's higher hurdle rate are indeed market failures in that rationality is a social, rather than an individual, construct. In this line of reasoning, a lack of market interactions in the energy sector, possibly driven by the regulated monopoly nature of energy provision in the US, leave individual consumers without the level of market learning common in other purchasing sectors (i.e. cable TV or phone service) that would naturally reduce the endowment effect [40] by increasing rationality over uncertain energy decisions. On two dimensions – the public goods nature of “market rationality spillover” from market interactions and the public policy-driven cause of the lack of market interactions - public policy interventions to address the inflated hurdle rates may be economically justified.

PACE loans address cognitive failures by developing social network learning, increasing certainty about expected benefits from an RPV installation and allowing for sharing of experiences in the RPV market. By sharing experiences, the over-perception of high cost/low probability incidences is limited. Furthermore, the perceived “endorsement” of RPV installations by a trusted source (the municipality) may act to reduce uncertainty and thus the cognitive failures.

**Illiquidity / Diversification Bias:** The inability to diversify non-systemic risks combined with dual uncertainty over baseline energy costs and effectiveness of RPV installations causes individuals to inflate their hurdle rate for an investment. By virtue of being “locked” into an

investment in RPV, individuals require a higher hurdle rate than is necessary to result in an expected positive NPV.

The extent to which this is a “market barrier” rather than a rational action is highly debatable. The Capital Asset Pricing Model (CAPM), a financial analysis tool which accounts for an asset's ability to be diversified (or “hedged”) on secondary markets, may explain and justify higher hurdle rates. For large-scale corporate investments, the secondary risk market is abundant. For individual residential “investors”, the secondary market for diversification does not exist, and thus a private hurdle rate higher than a social rate is rational [34], but may not be optimal.

A counter-argument, however, exists: if energy prices are perceived as uncertain, and households seek to reduce uncertainty, investments in energy efficiency or RPV both should be assigned a *lower* hurdle rate because they serve to insulate the buyer from uncertainty. In fact, maximum benefit from RPV occurs when future energy prices are in a “worst case scenario”, making RPV an effective hedge for risk-averse individuals. It should be noted that uncertainty exists over both the effectiveness of the investment *and* the future energy price [38]. The high hurdle rates observed may indicate that uncertainty over outcomes of investment outweighs uncertainty over outcomes of non-investment.

PACE programs permit a form of divestment through the sale of the property. A traditional form of financing requires either that a full repayment of the system price be completed upon sale (regardless of the sign of the balance of equity in the home), or that an installing homeowner continues to pay for an installed system even once the home has been sold. Though a PACE loan does not allow a RPV to be divested in the traditional market sense, the ability to transfer ownership is an important feature that addresses a well-established barrier to investment.

Closely related to the illiquidity bias, the concept of option value states that “uncertainty about the future benefits of energy-efficient technologies, combined with the irreversible nature of the efficiency investment, makes the effective discount rate for analyzing the net present value of energy savings significantly greater than is typically used in the calculations that suggest the existence of a paradox. When making irreversible investments that can be delayed, the presence of this uncertainty can lead to an investment hurdle rate that is larger than the discount rate used by an analyst who ignores this uncertainty” [29]. Hasset and Metcalf conclude that the inclusion of option value increases rational hurdle rate by a factor of four ([41], quoted in [42]). Option value over *uncertainty* is not to be confused with under-provision of information as a public good –the former is normal and present in every market, while the latter is best classified as a classic market failure.

The effect of an option value is disputed by Sanstad, Blumstein and Stoft, who found that the increase in hurdle rate due to option value is a function of both uncertainty *and* the underlying discount rate. Using the same model as Hasset and Metcalf, Sanstad et al. showed that an underlying discount rate of 15% (the upper bound of the expected consumer discount rate) results in a 17.4% option value-adjusted hurdle rate – a far cry from the factor of 4 originally hypothesized [42].

**Information Barriers:** A wide range of market barriers revolve around the acquisition, processing, and application of information. The invocation of transaction cost economics may classify many of these barriers “information market failures” rather than market barriers [31], however, an examination of these various types of information barriers is warranted by their contribution to individual decisions.

### ***Search Costs***

Although some level of uncertainty will always exist when estimating future RPV effectiveness, even in a perfect market, access to existing information, or the ability to gather potentially feasible information, represents a market barrier. Up-front costs are easily known yet the long-term payoff is not as easily known even though it is likely that reasonably accurate information exists. To the extent that others possess low-cost information on the effectiveness of their own investments, lack of access to that information is considered an information barrier. “It is by no means costless to learn how a generic technological improvement fits into one’s home...or to learn about reliable suppliers” [30].

A large portion of search costs for RPV lay in “balance of sale” costs – the cost of engineering an appropriate supporting roof structure, calculating expected solar exposure and generation given an exposure angle and solar potential, and understanding the ease of interfacing with the local power company. In neighborhoods with homogeneous construction and build as is common in Californian tract housing, one resident’s experience is likely to be an excellent predictor of another nearby resident, especially if they have a house situated at a similar angle and of similar construction. A high level of beneficial information sharing may be captured simply by increasing RPV installations in a neighborhood.

Lack of access to accurate information based on firsthand experience is relatively unique to the residential market – a firm may have reasonable knowledge of the returns to investment of another publicly owned firm or may infer such payoffs from changes in price or supply, while a homeowner has no such cues to follow. Golove and Eto consider this a provision of public goods (information) problem, and thus classify it as a market failure [31]. Others consider a high cost of information to

be a natural part of a market, and identify it only as a barrier when the “search costs” do not exceed the benefits of such information. Koomey and Sanstad examine these search costs for information and find that they do not single-handedly justify higher hurdle rates ([43], quoted in [33]). Clearly, some fraction of observed search costs are indeed private costs and are thus not market failures. However, some remaining fraction of search costs may be correctly classified as a public good, especially in communities where home structures are of similar build and construction.

Furthermore, these public/private search costs may address decision-maker’s difficulty in relying on manufacturer-published estimates of effectiveness which tend to be mistrusted by individuals due to “past experience with advertised misinformation” ([44], quoted in [31]).

A PACE program which increases the uptake of RPV contributes to social network learning, reducing information costs and addressing the public goods portion of these costs.

### ***Information for Finance***

Due to high up-front costs, many individuals use financing for their investments. An informational asymmetry exists between lenders and borrowers in two forms. First, lenders do not generally account for the savings on electricity bills when calculating a borrower’s income for loan amounts. An energy efficient investment may save a borrower \$100 per month, however, their income considered “available” to repay a loan is not usually increased by the expected savings. The exception to this is the Federal Housing Authority’s “Green Loan” program which performs this exact function. Second, communicating potential savings to lenders is a difficult process, and doubles up on many of the previously discussed issues: lack of trust in published estimates, uncertainty over effectiveness, etc.

Here, the classification of market barrier versus market failure is unclear. One can imagine a scenario where net social welfare would increase substantially after a socially-funded information campaign targeted at loan officers – if homeowners are capital-constrained but aware of NPV+ investments, pooling together and purchasing “information” for loan officers would lower the cost of capital for all, and thus would potentially increase welfare by some amount equal to the sum of the positive NPV over all homeowners minus the cost of informing loan officers.

Instead of addressing the public goods nature of lending information, PACE supplants the lending process with an alternative method of financing, essentially letting each informed and NPV+ homeowner become their own loan officer. Because the information for finance problem is partially a question of *who* does the lending rather than *what information* the lender uses,



categorization into market barrier or market failure is unclear. Similar to the previous search cost discussion, it is clear that some fraction of information for finance costs are actually public goods and are thus market failures that are appropriately addressed with a public policy intervention such as PACE.

### ***Information on Capitalization***

Any investment attached permanently to a home will be evaluated in terms of its sale price and its expected level of capitalization. Communicating gains in efficiency to potential buyers represents a significant information barrier similar to the lender information barrier discussed above. Recent studies on the capitalization of RPV into a home's resale value indicate that buyers are receptive to the value of a RPV system [20]. Homeowners may still view the resale value of an RPV-equipped home with an additional layer of uncertainty.

Through social network learning, PACE loans reduce the cost of information about effectiveness, search costs, and possibly information on capitalization of a RPV.

### **PACE and the Energy-Efficiency Gap**

To the extent that PACE addresses the market failures and market barriers identified here, then a positive effect of a PACE program, independent of the loan's pure price, may support the claim that (i) substantial market barriers to energy efficiency do exist, and (ii) a policy remedy may be appropriate. I leave open for debate whether the market barriers presented here actually reflect neoclassical market failure in information and transaction markets; regardless of how one conceptualizes these failures or barriers, the notion that consumers are not reaching a true optimum level of investment, one that is based on observed preferences and not an exogenously estimated "correct" hurdle rate, may serve as a justification for policy intervention.

## **IV. DATA**

To understand the magnitude of the energy-efficiency gap, I now turn to the data necessary for empirical measurement of the effect of PACE programs implemented in California prior to July of 2010. Data on RPV installations was collected from the California Solar Initiative public database [2]. The California Solar Initiative (CSI) is responsible for disbursing RPV incentive payments mandated under Senate Bill 1, originally passed in 2006. Under SB1, all RPV installations in California qualify for a one-time direct payment that represents a significant portion of the RPV system's cost. Although the CSI and its database cover only RPV installations within investor owner

utilities (IOUs)<sup>5</sup> service areas, the IOUs provide 75% of all of California's electricity. The incentives average \$5,526 and are obtained through a simple process: a customer first calls to "reserve" their incentive to lock in the current incentive rate. Once installation is completed, the customer submits a confirmation of installation, and a payment is sent by mail. Due to the significant size of incentives, it is assumed that the CSI database is the most accurate database of RPV installations available.

The CSI database contains individual installation-level data including installed wattage, cost of installation, date of first reservation, date of installation confirmation, installation city, and current status. Though the database became active in January of 2007, the first six months of operation was a transition from the prior incentive system. Only data from July 2007 forward was included in this analysis. To avoid counting uninstalled systems, only "completed" incentives were used through 2010. For the 2011 year, installations listed as "pending" were included.

CSI data was aggregated by city and summed by quarter to smooth the volatility of solar installations and to avoid excess masses of zeroes in the data. Dependent (outcome) variables used in this analysis are W/OOH (watts per owner-occupied household) and Q/OOH (quantity of installations per owner-occupied household). These variables are normalized by dividing the aggregated totals by owner-occupied households present in each quarter. CSI incentive data variables are listed in Table 3.1:

To control for economic and social characteristics that may drive RPV installation independent of a PACE program, socio-economic city-level data was taken from the US Census' American Community Survey (ACS) 3-year datasets for 2005-2010 and the 2010 US Census. RPV systems suffer from the principal-agent problem familiar to many economists – because an RPV system is fixed to a property, renters have little incentive to invest, and because electricity generated by an RPV system is used by the household first, with leftovers returned to the grid, landlords have little incentive to invest. Therefore, all household-level data is, whenever possible, exclusive to owner-occupied households. Owner-occupied household data is indicated with a "\*" in Table IV.1.

To capitalize on information inherent in the time series installation data, yearly measures of socio-economic data were used. ACS 3-year datasets are available on a yearly basis but are limited to

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<sup>5</sup> IOUs are San Diego Gas & Electric (SDGE), Southern California Edison (SCE), and Pacific Gas & Electric (PG&E). Other areas are served by municipal, state, or federal utilities.

cities and metropolitan areas greater than 20,000 in overall population.<sup>6</sup> Because all PACE programs studied were implemented in cities larger than 20,000, no statistical issues are raised over exclusion of very small cities or rural areas. In fact, small cities may have some unique unobservable characteristics that could confound their aggregate RPV installation choices and are thus not appropriate for inclusion in the analysis. For specifications including all size cities, US Census 2010 and 2000 data was used.

Power prices and state incentive amounts are likely drivers of RPV installations as these are the primary economic variables facing a homeowner. Power prices vary by year, but are constant over each utility. Incentive amounts are designed by legislation to be declining – once a set amount of capacity for a utility has been installed at a given “step”, the incentive rate decreases. In 2007, the incentive rate for all utilities was set at \$2.50 per watt. By the end of 2011, the incentive rate for SCE customers had dropped to \$.60 per watt, while PG&E customers were offered \$.25 per watt due to higher uptake of RPV in that service area. I exploit the cross-utility variation in incentive prices to disentangle the general upward time trend from the downward pressure of decreasing incentives. Real incentive rates are calculated by dividing total incentive amount by total watts installed over each utility and quarter. These rates accurately reflect the incentives faced by consumers, and may vary from the reported incentive rates.

Solar potential, a measure of the total annual gigawatt-hours absorbed in a given area, was extracted from GIS shapefiles created by the National Renewable Energy Laboratory (NREL)[45]. Legislative representation for each city was compiled from shapefiles maintained by the Statewide Database project at UC Berkeley [46]. Neither solar potential nor legislative representation varies over the time period studied.

Cities implementing PACE programs display a range of incomes, education, and power prices. Palm Desert is characterized as more Caucasian and of average income. Residents are older, are more likely to be veterans, and household sizes tend to be smaller, consistent with the city’s reputation as a suitable retirement location. Residents are more educated than the state average. Residents have access to average-priced electricity, have very high solar potential, and are represented in the State Assembly by a Republican.

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<sup>6</sup> ACS 3-year datasets consist of a weighted average from a rotating subsample consisting of 1/3 of the sample population. Data is conceptually a “rolling average” over these three groups. For this analysis, this data condition is not obtrusive as socio-economic covariates are best used to illustrate trends in population. The likely lag in RPV installations resulting from a change in socio-economic conditions is sufficient to justify using “rolling average” data.

Yucaipa is comprised of a lower percentage of minorities than the state average, but residents have slightly lower income and are approximately as old as the state average, and are considerably younger than Palm Desert residents. Veteran service is higher than the state average, but lower than Palm Desert. Education is below the state average. Yucaipa is served by the same IOU as Palm Desert and thus has the same RPV incentive schedule and power pricing. The city enjoys higher-than-average solar potential, but lower than Palm Desert. Yucaipa, like Palm Desert, is represented in the State Assembly by a Republican.

Sonoma County consists of 9 cities – Cloverdale, Cotati, Healdsburg, Petaluma, Rohnert Park, Santa Rosa, Sebastopol, Sonoma, and Windsor. County-wide means are shown in Table IV.1. For cities with a population of less than 20,000, no data is available for fields marked with “\*”. These cities are omitted from the means shown here.

Sonoma County has a lower percentage of minorities, is much wealthier than the state average and both Palm Desert and Yucaipa, and is of average age, slightly younger than Yucaipa. Within the county, the percentage of owner-occupied households with income over \$100,000 per year ranges from 25.59% to 44.83%. Residents are more likely to be veterans than the state average, but less likely than both Palm Desert and Yucaipa. The county-wide average for undergraduate education is considerably higher than the state and higher than both Palm Desert and Yucaipa. Graduate degree education, however, is lower than the state average. The average RPV incentive rate is lower than that enjoyed by Palm Desert and Yucaipa. This is a result of an accelerated schedule for incentives – for each IOU, a certain amount of incentive is scheduled for each level. Once an IOU’s customers exhaust the top incentive rate, the incentive rate steps down and remains at that level until the next allotment is exhausted. A lower average incentive rate, therefore, indicates that the IOU’s customers used their allotted incentives at a faster rate. Sonoma County residents have average power prices and, due to their coastal range location, have lower-than-average solar potential. All cities in Sonoma County are represented in the State Assembly by Democrats.

TABLE IV.1: DESCRIPTIVE STATISTICS

Variable Name	Variable Meaning	Units	Statewide Mean	SD	Min	Max	Palm Desert Mean	Yucaipa Mean	Sonoma County Mean
<b>CSI Database</b>									
W/OOH	Watts installed per owner-occupied household	Watts of RPV installed	2.080	2.894	0.000	27.024	5.902	3.837	4.677
Q/OOH	Quantity of RPV installation per owner-occupied household	Quantity of installations	0.00044	0.00055	0.000	0.005	0.00095	0.00080	0.00103
<b>US Census / ACS</b>									
PCTCAUC	Percentage of residential population of Caucasian descent	%	63.557	17.575	19.400	95.200	82.500	79.500	75.350
PCTWEALTHOOH *	Percent of owner-occupied households earning >\$100,000 per year	%	26.502	21.688	0.000	74.246	26.995	24.868	37.261
MEDIANAGE	Median resident age	Years	37.196	7.178	23.500	77.000	53.000	37.800	36.750
PCTVET	Percentage of residential population with prior military service	%	5.395	4.589	0.000	25.804	11.419	9.698	8.632
HHS_OOH *	Average household size of owner-occupied households	Persons	1.996	1.380	0.000	4.177	1.547	2.165	2.644
PCTBS	Percentage of residents holding a bachelor's degree	%	20.946	20.248	0.000	80.700	24.956	16.456	27.911
PCTGRAD_FULL	Percentage of residents holding a graduate degree or higher	%	11.844	10.371	0.000	51.200	12.300	9.100	8.775
<b>Other Sources</b>									
REALINCENTIVERATE	Real CSI incentive rate	\$ per watt installed	1.482	0.702	0.250	2.500	1.786	1.786	1.569
PWRPRICE	Base tier power price	Cents per kilowatt-hour	0.158	0.007	0.148	0.184	0.155	0.155	0.157
CITYSOLARPOT	Annual average solar radiation	Gigawatt-hours per year	5.565	0.291	4.290	6.380	6.280	5.990	5.415
REP	Representation in State Assembly	0 if Democrat, 1 if Republican	0.405	0.491	0.000	1.000	1.000	1.000	0.000

\* indicates census variables specific to owner-occupied households

## V. METHODOLOGY AND ESTIMATION STRATEGY

Estimating the effect of a PACE program expressed in quantity and wattage of RPV installations over time allows this analysis to go beyond a simple measure of customers utilizing PACE financing. Instead, these measures of effectiveness capture effects of a PACE program among both users and non-users of PACE loans, and account for PACE users who would have installed RPV without PACE financing, isolating the true effect of each PACE program.

In this analysis, I will first test the effect of PACE within a difference-in-differences framework. Due to the limited number of treatment cities in this quasi-natural experiment, I will also employ a synthetic counterfactual for two of the PACE programs studied, PDEIP and YEIP. The synthetic counterfactual constructs a “without PACE” time trend for each treatment city and allows for comparison of the “with” and “without” PACE scenarios. Both methods are described in more detail below.

### **Difference-in-differences**

I use a differences-in-differences model to control for unobserved city-specific variables that may confound the effect of a PACE program. For instance, it is possible that the City of Palm Desert may have some unseen propensity to adopt new renewable energy technologies. The area is the former home to many defense and aerospace manufacturing facilities, and it is possible that the residents of Palm Desert are therefore more open to trying new technologies. Unless this propensity to adopt varies over time (and is correlated with the introduction of a PACE program), a difference-in-differences model with city-level fixed effects would return unbiased treatment estimates by allowing for a constant difference in RPV installations per quarter; the effect of a PACE program is then measured above and beyond this fixed difference. Exogenous, statewide time-shocks resulting from non-linear drops in solar panel prices or unobserved changes in tax incentives for renewable energy are accounted for with quarter fixed effects. These fixed effects are common across all cities in California and could be the result of economic conditions, changes in prices of panels, or changes in federal or state tax incentives. In each quarter, the effect of a PACE program is measured after accounting for the common, state-wide quarter fixed effect.

With proper specification, the difference-in-differences model is able to control for exogenous statewide changes in RPV installation as well as unobserved city-level effects that are time consistent. However, these models cannot control for any exogenous jumps or dips in RPV installations that occur only in a treatment city, and only at a specific quarter or quarters. If such an

exogenous shock were to occur at the same time as the start of a PACE program, the difference-in-differences model would mistakenly attribute it to the PACE policy. Because each observed program began in a different quarter ranging from July 2008 to August 2009, it is unlikely that an exogenous, city-level, time-variant shock could occur at the initial program start time for every program in a manner sufficient to bias estimates. A media search of relevant newsletters and papers was performed to ensure no confounding events occurred. When available, quarterly variation in important covariates is exploited.

The difference-in-differences model is primarily specified in three forms. First, a two-way fixed effects model:

$$(1) \text{ WPOHH}_{it} = \alpha_0 + \alpha X_{it} + \beta D_{it} + \gamma_t + \theta_i + \varepsilon_{it}$$

Where  $\text{WPOHH}_{it}$  is the installed watts per owner-occupied household in time  $t$  and city  $i$ .  $X_{it}$  is a vector of time-variant socio-economic variables consisting of owner-occupied household income, bachelor's degree attainment, veteran status, owner-occupied household size, CSI incentive rate, and base tier power price.  $D_{it}$  is the binary variable for the presence of a PACE program at time  $t$  and in city  $i$ , and  $\beta$  is the treatment effect to be estimated.  $\gamma_t$  are quarter fixed effects,  $\theta_i$  are the city-level fixed effects, and  $\varepsilon_{it}$  are errors assumed to be independent but heteroskedastic.

For two of the covariates, percentage of owner-occupied households that earned greater than \$100,000 per year and median age, the model also includes the square of the variable to allow for non-linear relationships between these variables and W/OOH.

The second model estimated assumes that unobservable covariates may drive separate time trends of RPV installation in each city. A flexible functional form is specified which allows for a linear continuous city-level time trend as well as a common linear time trend and quarter fixed effects to control for exogenous, state-wide time-shocks.

$$(2) \text{ WPOHH}_{it} = \alpha_0 + \alpha X_{it} + \tau_i * QTRYEAR_t + \delta * QTRYEAR_t + \beta D_{it} + \gamma_t + \theta_i + \varepsilon_{it}$$

Where  $X_{it}$ ,  $\gamma_t$ ,  $\theta_i$ , and  $D_{it}$  and remain identical to (1), but an individual city-level time trend,  $\tau_i$ , is also allowed.

The final difference-in-differences model is a semi-reduced form which allows for use of the full set of census-recognized cities in California. Because data for cities less than 20,000 in population is only available in the decennial (2000, 2010) census, a difference-in-differences model cannot exploit time variation of covariates. Therefore, I rely on a two-way fixed effect model with city-

specific time trends, a common time trend, quarter fixed effects, and include all cities. This model equation is specified as:

$$(3) \text{ WPOHH}_{it} = \alpha_0 + \alpha X_{it} + \tau_i * \text{QTRYEAR}_t + \delta * \text{QTRYEAR}_t + \beta D_{it} + \gamma_t + \theta_i + \varepsilon_{it}$$

All variables are designated identical to previous specification.  $X_{it}$  consists only of base tier power pricing and real incentive rate.  $\theta_i$ , city-level fixed effects, absorb previously explicitly modeled socio-economic characteristics such as education, age, and income.

All models may be estimated using Q/OOH (quantity per owner-occupied household) in place of W/OOH. The parameter of interest,  $\beta$ , is interpreted as the average per-quarter mean effect of a PACE program. Examining the W/OOH paths of PACE municipalities (Figure II-1 through Figure II-3) shows a significant spike in RPV installations surrounding the implementation of the program followed by a decline. In the case of PDEIP, the decline may have been motivated by a lack of funding prior to the February 2010 tranche of funding, however, it is clear that a PACE program may have a significant initial effect followed by a decline or reduction. A lack of widespread treatment for this quasi-natural experiment renders analysis of a PACE effect over time statistically impossible. Therefore,  $\beta$  cannot be interpreted as the additional per-quarter contribution of a PACE program. The extent to which  $\beta$  may be considered relevant is, at most, the average length of a PACE program analyzed here, or 3.8 quarters. It must be noted that this average length of program reflects truncation by the FHFA letter of 2010 and not a decline in effectiveness.

### **Synthetic Counterfactual**

The above methodological issue surrounding the limited number of treatment groups available for study extends to the size of errors on the treatment coefficient. A larger number of treatment groups may result in more efficient estimators; however, following the FHFA letter of 2010, no consistent treatment is available. With a limited number of treatments available for observation, a greater emphasis must be placed on the effect of PACE in each individual treatment city. Under a difference in differences model, a PACE program's effect is estimated as the difference between the observed W/OOH in a given treated quarter and the expected W/OOH, conditional on observed characteristics, unobserved fixed effects, and no treatment. Alternatively, a suitable counterfactual may be drawn from actual, instead of conditional, outcomes. In these cases where a city's counterfactual may be developed, city-level analysis may provide further insights into the effectiveness of a PACE program. With this in mind, I now turn to a semi-parametric method of establishing a synthetic counterfactual.



The synthetic counterfactual process (herein “Synthetic method”) bears resemblance to a matching method where important covariates are used to find non-treatment cities of similar composition to treatment cities. However, instead of matching only on observable covariates, the Synthetic method matches based on observable covariates *and observed outcomes over the pre-treatment period*. The result is a counterfactual which, over both the pre-treatment period and the treatment period, behaves as the treatment city would have in absence of the treatment. By minimizing the difference between the counterfactual and the actual city in the pre-treatment period, a reliable counterfactual is developed.

To create the synthetic counterfactual, city-level weights are established through a nested optimization function where, on the first level, a vector,  $W$ , consisting of weights for each city in the “control pool” (non-PACE cities) is estimated with the intent of minimizing the difference between a  $[(r + M) \times 1]$  vector containing the treatment city’s  $r$  covariates (averaged over time) and  $M$  pre-treatment values of the treatment city’s dependent variable ( $W/OOH$ ) where each value is a different weighting of the average of the treatment city’s pre-treatment outcome variable, and a  $[(r + M) \times J]$  matrix of similar vectors for each potential control city. To evaluate the resulting difference vector in a single dimension, a second level of weighting is introduced. This matrix,  $V$ , is a  $[(r + M) \times (r + M)]$  positive, definite and diagonal matrix which is chosen to minimize the difference between treatment city’s outcome variable and the weighted pool (or “synthetic”) outcome during the pretreatment period. The weights in  $V$  correspond to the “importance” of each covariate in explaining the relationship between observed covariates and the outcome.

The advantage of the Synthetic method over a difference-in-differences model is that it allows the difference between the counterfactual and the treatment to vary non-linearly over time based on the outcomes of the weighted control pool. In estimating  $V$  and  $W$  over both observable covariates *and* outcomes, the Synthetic method establishes a counterfactual which minimizes the *unobserved* errors for the pre- and during-treatment periods. Although this method is unable to account for unobserved city- and time-specific exogenous shocks, no alternative model exists that does. Furthermore, the usefulness of the Synthetic method lies in its ability to account for a non-linear, unobserved time trend, even if the trend would impact only a certain type of city, provided the identifying characteristics are included as covariates, or that the unobserved relationship existed during the pre-treatment period and thus contributed to selection of  $W$ , city weights. Because the Synthetic method best accounts for unobserved shocks and it is effective with one treatment city, it is selected as the second method of analysis. Further details and mathematical proofs on the

Synthetic method are available in Abadie, Diamond [47], Abadie and Gardeazabal [48], and Abadie, Diamond [49].

Estimation of errors in the Synthetic method relies on a pseudo-bootstrapping method. Errors in a regression-based case study comparison reflect only errors in data aggregation, while comparative case studies suffer from uncertainty around “the ability of the control group to reproduce the counterfactual of how the treated unit would have evolved in the absence of the treatment”. Therefore, “large sample inferential techniques are not well-suited to comparative case studies when the number of units in the comparison group and the number of periods in the sample are relatively small” [47]. While Abadie and Diamond recommend permutation testing by artificially reassigning treatment to a non-treated control city, a 95% confidence interval that reflects the limitations of the control pool in reproducing an accurate synthetic may be estimated by repeatedly limiting the existing pool of 411 cities to a random subset and developing the optimum synthetic counterfactual. Both techniques are employed here. In pseudo-bootstrapping, the initial subset of 411 cities is further limited to those cities that are relatively similar in important covariates (education and income), and a smaller subset is drawn for each iteration. 1,100 iterations were performed for each studied program and each iteration was performed with a random draw of 60 control cities from a sample universe of approximately 200 similar cities. This method results in errors that reflect the lack of infinite control cities.

The Synthetic method may be applied to each single-city PACE program (PDEIP and YEIP). The county-wide SCEIP would require aggregation of all six Sonoma County cities into one artificial city not observed in the real world. Therefore, I omit SCEIP from analysis using the Synthetic method, but retain the county in the difference-in-differences model.

## **VI. RESULTS**

A simple difference-in-differences estimator was constructed over the 4 quarters preceding the implementation of PDEIP compared to the 4 quarters following implementation of PDEIP. Results, shown in Table VI.1, suggest a difference; however, the variance of the simple estimators is large. Controlling for time trends, city fixed effects, and socio-economic covariates is necessary.

TABLE VI.1 : SIMPLE DIFFERENCE-IN-DIFFERENCES – PALM DESERT

	Before	After	Difference
<b>Palm Desert</b>			
Palm Desert mean	2.553	8.567	6.014
Palm Desert variance	1.655	17.306	18.961
<b>Rest of State</b>			
Rest of State mean	3.061	3.058	-0.003
Rest of state variance	53.261	40.641	93.901
<b>Difference</b>			
mean	-0.508	5.509	<b>6.017</b>
variance	54.916	57.946	112.862

### Difference-in-differences

Estimates from difference-in-differences models are reported in Table VI.2.

TABLE VI.2: DIFFERENCE-IN-DIFFERENCES RESULTS

	W/OOH			Q/OOH		
	(1a)	(2a)	(3a)	(1b)	(2b)	(3b)
	Two-way FE	QTRYEAR FE, city-level time trend	Two-way FE, city-level time trend, all cities	Two-way FE	QTRYEAR FE, city-level time trend	Two-way FE, city- level time trend, all cities
<b>PACE</b>	<b>3.829**</b> (0.000)	<b>1.804</b> (0.193)	<b>3.595*</b> (0.016)	<b>0.740**</b> (0.000)	<b>0.233</b> (0.403)	<b>0.519</b> (0.077)
PCTWEALTHOOH	0.096 (0.176)	0.118 (0.173)		0.023 (0.084)	0.031 (0.093)	
PCTWEALTHOOH2	-0.002 (0.052)	-0.001 (0.237)		-0.000* (0.020)	-0.000 (0.116)	
PCTVET	-0.067 (0.487)	-0.062 (0.620)		-0.025 (0.148)	-0.018 (0.430)	
HHS_OOH	0.752 (0.325)	2.217* (0.028)		0.059 (0.675)	0.403* (0.027)	
PCTBS	0.105** (0.010)	0.085 (0.242)		0.022** (0.005)	0.016 (0.229)	
REALINCENTIVERATE	0.649 (0.065)	4.709** (0.000)	7.448** (0.000)	0.277** (0.000)	0.883** (0.000)	1.263** (0.000)
PWRPRICE	70.410* (0.024)	23.378 (0.254)	-16.149 (0.670)	14.943** (0.001)	4.662 (0.108)	0.227 (0.973)
Constant	-15.919** (0.009)	-141.025** (0.000)	-214.081** (0.000)	-3.288** (0.000)	-26.512** (0.000)	-36.847** (0.000)
<b>Model Statistics</b>						
Observations	3,409	3,409	5,356	3,409	3,409	5,356
R-squared	0.185	0.384	0.195	0.219	0.398	0.207
Number of Cities	263	263	412	263	263	412

Robust p-value in parentheses; \*\* p<0.01, \* p<0.05

Q/OOH reported in QTY per 1,000 OOH

The overall results are consistent with expectations. Measures of wealth, when significant, are positive in the linear term and negative in the squared term indicating a “peak” effect of income on RPV installation. Percentage of residents with military service was not significant in any specification, but was consistently negative. Household size for owner-occupied households was positive, as expected, and significant in (2). The positive household size coefficient (HHS\_OOH) reflects the tiered electricity pricing system and higher usage for larger households – residential customers face increasing power prices as usage increases, and as a result, power generated from an RPV system offsets more expensive (top-tier) power and therefore has a higher rate of return. Similarly, base tier power price had a positive effect, significant in model (1), and incentive rate had a positive effect, significant only in models (2) and (3). As expected, Bachelor’s degree attainment was positive and significant, but only in model (1).

Coefficients are robust to specification and inclusion of cities smaller than 20,000 in population. In fact, over all specifications, only the sign on base tier power price switches in model (3a), though it is highly non-significant when switching.

To compare models for W/OOH to models for Q/OOH, I simply multiply by the average installation size, approximately 7 kW. Multiplying the Q/OOH treatment variable by 7 yields an estimate of W/OOH. The effect of treatment is consistently positive across all specifications, ranging from 1.631 W/OOH (.233 Q/OOH \* 7kW) to the equivalent of 5.18 W/OOH per quarter of treatment (.740 Q/OOH \* 7kW), and is significant in almost every specification with the exception of model (2). Model (2) is the most flexible specification and allows for a common time trend, a city-level time trend, a common set of exogenous time-shocks, and a city-level fixed effect. Furthermore, model (2) is based only on cities greater than 20,000 in population, while model (3) is an identical specification but includes all cities. The additional data provides a more reliable estimate in (3).

### ***PACE Effect on Amount Spent per Installation***

The previous assumption of PACE as a non-subsidy requires further empirical evidence. While PACE interest rates were higher than both 30-year fixed rate mortgages and the average home equity line of credit available during the same time period, these forms of financing are not necessarily available to every homeowner.

To empirically test for a subsidy effect from the studied PACE programs, I substitute the average amount spent per installation as the dependent variable. If PACE acts as a pure-price subsidy by lowering the cost of capital, it would be expected that the existence of a PACE program would

increase the amount spent per installation. The results from models (1) through (3) are shown in Table VI.3. Only coefficients for average cost per installation are shown; all model specifications correspond to models (1) – (3).

TABLE VI.3:TREATMENT EFFECT ON AMOUNT SPENT PER INSTALLATION

	Cost per Installation		
	(1)	(2)	(3)
	Two-way FE	QTRYEAR FE, city-level time trend	Two-way FE, city-level time trend, all cities
PACE	\$1,263.731 (0.609)	\$4,053.867 (0.142)	\$3,868.709 (0.271)
<b>Model Statistics</b>			
Observations	2,778	2,778	3,938
R-squared	0.041	0.151	0.177
Number of Cities	260	260	404

Robust p-value in parentheses; \*\* p<0.01, \* p<0.05

Though the sign in each model is positive, none are significant. PACE does not have a significant impact on the cost invested per RPV and does not behave as a pure-price subsidy.

### **Methodological Issues**

Both the difference-in-differences method requires that the outcome (W/OOH) for each city be independent of other cities. This condition does not strictly hold – neighboring cities may share solar installation contractors and thus pricing (and installations) may be correlated. For the estimate of interest,  $\beta$ , this condition holds provided the treatment is isolated only to the treated city. Palm Desert shares a newspaper of record with the nearby communities of Palm Springs and Indian Wells (with which Palm Desert shares a city boundary), and publicity surrounding the “first-in-the-state” PACE program could potentially drive interest in RPV in nearby cities. Furthermore, it is possible that residents of Palm Desert located near the city boundary may use an Indian Wells mailing address, further confounding the distinction in treatment. To avoid capturing a spillover effect, both Indian Wells and Palm Springs are removed from analysis.

Aggregating to quarterly dependent variables introduces the issue of timing in two respects. First, treatment may stop or start in the middle of a quarter, potentially biasing estimates of treatment effect. Because the difference-in-differences model estimates the average effect of a PACE program,

the bias inherent in a mid-quarter start or a mid-quarter stop is minimized. Furthermore, treatment was designated in the most conservative manner possible. Though Palm Desert began their program in August (middle of 3<sup>rd</sup> Quarter) 2008, treatment was designated to start at the beginning of the 3<sup>rd</sup> quarter, or July of 2008. Therefore, the estimated effect of a PDEIP includes the month of July, where a PACE program did not exist. SCEIP officially began in March of 2009 (end of 1<sup>st</sup> Quarter), but treatment is assigned to all of 1<sup>st</sup> Quarter. Therefore, estimates for SCEIP are downwardly biased as they include two months where a PACE program did not exist. YEIP initiated their program in August of 2009, but did not officially begin lending until December of 2010 after a “false start”. As a conservative estimate, treatment is designated for YEIP starting in 3<sup>rd</sup> Quarter of 2009.

Second, the conceptual question of “installation” arises. The CSI requires that homeowners reserve their credit with an initial call, and then submit verification paperwork following the physical installation. For this analysis, I use the first *reservation* date as the “installation” date as it best represents the date of decision of the homeowner. For the period 2007-2010, I exclude any reservation which was not completed by January 2012. It is possible that a homeowner, anticipating the beginning of a PACE program, may reserve a credit prior to the actual treatment period. In the case of SCEIP and YEIP, a significant lead-up time was used to allow publicity from the city and from installation contractors. In the case of PDEIP, the state legislature only authorized cities to create PACE programs in July 2008; however, the city council appears to have had some prior knowledge of the coming passage as the implementation process was uniquely accelerated immediately following state authorization. If a PACE program was initiated mid-quarter, but customers anticipated the program and placed CSI reservations prior to the program start date but within the same quarter, the difference in differences model would capture that installation within the treatment period. If the customer anticipated the PACE program and placed CSI reservations in a previous quarter, as may be the case for PDEIP, the difference-in-differences model would attribute that reservation to the pre-treatment period, biasing the treatment effect estimate downward. The “fuzzy” nature of both installation date and treatment start times must be kept in mind when analyzing the treatment effect.

Placer County’s mPower program is the only remaining PACE program in California not examined in this analysis. A paucity of information on the implementation of this program necessitates that it be omitted from this study. It is unlikely that any bias may occur in either method as a result.

Following the FHFA letter of July 2010, existing PACE programs were halted for a variety of lengths of time. Though PDEIP resumed shortly after, new conditions were placed upon PACE loans, as discussed in Section II. Because treatment following July 2010 was not consistent with treatment prior to this period, and because each program instituted different requirements at different times, analysis is limited to 3<sup>rd</sup> Quarter of 2010 and earlier. The PDEIP funding shortfall of February, 2010 is not distinguished in treatment. Inclusion of this temporary gap in PACE funding would likely increase the measured effect of treatment.

### **Synthetic method**

Results of the Synthetic method for PDEIP and YEIP are consistent with most specifications of the difference-in-differences models. Because the Synthetic method returns a counterfactual, this analysis allows observation of the effect of a PACE program over time. If PACE addresses the energy-efficiency gap, as discussed in Section III, we should see an initial spike as residents with near-threshold hurdle rates driven by market barriers adopt PACE loans to remove the barriers of transferability and high information (lending) costs. This spike should not be sustained in the middle-term, but over time, social network learning that reduces uncertainty over payback and costs should lead to a steady increase in RPV installation in comparison to a non-PACE city.



FIGURE VI-1: PALM DESERT ACTUAL VS. SYNTHETIC

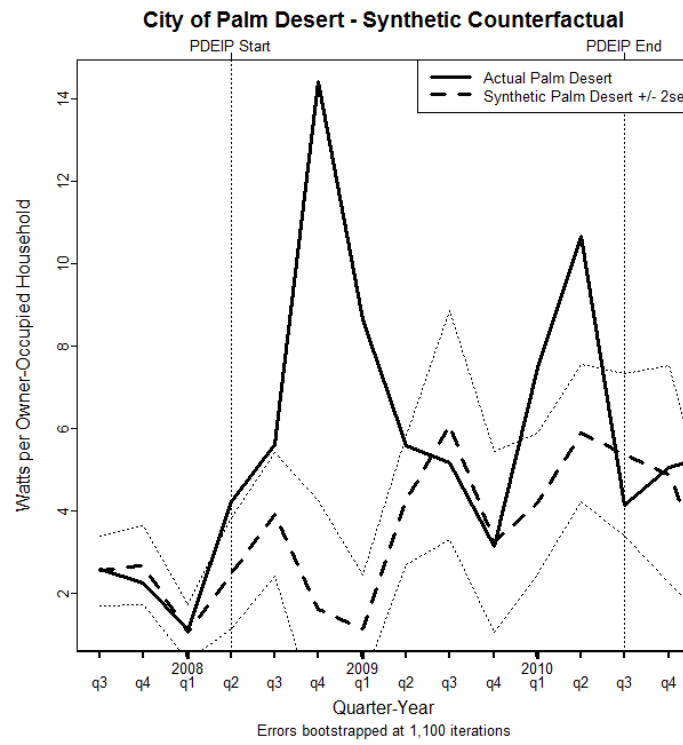
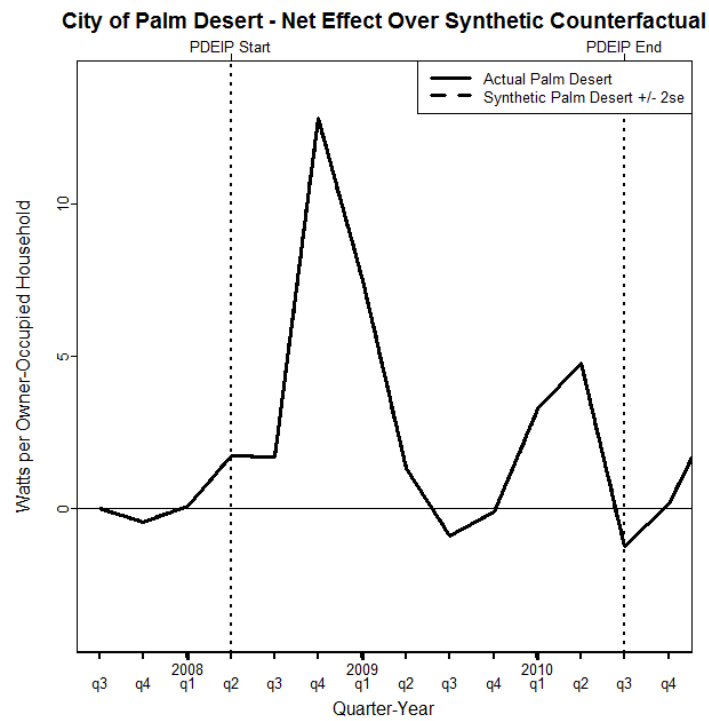


FIGURE VI-2: PALM DESERT ACTUAL-SYNTHETIC



### ***Palm Desert EIP***

After implementation, Palm Desert saw a significant spike in W/OOH, followed by a steady decline up to the end of 2009. The first quarter of 2010 sees another, slightly smaller spike, ending in 3<sup>rd</sup> Quarter of 2010.

This pattern tracks closely to the availability of PACE funding – a spike occurs following introduction of the EIP program, the spike fades by the end of 2009, and then jumps again following the second tranche of funding issued in February of 2010. The quarter containing the FHFA letter of July 2010 marks a significant drop in RPV installation.

Relative to the synthetic Palm Desert, the pattern indicates a significant effect of the treatment. With the introduction of the EIP program, the actual Palm Desert increases over the synthetic, reaching a peak gap of 12.804 at the end of 2008 (see Figure VI-2). As the financing choke-point at the end of 2009 is approached, the actual Palm Desert approaches the behavior of synthetic Palm Desert. Following the additional tranche of funding, the gap increases but then returns to near-parity in the quarter containing the FHFA letter. Following the hiatus of the PDEIP program, the synthetic and the actual Palm Desert display a great deal of noise expected under the inconsistent nature of the EIP program after July of 2010.

Notably, the financing choke-point at the end of 2009 as well as the post-FHFA period do not show actual Palm Desert RPV installations dropping below the synthetic Palm Desert. This indicates that the effect of a PACE program does not simply “borrow” homeowners who would, in the future, install RPV, but rather, it encourages *additional* installations.

2<sup>nd</sup> Quarter of 2008 is an untreated time period as PDEIP was authorized by state law in early July 2008, and was enacted in August 2008. As was discussed in Section II, a delay is common between the reservation of a CSI incentive and the actual installation. Residents anticipating the availability of a PACE loan may reserve their incentive early with actual installation occurring later, once a loan is completed and disbursed. In fact, residents would have a positive, risk-free incentive to call prior to a loan approval – the highest possible incentive is ensured when calling early, and no penalty is incurred for failing to complete a reserved incentive. This effect may explain the level of RPV shown in 2<sup>nd</sup> Quarter of 2008. Here, the actual Palm Desert exceeds the synthetic Palm Desert by 1.74 (reserved) W/OOH, despite occurring prior to the existence of the PDEIP. In fact, these reservations occurred prior to AB811, the state-wide authorization for PACE programs. It must be

considered that an unobserved, exogenous change that occurred near the time of the start of the PDEIP could confound the effect of the program.

It is, however, possible that these reservations were indeed done in anticipation of a PACE program. A large amount of publicity surrounded the passage of AB811 [50], increasing the likelihood of public anticipation of the EIP program. The speed at which the City Council of Palm Desert implemented a PACE program indicates prior knowledge of the program. The reservations responsible for this pre-PDEIP spike are shown in Table VI.4. The average statewide delay between reservation and installation was 120 days. For 2<sup>nd</sup> Quarter of 2008, the delay was considerably longer. For the four reservations placed closest to the PDEIP start date (May and June of 2008), only one was less than 6 months. If prior knowledge of a PACE program existed, a spike in reservations with long delays would be expected; indeed, this spike occurs here. No conclusive explanation may be made without individual private contact information not publicly available.

TABLE VI.4: INSTALLATION RESERVATIONS IN 2ND QUARTER 2008, PALM DESERT

Reservation Date	Incentive Claim Review (installed)	Delay (days)
4/2/2008	6/3/2008	62
4/21/2008	10/21/2008	183
4/22/2008	7/29/2008	98
4/23/2008	7/30/2008	98
5/7/2008	1/27/2009	265
5/8/2008	10/7/2008	152
5/27/2008	6/30/2009	399
6/19/2008	1/13/2009	208
<b>State-wide mean delay:</b>		120

FIGURE VI-3: YUCAIPA ACTUAL VS. SYNTHETIC

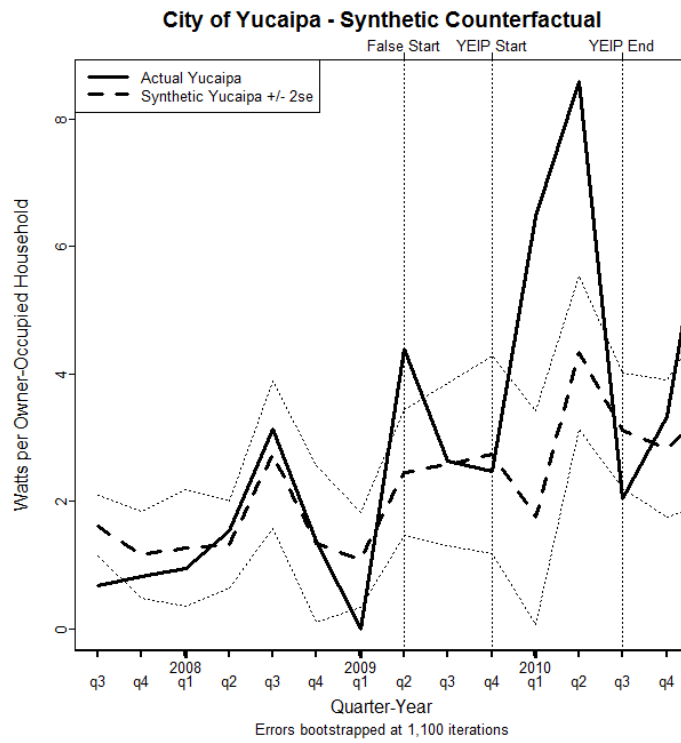
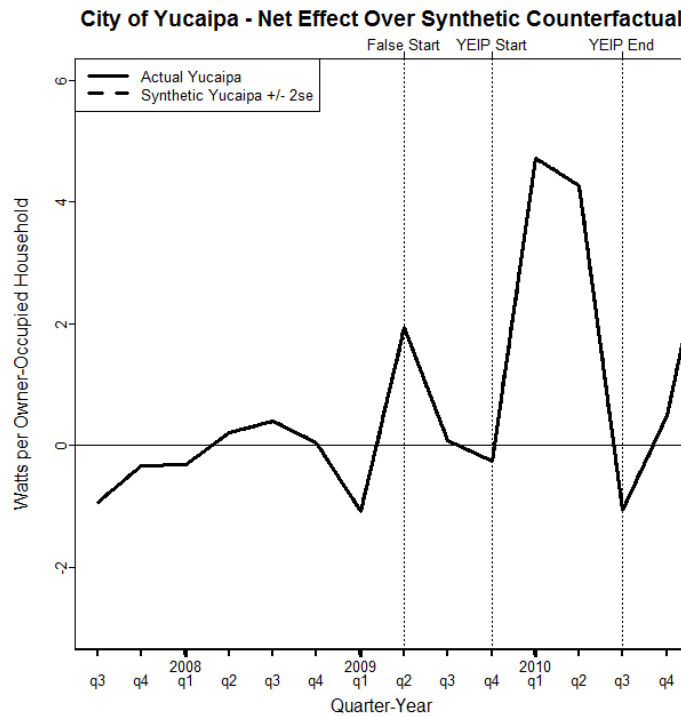


FIGURE VI-4: YUCAIPA ACTUAL-SYNTHETIC



### ***Yucaipa EIP***

Prior to the scheduled implementation of YEIP, the data shows a dip followed by a jump, possibly as homeowners anticipated the availability of PACE loans and reserved incentives. The first quarter with PACE loans available was the fourth quarter of 2009, though the synthetic analysis reveals that both 3<sup>rd</sup> and 4<sup>th</sup> Quarter W/OOH was not different from the synthetic counterfactual. RPV in 2010 shows a marked increase over the counterfactual. In this case, the “fuzzy” nature of implementation confounds determination of the full effect of the program. A clear deviation from the synthetic is present in the first 2 quarters of 2010. Absent any alternative exogenous and unobserved time- and location-specific shock, the deviation corresponds to existence of the YEIP.

### ***Methodological Issues***

A drawback to this method, however, is that it may not account entirely for endogenous self-selection into treatment – if there exists an unobserved variable correlated with likelihood of enacting a PACE program and that variable is not specified in matching, results will be biased. The advantage of the synthetic control group method is that it fully accounts for exogenous, state-wide trends and shocks as all matched cities are subject to similar conditions as well as observable endogenous selection. To the extent that exogenous, state-wide trends and shocks occur only to cities similar to the treatment city, this method captures localized effects.

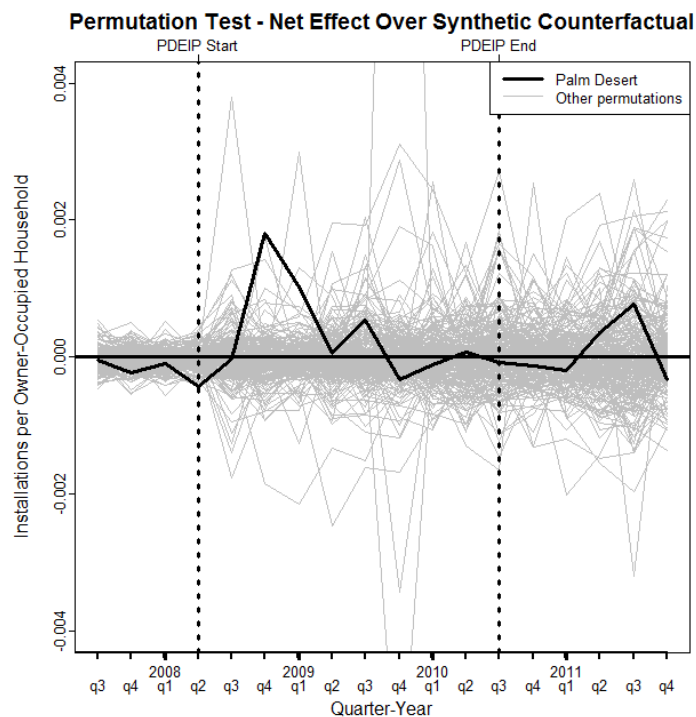
As discussed in the difference-in-differences section, the issue of timing affects the presentation of the analysis. It is assumed that some ramp-up in reservations occurred prior to the start of the EIP programs in both Palm Desert and Yucaipa. “Start” times shown all Synthetic plots indicate the final quarter which was unaffected by the PACE program. For Palm Desert, 2<sup>nd</sup> Quarter of 2008 likely included some reservations anticipating the start of a PACE program as detailed in the previous section. Start time for YEIP is indicated in the same manner. Due to YEIP’s “false start”, the actual “start” quarter shown is the final quarter in which the program had not yet begun funding loans. Due to the noisy nature of YEIP’s actual treatment start time, exact interpretation of start and stop times is not possible.

### ***Synthetic Counterfactual Model Verification***

As suggested by Abadie, Diamond, and Hainmueller in [49], a permutation test is used to visualize the strength of the Synthetic method. In a permutation test, individual synthetic counterfactuals are built for each of the untreated control pool cities. In this case, synthetic counterfactuals are matched through the same start date as the PDEIP synthetic counterfactual: 3<sup>rd</sup> Quarter of 2008. The assumption used in creating the treated city counterfactuals should hold here, namely, by

matching during the pre-treated period, an accurate counterfactual is built that represents the city’s RPV installation rate over the treatment period. However, in the case of the permutation tests, we actually observe the “without-treatment” outcomes during this period. Synthetic counterfactuals in the permutation tests should behave identical to the observed. Figure VI-5 shows the difference between synthetic and actual for all cities in California (in grey), as well as the PDEIP difference identical to that shown in Figure VI-2 (in black). Cities with a mean squared prediction error (MSPE) of greater than five times that of Palm Desert were omitted from this plot as they represent poorly-synthesized counterfactuals. The result clearly shows that the difference in PDEIP is greater than most, but not all, other observed differences, indicating that the Synthetic method is capable of creating accurate counterfactuals, and that the results of PDEIP are not within the expected range of untreated observations.

FIGURE VI-5: PERMUTATION TEST RESULTS - PALM DESERT



### Comparison to Difference-in-Differences Models

Alternative methods of analysis create a natural means of model verification. If results from the Synthetic method are within the reasonably predicted range of the difference-in-differences model then confidence in the results is warranted.

TABLE VI.5: 95% CONFIDENCE INTERVALS - DIFFERENCE-IN-DIFFERENCES MODELS

	(1)	(2)	(3)
Coefficient	3.829	3.591	3.595
Lower 95% Bound	2.259	-0.804	0.785
Upper 95% Bound	5.398	4.412	6.404
	Net W/OOH	Per-quarter W/OOH	Within CI?
PDEIP	29.106	3.638	3 of 3
YEIP	7.711	1.928	2 of 3

Synthetic estimates are similar to those measured by the difference-in-differences models with the exception of YEIP and model (1). Cross-validation of the results of each method lends credibility to the measures of effectiveness of PACE, but additional question about the range of effects of PACE remain. Unfortunately, further controlling for variation in treatment effectiveness would require a larger number of treatment cities. Even with the limited number of treatment cities, the data includes a wide cross-section of types of cities in California enacting PACE programs, ranging from the young and low-income Yucaipa to the older Palm Desert and the highly-wealthy Sonoma County cities. It is clear that the effect of PACE over the range of treatment cities is fairly robust to the observed socio-economic covariates included in this analysis.

### Results in Context

To place the results in a statewide policy context, results must be translated into RPV installations per average-sized city, or to a statewide rate. Using the results from model (3), which included a full range of city sizes, and assuming 11.5 million households and an average of 59.9% homeownership,<sup>7</sup> an estimate of 21,628 to 176,455 kW of installed capacity per year is generated. In quantity of installations at an average of 7 kW per installation, this estimate translates to 3,089 to 25,207 installations statewide per year. As previously discussed, the length of the effectiveness of a PACE program is unknown due to the short existence time; therefore, impacts cannot be estimated beyond the first year.

Statewide, California has set a goal of 1,000,000 solar roofs, and PACE is only capable of contributing to a small fraction of this goal, but would do so without interrupting or altering

<sup>7</sup> Within the dataset, the average rate of homeownership is 59.9%. The dataset contains only cities and does not include unincorporated areas or census-designated places. The total number of households given, however, is over all of California, incorporated and unincorporated, and thus represents a reasonable approximation of households affected by a statewide PACE program.

existing incentives or promotional programs. Any program which generates an *additional* 3,089 to 25,207 RPV installations clearly makes a significant impact from an environmental perspective. However, as a percentage of California's overall solar goals, even a statewide PACE program performing at the top end of estimates would contribute only 2.5% of the overall goal in the first year.

The most attractive aspect of a PACE program is its effectiveness relative to its investment cost. At an interest rate of 7%, the cost of capital to the lending city is low as municipal bond rates tend to be in the 8% range. In the case of PDEIP, a negative point spread of 1% would have resulted in a cost to the city of \$525,000 over the life of the pool. However, the city never accessed the municipal bond market and instead used existing surplus general fund reserves. The alternative investment portfolio for surplus reserves returned at 3.75% during the study period; investments in PACE loans resulted in a net positive spread for Palm Desert[8]. Though results vary by city, an interest rate of 7% is generally close to the actual cost of capital for municipal lending.

The effect of PACE may also be compared to the effect of the incentive rate (\$/Watt installed). Dividing the coefficient on PACE by the coefficient on REALINCENTIVERATE (the marginal effect of a \$1 increase in the \$/Watt incentive rate) yields an equivalent effectiveness (the effect of PACE expressed as an increase in incentive rate) of \$.48/Watt (model (3)).

Furthermore, the estimated PACE effect is not infra-marginal. While the subsidy level equivalent was approximately \$.48 under Model (3), the equivalent subsidy would have been given to all installing homeowners, not just the additional installing homeowners. Therefore, PACE achieves subsidy-like responses without infra-marginal losses inherent in most subsidy systems.

## **VII. IMPLICATIONS OF PACE ON THE ENERGY-EFFICIENCY GAP**

Results of both methods for measuring the effect of PACE programs indicate a positive and significant effect while comparisons to next-best sources of funding indicate that PACE loans are not likely to be viewed as subsidies, an assertion reflected in the BerkeleyFIRST survey of participants. In the absence of pure price subsidies, the observed effect of PACE programs must be attributed to other aspects of the program. Although disentangling consumer behavior around household-level investments is difficult, the previously-identified aspects of the energy-efficiency gap are likely explanations for the effectiveness of PACE programs: high up-front costs leading to inflations of uncertainty and cognitive failures; diversification bias leading to higher hurdle rates



for investment resulting from an inability to transfer the investment to a new purchaser; and information costs on effectiveness of RPV installations as well and information asymmetries between borrower and financing institutions. The direct effect of PACE financing on an individual consumer's energy-efficiency gap may be an unobservable combination of these aspects, or may be due to other exogenous factors. Methods of estimating changes in aggregated city-level RPV installations generally rule out other potential explanations – changes in incentives or RPV prices fail to explain the increases in RPV installations observed during PACE programs. Although some of the effect of a PACE program may be explained by the higher levels of advertising associated with PACE program roll-out, either by the municipality itself or by contractors touting the new form of financing, these are attributes of the treatment that do not occur independent of the program.

The findings in this analysis are consistent with much of the existing literature on the energy-efficiency gap but, unlike many theoretical propositions, an empirical link between aspects of the energy-efficiency gap and consumer choices is established, albeit weakly. The collection of study PACE programs observed here represent a rare opportunity to measure aspects of household energy decisions that are not directly price related. By altering the transferability and information asymmetries inherent in household energy choices without altering the household cost, this quasi-natural experiment confirms the existence of an energy-efficiency gap.

## **VIII. CONCLUSION**

Because household decisions on RPV mirror those of energy efficiency investments, the existence of substantial market barriers to household uptake of RPV likely extends to investments in energy efficiency as well. Energy efficiency investments are subject to the same transferability issues, the same information for financing asymmetries and search costs, and cognitive biases are inflated by the same high up-front costs. Although all PACE programs studied in this analysis also provided loans for energy efficiency investments, these outcomes are much harder to measure on an aggregated city level. By association, however, the positive RPV results strongly suggest positive energy efficiency results.

The question of appropriateness of public policy to address market barriers (as opposed to market failures) is a complicated one and cannot be answered definitively here. The tautology of the “correct” hurdle rate is not necessarily resolved simply because a PACE program is effective at addressing market barriers. However, given that participation in a PACE program is entirely voluntary, and that changes to the loan process, rather than changes in cost, drive increases in RPV

installations, there can be little justification for claims that a PACE program to address market barriers could be a negative effect on net social welfare.

A reasonable argument regarding search costs and information for financing costs may be made on a social welfare level – for example, if one considers the high cost of communicating the benefits of an RPV installation to a potential private finance entity to be a natural market cost, then a PACE program effectively subsidizes these costs with government efforts. The argument must continue, then, that subsidizing transaction costs may result in use of financing beyond an efficient level inclusive of transaction costs. This analysis rejects this notion in that the magnitude of RPV uptake following a PACE program suggests that the relatively small cost of communicating RPV effectiveness to a private financing entity is outweighed by the individual benefit from installing an RPV as indicated by a higher installation rate under PACE programs. The cost being subsidized is limited compared to the change in RPV installations.

Independent of the market barriers question, use of public policy to encourage efficiency and RPV installations may be justified by market failures; namely, the environmental externality resulting from electricity generation and the public goods component of information on performance and information for finance. However, use of PACE-type programs to address environmental externalities are “second-best responses...because they do not discriminate among the emissions intensities of different energy sources” [33]. In this respect, PACE’s effectiveness in addressing market failures resembles other technology policy oriented efforts in that it indirectly addresses the failure. Unlike most technology policy efforts, PACE loans are of limited cost to the implementing government and may be performed on a local level.

This analysis does not examine or measure the increase in risk to the national mortgage market. Currently, no known defaults have occurred on properties carrying PACE loans. Because early adopters are likely to be distinctly different from the type of PACE borrowers who would participate in a large-scale PACE roll-out, policymakers must address concerns over the creditworthiness of participants and the parity between PACE payments and electricity generation or savings. This analysis may guide the benefits side of the equation; however, quantification of overall social costs must be examined in the same level of detail before public policy recommendations may be made.

In this analysis, I have shown through two methodologies that existing PACE programs implemented in California prior to 2010 have generated additional installations of RPV above the rate expected. The subsidy level with equivalent results has been estimated at \$.48/W installed.

Analysis further showed that the amount spent per installation did not significantly change with the presence or absence of a PACE program, suggesting that PACE loans address non-price barriers or failures. This is further confirmed by comparing the best alternatives to PACE financing, both of which were lower-cost than PACE loans. These barriers and failures intersect with the existing literature on the Energy-Efficiency Gap and provide confirmation of the existence of this gap, though it is not possible to disentangle market barriers from non-externality market failures. No general rule of public policy exists to determine suitability of public policy intended to address market *barriers*, though the low cost of implementing a PACE program strongly indicates that PACE avoids a potentially social welfare-reducing scenario. Therefore, PACE is likely justified as an appropriate policy instrument. Results may be generalized over the state of California, but caution must be taken when applying to other states with varying intervening RPV incentives and policies.

The low cost of implementing a PACE program combined with the voluntary nature of PACE financing strongly suggest that expansion of PACE programs would provide benefits beyond the overall cost of such a program. In addition to the benefits of reducing environmental externalities, the facilitation of projects that are likely to be NPV positive, as determined by each individual homeowner's internal decision, increases overall welfare.

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