Energy Economics 66 (2017) 328–336

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

Soak up the sun: Impact of solar energy systems on residential home values in Arizona

Yueming Qiu [a], Yi David Wang [b,*], Jianfeng Wang [b]

[a] University of Maryland, School of Public Policy, 2101 Van Munching Hall, College Park, MD 20742, United States
[b] University of International Business and Economics, School of Banking and Finance, No. 10, Huixin Dongjie, Chaoyang District, Beijing 100029, China

ARTICLE INFO

Article history:
Received 12 October 2015
Received in revised form 27 June 2017
Accepted 2 July 2017
Available online 13 July 2017

JEL classification:
R31
Q20

Keywords:
Solar photovoltaics
Solar water heater
Residential house price
Estimated market value

ABSTRACT

Recent increase of installations of solar energy systems on residential properties begs the question of whether such investments are being recognized by the market. Studies that estimate the impact of solar technologies on home values have been scarce. Using transaction and valuation data for a sample of residential properties in Arizona and matching methodology, results show that solar photovoltaics installation indeed has positive impacts on both house value and transaction prices. This is the first empirical study conducted in Arizona, a state of crucial importance for solar energy development with its abundant solar resources. In particular, properties with electricity-generating solar panels enjoy an average premium of approximately $45,000 (15% of medium home value) and transaction price premium of $28,000 (17% of medium home sales price). We do not find a statistically significant premium on homes with solar water heaters alone.

1. Introduction

Over recent years, installation of photovoltaic energy systems (hereafter solar panels or solar PV) has experienced rapid growth in the United States, but the distribution is not uniform across states and there remains plenty of room for further growth. As of 2014, the three states with the highest per capita cumulative capacity of solar electrical generating capacity (as measured by megawatts per 1 million people) are Hawaii, Arizona, and Nevada (Weissman and Sargent, 2015). In terms of total installed capacity, the top three states of California, New Jersey, and Arizona account for more than half of the solar panels in the country. Take Arizona for instance, the popularity of solar panels increased drastically within a relatively short period of time. Despite such phenomenal expansion, studies that estimate the impact of solar panels and other solar technologies such as solar water heaters on home value remain scarce. An enhanced understanding of such impact would not only be useful to home owners or house purchasers when deciding whether to install solar technologies or purchase a house with solar energy systems, but also important to policy makers trying to encourage the renewable energy technology adoption as well as local fiscal authorities when calculating property tax base.

As mentioned above, studies focusing on the impact of solar panels on house prices have been limited. Hoen et al. (2015) analyze a large dataset of eight states' PV homes and find a sales price premium of $15,000 for an average-sized 3.6-kW PV system. Dastrup et al. (2012) find that houses with solar panels enjoy a 3.5% (or $23,000) premium over comparable houses without solar panels in terms of sales price using data from San Diego and Sacramento counties of California, and that the premium is larger in communities with greater share of college graduates and of registered Prius hybrid vehicles. Hoen et al. (2011) and Hoen et al. (2013) examine a sample of California homes sold from 2009 to mid-2009 and discover that homes with solar panel installation enjoy a sales price premium of approximately $17,000, which is approximately equal to the cost of installation. Regarding solar hot water heaters, to the best of our knowledge, there is no published study on the impact on housing price premium. Outside of the residential solar homes sphere, there is evidence that "green" hotels indeed charge a premium relative to non-green hotels, suggesting that there is a willingness to pay by consumers for "green" sheltering (Kuminoff et al., 2010). However, the study does not concentrate on the effects of solar panels in particular. Some recent papers have identified the positive correlation between energy-related improvements (green certificates) and selling prices for commercial properties (Eichholtz et al., 2010, 2013), while other papers have found premiums enjoyed by green-labeled homes, again not restricting to solar panels (Brounen and Kok, 2011; Walls et al., 2017).

Recognizing the absence of extensive research on solar-panel premiums, Black (2010) uses studies on the impact of energy efficiency

* Corresponding author.
E-mail addresses: yqiu16@umd.edu (Y. Qiu), dyiwang@uchicago.edu (Y.D. Wang), wjfruc@126.com (J. Wang).

http://dx.doi.org/10.1016/j.eneco.2017.07.001
0140-9883/

investments and energy bill savings to justify the hypothesis that solar panels can increase home sales prices. Although logically valid, such approximations might not be completely satisfactory and reliable. In theory, when the carrying cost (which includes electricity cost) of a home is lowered, all else equal a potential buyer should be willing to pay more for that home. Consequently, the present value of the expected savings derived from solar-panel installation should be capitalized into the value of the home. Indeed, there have been some older studies revealing a positive correlation between lower energy bills (presumably a consequence of energy related home improvements, which include but not restricted to solar panel installation) and residential selling prices (Johnson and Kaserman, 1983; Longstreth et al., 1984; Laquatra, 1986; Dinan and Miranowski, 1986; Horowitz and Haeri, 1990; Nevin and Watson, 1998; Nevin et al., 1999). This translation mechanism between lower energy cost and house sales prices might hold for solar panels as well because solar panels generate electricity on-site for customers and thus customers pay less to the utilities.

Of course, the fact that houses with solar panels enjoy a premium in sales price alone does not necessarily mean that such installation is a sound investment. It might very well be the case that the premium enjoyed is insufficient to cover the cost of installation. Purely based on energy savings, solar panels might not be a NPV positive investment (Borenstein, 2008). However, Borenstein's study does not include sales price premium and only focuses on energy savings. One might ask why house price premium in equilibrium should be greater than the present value of energy savings. One potential explanation is that solar panel installation is a type of conspicuous consumption (Kotchen, 2006), and assume that certain house buyers attach value to enjoying the common knowledge that their homes are "green," it would induce houses with solar panels to enjoy a price premium relative to otherwise comparable houses.

Intuitively, the main incentive for homeowners to install solar panels to their homes and for buyers to prefer a home with solar panels is the reduction in electricity cost. However, someone facing the installation decision also faces many uncertainties regarding the potential benefits of the solar panels, and these uncertainties often deter the agent from installing the panels. Uncertainties include the duration of occupancy/ownership relative to the payback period of the panels, the performance of the panels (in terms of energy saving capabilities) which impacts the payback period calculation (Qiu et al., 2014), and the impact on house value after installation, all of which are important variables determining whether solar panel installation is a sound investment.

Out of the three main uncertainties mentioned above, the impact on the house value is especially important and is the focus of this study. Assuming that installation of solar panels has an immediate and positive impact on house value, then at least a fraction of this value should be captured by the seller when the home is sold.[1] If the magnitude of this positive impact is sufficiently large, it would mitigate the deterrence on solar panel installation from the uncertainty of occupancy period. Of course, the magnitude of the impact will likely be a function of the expected payback period, which in turn depends on the expected performance of the panels. But at the very least, the fact that the current owner might need to sell the property prior to the breakeven threshold would no longer be a barrier to solar panel installation if he can capture the gains immediately in the terms of house value[2] and realize that gain when he needs to sell. Consequently, this study not only focuses on the impact of solar panels on home sales prices, but also on estimated market values.

There are three major contributions of this study. First, it is the first study estimating the impact of solar energy systems on home values in Arizona. Given Arizona's abundant solar resources and the on-going debate in the state about whether utilities should impose demand charge for solar homes (RMI, 2015), it is important to demonstrate the impact of solar energy systems on home values in order to provide a clear signal of the potential benefit of installing solar energy systems. Second, in addition to solar panel, this study also analyzes values of houses with solar hot water heaters, which has been rarely studied in existing literature. Water heaters account for about 17% of a home's energy use (Energy.Gov, 2014) thus investment in solar water heater is also important for saving energy. Third, this study improves on methodology through a matching approach controlling for confounding home energy attributes such as energy audit, fresh air mechanical ventilation, load controller, energy efficiency certificates, multi-zone heating and cooling, and ceiling fans that can also impact home values.

Using transaction and valuation data for a sample of residential properties in Arizona in 2014 and matching methodology, results show that solar installation indeed has positive impacts on both house value and transaction prices. In particular, solar panel installation in Arizona increases house value by 15% ($45,000) and transaction price by 17% ($28,000) on average. The results have important implications for policy makers, solar industry, real estate investors, and home owners. The rest of the paper is organized as the following. Section 2 discusses the empirical strategy. Section 3 describes the data. Section 4 presents the results and their implications. Section 5 discusses the implications and concludes.

2. Empirical strategy

A matching approach similar to the one in Qiu et al. (2016) is utilized to eliminate the selection bias and to estimate the causal impact. In particular, matching methods select a control group that is as similar to the treatment group as possible prior to the treatment (Abbott and Klaiber, 2013), which is referred to as a Nonequivalent Control Group Design (Campbell and Stanley, 1963). The Electric Power Research Institute (EPRI) Research Protocol (EPRI, 2010a) states that "the objective of this approach is to create a non-equivalent control group that is as similar as possible to the treatment group formed by volunteer participants."

In the case of voluntary program participation (in this case the "program" would be solar energy system installation), researchers can implement a matching method if the following two assumptions hold: 1) if conditional on the observed control variables, the participation and the outcome variables are independent or that only observable factors influence participation and the outcome variables simultaneously, the so-called selection on observables (Conditional Independence or CIA); 2) given a level of the observed control variables, the probability of a subject participating in the program is between zero and one (Common Support or CS).

In this study, Assumptions 2 can be justified to hold: given a level of the key observable attributes such as – number of bedrooms, number of bathrooms, square footage, lot size, whether a house has a pool, whether a house has a desirable view, and years built– there are both homes that volunteered to install solar energy systems and homes that did not. Regarding Assumption 1, since the rich dataset includes various home attributes, in our analysis we have included a comprehensive list of observable characteristics to make the selection based on observables. Location is a key factor determining property values. As Dastrup et al. (2012) found, community characteristics can influence the valuation of energy features in a house. Thus during the matching process, for a solar home, we find a control home that is located in the same zip code to control for any regional factors influencing property values. In addition, the standard errors are clustered at zip code level, in order to control for any intra-zip-code correlation in property values.

Inexact matching is utilized when exact matching is not feasible. Inexact matching requires a measurement of "distance" between any two observations, i and j. However, as the dimension of the variables being matched increases, it is hard to calculate such distance. As mentioned earlier, the rich dataset in this study provides information of various

[1] The exact fraction would depend on market conditions at the time of the sale and the relative bargaining skills of the two parties.

[2] Perhaps via a home equity loan.

home attributes. To have a balanced match on these many attributes, we adopt the coarsened exact matching (CEM) method by Blackwell et al. (2009). CEM matching method first coarsens each attribute into substantively meaningful categories, then exact matches on the coarsened category, and finally only retains the original coarsened values of the data. Iacus et al. (2012) discuss the benefits of the CEM method and the key property is that CEM is in a class of matching methods called Monotonic Imbalance Bounding (MIB). MIB can bound the maximum imbalance in some feature of the empirical distributions.

When analyzing the impact of solar energy systems on home values, there are some confounding factors that can be related to both the installation of solar energy systems and home values. The factors that are often omitted in existing studies due to lack of sufficient data are home energy attributes such as the existence of ceiling fans, multi-zone temperature control, energy audit, fresh air mechanical ventilation, load controller, and home energy certificates such as Energy Star homes. In this study we are able to obtain such information. Due to the small sample sizes of homes with multi-zone temperature control, energy audit, fresh air mechanical ventilation, load controller, and home energy certificates such as Energy Star homes, we only analyze homes with the energy feature of ceiling fans. By doing this, we can get rid of the confounding impact of other home energy features on home values.[3]

Matching results' balancing statistics are also checked to ensure balancing of groups, which means that the treatment group and control group are indeed comparable on all attributes except for the treatment status. Two important balancing statistics used to test for sample equivalence are: standardized mean difference (SMD), which compares the sample means, and variance ratios (VRs), which compares the sample distributions and higher-order sample moments (Linden and Samuels, 2013). SMD for a given attribute X_j is defined as.

$$smd_j = \frac{|\overline{X}_{jT} - \overline{X}_{jC}|}{\sqrt{\frac{(S_{jT})^2 + (S_{jC})^2}{2}}},$$

where the numerator is the absolute difference in average X_j between the treatment and control groups (subscripts T and C, respectively); the denominator is the average standard deviation of the two groups. The greater the SMD reading, the more unbalanced the two groups are. Although the cut-off threshold varies from study to study, Normand et al. (2001) suggests a threshold of 0.1 and Rubin (2001) suggests 0.25.

VR for a given attribute X_j is defined as

$$VR_j = \frac{(S_{jT})^2}{(S_{jC})^2},$$

where S_{jT} is the standard deviation of X_j in the treatment group and S_{jC} is the standard deviation of X_j in the control group. Here, the farther the VR reading deviates from 1, the more unbalanced the two groups are. Rubin suggests thresholds of 0.5 and 2.

3. Data

The data set used is relatively straightforward. As mentioned in introduction, this study focuses on residential properties in Arizona. In particular, data includes all single family houses listed for sale in the Phoenix metropolitan area on a randomly selected day in Feb of 2014. Addresses of the houses for sale are obtained from a local real estate agent's website (http://www.dianecain.com/) and the randomly selected date is Feb 27th, 2014. This real estate website lists all residential properties for sale on a given day in Phoenix metropolitan area. The website also provides very detailed information of properties including key energy features such as solar installation, energy certification, and HVAC systems for all properties listed. Property description includes (but is not limited to) basic features such area, number of bedrooms, number of bathrooms, as well as the existence of any special energy features. Price data contains sales price (measured by the asked price of the seller), estimated market value of the house, as well as any historical transaction prices[4] if the property has been transacted before. Hence, besides the historical transaction prices, the data set contains no time dimension. Fig. 1 shows the locations of these single family houses, which contains 26,335 properties.

The lack of a time-dimension is not as undesirable as it might first appear for the investigation at hand. In fact, given that the main hypothesis pertains to the impact on property value by solar panels, and that property values are also impacted by macroeconomic variables (in addition to property-specific features) which fluctuate over time, focusing on one particular moment in time removes the fluctuations of these systematic influencers. Consequently, the empirical verification does not need to control for a time dimension and would be more focused on the impact of the property-specific features (in this case solar panels) on house value. In addition, the lack of a time dimension avoids the potential criticism that any estimated impacts of solar panels on house value obtained from previous studies that do include a time-dimension might be confounding the impact of uncontrolled variables that are not property-specific (such as macroeconomic conditions).

On the other hand, the lack of a time dimension prevents tests on the time-variance of the impact by solar panels. Indeed, with the existing data set one cannot verify whether solar PV's impact on house value varies over time, and if it does, what factors might drive such variations. Hence, results obtained using existing data should not be generalized without caution and are vulnerable to time-robustness concerns. The main barrier that prevents us from adding a time dimension to the dataset is the absence of solar PV installation dates. Hence, despite the fact that historical transaction prices (if exist) are contained in public records, it is not yet feasible to determine the initiation dates beyond which solar panels should have an impact on property value. That said, given that the data collection date falls in the first calendar quarter of 2014, it is relatively safe to assume that if the property in question has a previous transaction in 2014, and that it contains solar panels, then those solar panels were installed before the previous transaction. However, the validity of such assumption becomes more questionable if the transaction took place prior to 2014.

Out of the properties for sale, those with solar energy systems are identified and placed into the treatment group. For each property in the treatment group, a corresponding control property is identified using the matching strategy described in Section 2 after controlling for other common features (location, number of bedrooms, square footage, other energy features, etc.) of the property. This generates treatment and control groups of equal size.[5] We have two separate study groups:

[3] We are agnostic on whether ceiling fan installation can impact the investment decision of solar panels for the purpose of either water heating or electricity generation. By controlling for this variable in our analysis, we only want to make sure that any impact on home values by solar panels for properties with both solar panels and ceiling fans are not confounded by the existence of ceiling fans.

[4] Historical transaction prices and estimated market values are obtained from Zillow.com using the property address.

[5] The initial sample size was 26,335 properties, out of which 247 properties have solar panels and 146 have solar water heaters. During the matching process, we dropped those solar properties which we could not find good matching properties within the same zip code. This left us with 123 solar panel homes and 71 solar water heater homes. Given the small fraction of properties with solar panels and water heaters, extending the data-collection time range from 1 random day to a month did not increase the number of relevant observations in any meaningful way. And extending the time range too much increases the chance of meaningful changes to macroeconomic conditions that impact the housing market in general. Hence, we decided to use 1 random day to eliminate any change to uncontrolled market conditions at the expense of missing only a few relevant observations.

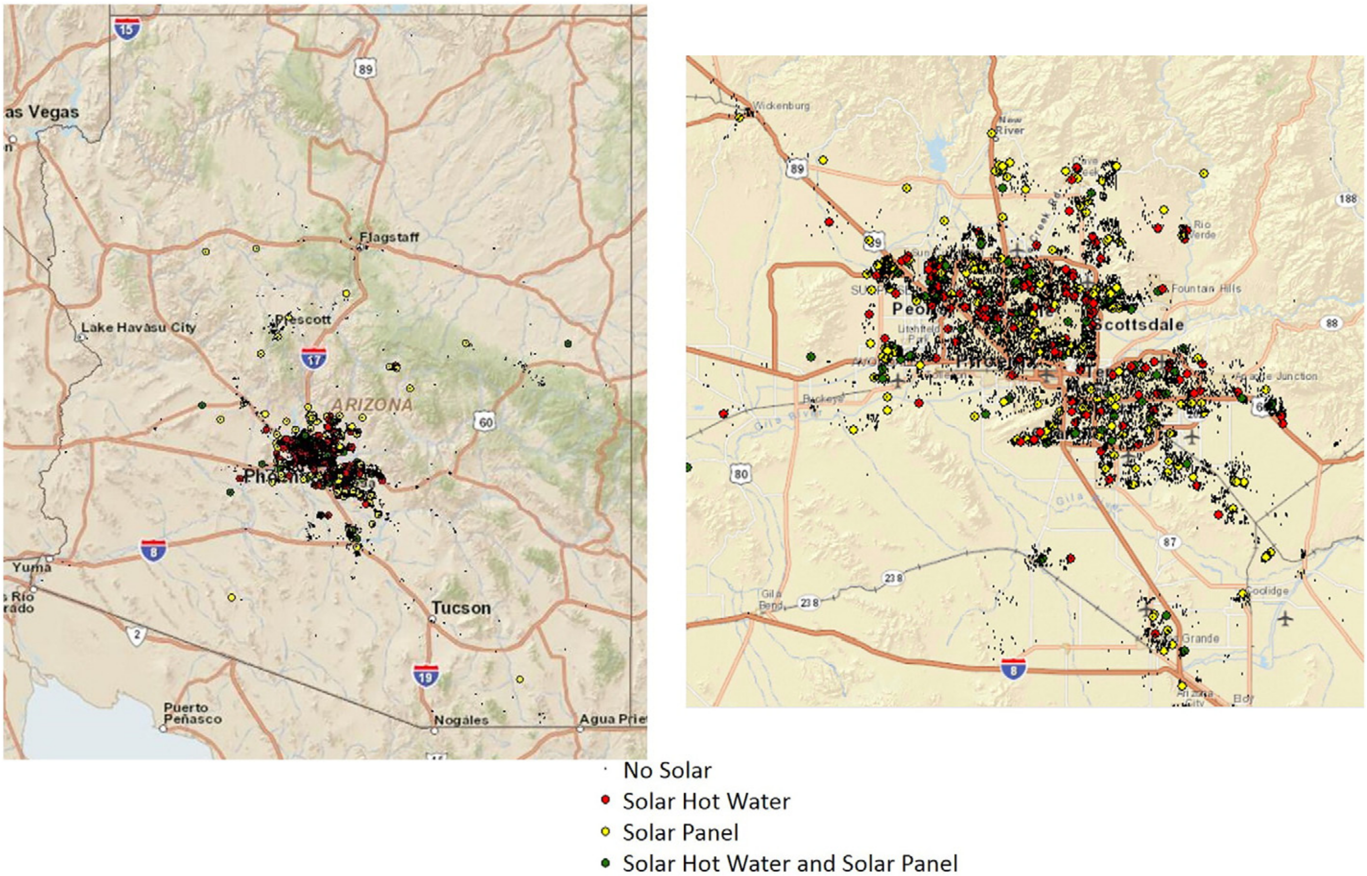

Fig. 1. Single family houses listed for sale in the Phoenix metropolitan area on a randomly selected day in Feb 2014 (The right-hand side figure is a zoom-in image of the left-hand side figure).

one group is to study the impact of solar panels on home values; the second group is to study the impact of solar hot water heaters on home values. We do not look at homes with both solar panels and solar hot water heaters due to small sample size of such dual solar energy system homes. Descriptive statistics of the treatment and control groups are summarized in Table 1 (with Table 1a summarizing the study groups on solar panels for electricity generation and Table 1b summarizing those on solar water heaters). For the study of analyzing solar panels, there are 123 solar homes and 123 control homes; for the study of analyzing solar hot water heaters, there are 71 solar homes and 71 control homes. Based on the balancing statistics, we are confident that the treatment and control groups are indeed comparable in terms of the major home attributes. Figs. 2 and 3 show the locations of the treatment and control groups for the solar panel and solar hot water heater studies, respectively.

4. Results

Using the control and treatment groups, we conduct semi-parametric and non-parametric statistical tests as well as hedonic regressions to determine whether having solar energy systems (either for electricity generation or specifically for water heating) have positive impacts on the estimated house value and transaction price.

Table 2 lists the statistical test results, including both t-test and Wilcoxon rank-sum test for whether the treatment effects $\widehat{\alpha_{TT}}$ are statistically significantly different from zero. Here $\alpha_{TT} = T_{post}$-C_{post} where

Table 1a
Summary statistics and balancing checks for solar panel treatment and control groups.

Treatment group: Has solar panel installed						Balancing check results		Control group: No solar panel					
Variable	# Obs	Mean	Std. Dev.	Min	Max	SMD	VR	Variable	# Obs	Mean	Std. Dev.	Min	Max
# of bedrooms	123	3.20	1.14	2	8	0.007	1.210	# of bedrooms	123	3.21	1.03	2	6
# of bathrooms	123	2.43	0.82	1.75	7.5	0.008	1.220	# of bathrooms	123	2.44	0.75	1.75	6
Sqft2	123	2401.45	996.17	1245	7126	0.074	1.158	Sqft2	123	2330.31	925.83	1130	7340
Lot sqft2	123	16,456.17	43,522.05	4399	419,568	0.078	2.270	Lot sqft2	123	13,570.12	28,887.94	2849	245,155
Pool	123	0.28	0.45	0	1	0.000	1.000	Pool	123	0.28	0.45	0	1
Year built	123	2000.06	11.41	1953	2013	0.072	0.997	Year built	123	1999.24	11.43	1953	2013
View	123	0.33	0.47	0	1	0.000	1.000	View	123	0.33	0.47	0	1

Definitions of variables: # of bedrooms – number of bedrooms, # of bathrooms – number of bathrooms, Sqft2 – square footage of the house, Lot sqft2 – square footage of the lot, Pool – indicator variable of whether a house has a pool, Year built – the year the house was built, View – indicator variable of whether a house has good views such as mountain views, city light views, park views, lake views, or golf course views.

Table 1b
Summary statistics and balancing checks for solar hot water treatment and control groups.

Treatment group: Has solar hot water installed						Balancing check results		Control group: No solar hot water					
Variable	# Obs	Mean	Std. Dev.	Min	Max	SMD	VR	Variable	# Obs	Mean	Std. Dev.	Min	Max
# of bedrooms	71	3.23	0.83	2	5	0.034	1.020	# of bedrooms	71	3.25	0.82	2	5
# of bathrooms	71	2.31	0.51	1.75	3.5	0.038	0.760	# of bathrooms	71	2.33	0.59	1.75	4.5
Sqft2	71	2255.39	713.58	802	4605	0.031	1.251	Sqft2	71	2234.69	638.06	1370	4619
Lot sqft2	71	22,580.90	58,565.21	4792	435,600	0.053	1.357	Lot sqft2	71	19,691.28	50,276.73	4950	413,384
Pool	71	0.41	0.50	0	1	0.028	0.990	Pool	71	0.42	0.50	0	1
Year built	71	1987.41	15.78	1950	2013	0.067	0.884	Year built	71	1988.49	16.79	1939	2014
View	71	0.27	0.45	0	1	0.182	0.859	View	71	0.35	0.48	0	1

Definitions of variables: # of bedrooms – number of bedrooms, # of bathrooms – number of bathrooms, Sqft2 – square footage of the house, Lot sqft2 – square footage of the lot, Pool – indicator variable of whether a house has a pool, Year built – the year the house was built, View – indicator variable of whether a house has good views such as mountain views, city light views, park views, lake views, or golf course views.

T_{post} is the property value of solar homes and C_{post} is the property value of non-solar homes. The samples analyzing transaction prices are much smaller than the samples analyzing home values because as discussed in Section 3, we only analyze the transaction prices in 2014 due to the lack of information on the installation dates of solar energy systems. The results show that solar panels have statistically significant positive impacts on both estimated market values and transaction prices while solar hot water heaters do not have statistically significant impact on either home values or transaction prices.

To control for more factors related to home values, following hedonic regressions are used:

$$V_i = \alpha + \beta^* Solar_i + \sum_k \lambda^k X_i^k + \tau_i$$

where
i indicates individual house; *Solar* is a dummy variable which equals one if a house has installed a solar energy system; X_i^k is the k^{th} home attribute such as number of bedrooms, square footage and so on; τ_i is the independent and identically distributed error term with mean zero. Tables 3 and 4 present the hedonic regression results with Table 3 depicting the results for electricity-generating solar panels and Table 4 for water-heating solar panels. The standard errors are clustered at the zip code level in order to control for any zip-code level shocks on property values.

Solar panels for electricity generation indeed have significantly positive impacts on both the estimated value of the home and on realized sale price. Regression results show that having solar panels for electricity generation increases the house value by over $45,000. At the mean house value of $294,307.3 based on the control homes, this increase amounts to 15% increase in estimated market values. Of course, how much of such value is transferred and reflected in transaction prices is also a function of market conditions. Although a significantly positive impact is also present when examining transaction price (approximately $28,000 or 17% increase based on the mean transaction price of

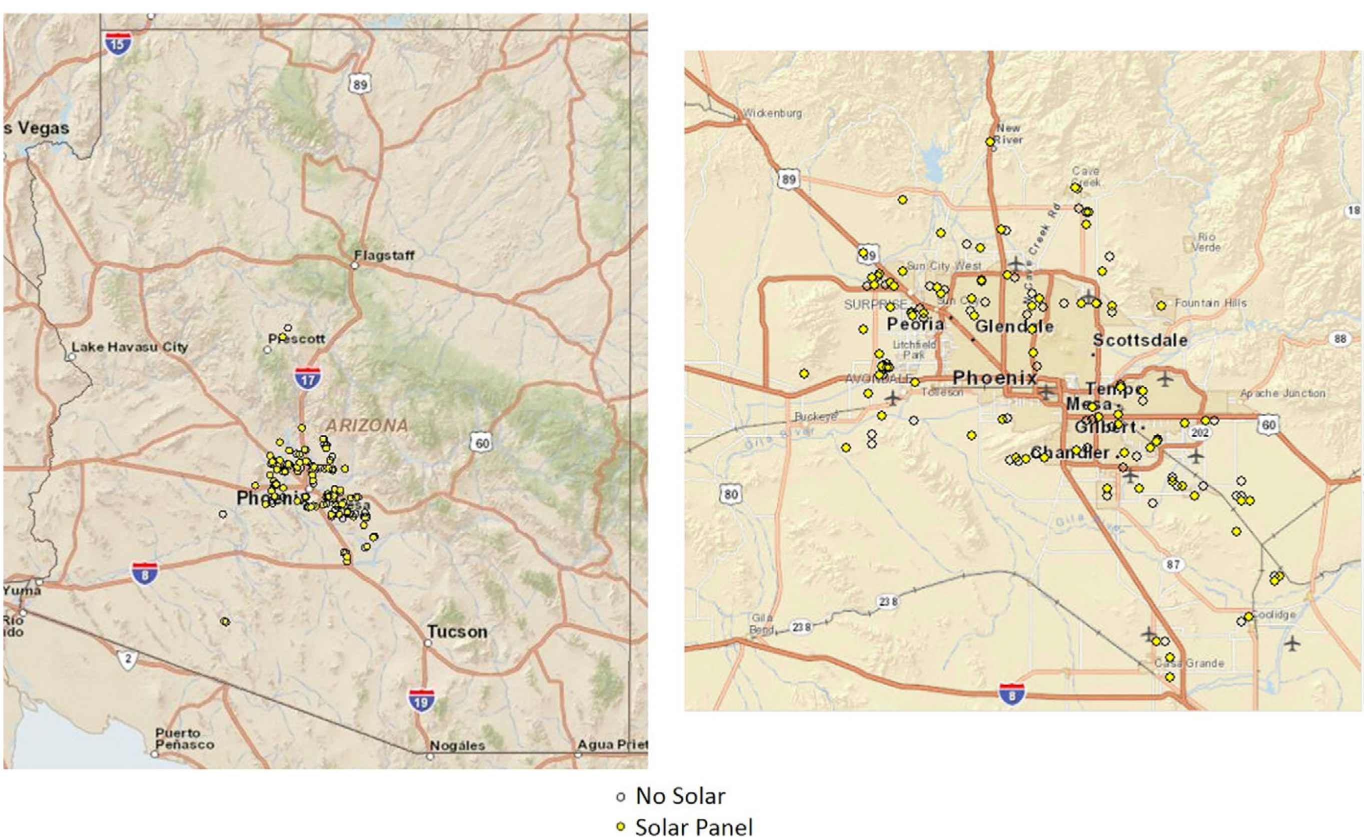

Fig. 2. Matched control and treatment groups for studying solar panel's impact (The right-hand side figure is a zoom-in image of the left-hand side figure).

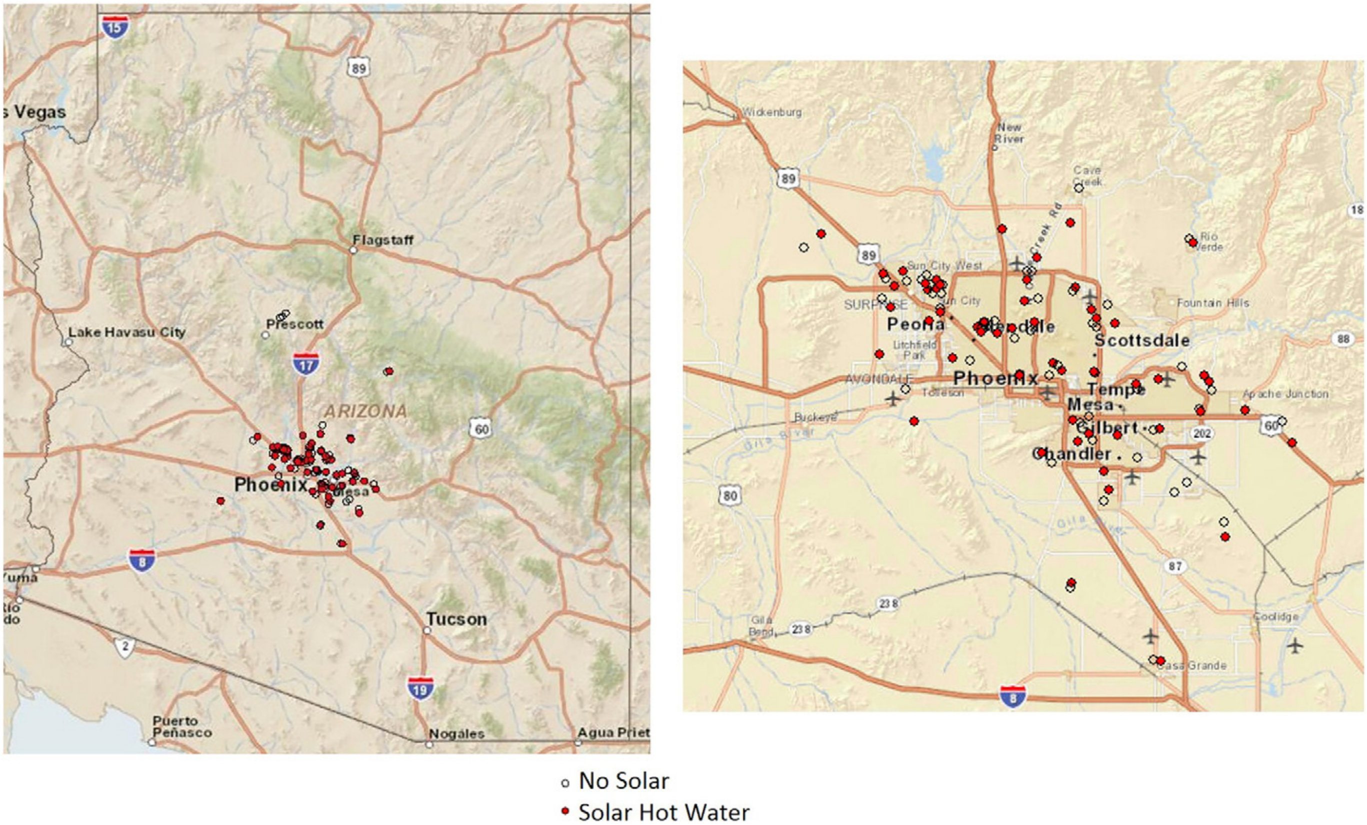

Fig. 3. Matched control and treatment groups for studying solar hot water's impact (The right-hand side figure is a zoom-in image of the left-hand side figure).

$163,491 of control homes), the results of realized sales price should be read with extra caution given the small number of observations available and are reported for completeness. It is possible that using the estimated market value can inflate the renewable energy feature, compared to using transaction price, because the negotiation in the transaction process can reduce sales price. As a result, buyers do not appreciate the value of solar technologies as much as the market expects.

The impacts of solar water heaters are insignificant. The types of energy saved from the adoption of solar panel versus solar water heater could be different. Solar panel generates electricity while solar water heater is used for heating water used in the household. Consequently, solar panels save electricity directly regardless of the source of electricity usage, while a solar water heater focuses on energy used for water heating by saving either natural gas or electricity, depending on the status quo technology used for heating water in a given house. In the Phoenix metropolitan area, both electric water heater and natural gas water heater are commonly used by households. Gas water heaters have lower operating cost due to cheaper natural gas price than electricity price. If the status quo energy source for water heating in a house is gas, then the energy cost savings would be lower compared to a house that uses electricity for water heating. Hence, investment in solar water heater tends to be less attractive for houses that use gas for water heating. In addition, solar water heater also needs rooftop space, making it a competitor for solar panels. If a solar water heater only saves natural gas, then it might make more sense to use the limited rooftop space for solar panels, because solar panels are more likely to offer higher savings, thus increasing the marginal returns of roof top space. Because both types of water heating technologies (gas versus electric) are equally common, we do not observe significant impact of solar hot water heaters on property values.

The second difference between solar panels and solar water heaters is that solar panels have the ability to generate excessive electricity that

Table 2
Semi-parametric results and statistical tests.

Solar panel					
Sample for analysis of estimated market values $N = 123{*}2$			Sample for analysis of transaction price $N = 11{*}2$		
$\widehat{\alpha_{TT}} = 57{,}920.81$	P-value for testing $\widehat{\alpha_{TT}} = 0$ t-test: $p = 0.0431$	Wilcoxon rank-sum test $P = 0.0349$	$\widehat{\alpha_{TT}} = 55{,}884.45$	P-value for testing $\widehat{\alpha_{TT}} = 0$ t-test: $p = 0.0138$	Wilcoxon rank-sum test $P = 0.0940$
Solar hot water heater					
Sample for analysis of estimated market values $N = 71{*}2$			Sample for analysis of transaction price $N = 8{*}2$		
$\widehat{\alpha_{TT}} = -6207.296$	P-value for testing $\widehat{\alpha_{TT}} = 0$ t-test: $p = 0.5936$	Wilcoxon rank-sum test $P = 0.9919$	$\widehat{\alpha_{TT}} = -22{,}133.38$	P-value for testing $\widehat{\alpha_{TT}} = 0$ t-test: $p = 0.3787$	Wilcoxon rank-sum test $P = 0.7525$

Table 3
Hedonic regression results for solar panel treatment and control groups.

Dependent variable	Estimated value		Last sold price	
	Coefficient	Clustered standard error	Coefficient	Clustered standard error
Solar panel	45,511.390**	19,561.037	28,005.613*	13,526.362
# of bedrooms	−69,723.271***	13,512.965	−20,626.541	17,946.682
# of bathrooms	116,399.489***	34,332.171	−65,231.011	37,430.293
Sqft2	149.635***	40.539	89.686**	31.689
Lot sqft2	1.078**	0.463	−0.634	0.640
Pool	27,310.424	22,518.564	−22,262.991	31,834.420
Year built	−1466.522	947.577	608.371	455.707
View	38,842.388**	19,178.654	24,827.986	20,340.264
Constant	2,782,190.892	1,863,766.407	−1.013,627.175	913,408.530
N	246		22	
R-squared	0.6974		0.5782	
	Std. Err. adjusted for 61 clusters in zip code		Std. Err. adjusted for 9 clusters in zip code	

Definitions of variables: Solar panel – whether a house has solar panels installed, # of bedrooms – number of bedrooms, # of bathrooms – number of bathrooms, Sqft2 – square footage of the house, Lot sqft2 – square footage of the lot, Pool – indicator variable of whether a house has a pool, Year built – the year the house was built, View – indicator variable of whether a house has good views such as mountain views, city light views, park views, lake views, or golf course views.

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

can be fed back to the grid through net metering programs. During the study period, the two major electric utilities in Phoenix metropolitan area – Arizona Public Service Electric Company (APS) and Salt River Project (SRP) both had effective net metering programs. For solar panels, the benefit for consumers is not just offsetting the electricity usage of the household, but also gaining extra electricity usage credit from the electric utilities if the solar panel generates more electricity than the household consumes at any given time. For solar water heaters however, this second benefit is absent, which could be another reason why solar water heater does not have significant impact on property values.

Water heating is only one out of many energy consuming activities, and by restricting the usage of solar energy to only one activity greatly limits the marginal utility of the solar energy system when compared to electricity-generating solar panels. Consequently, buyers attach less value to such equipment. In addition, assuming there are only a fixed amount of space for which solar technologies can be installed on any given property, having solar water heater only also makes installing electricity-generating solar panels more costly and possibly unfeasible. Consequently, although the regression results do not reflect any significance, it is conceivable that solar water-heaters are actually undesirable and hence have negative impact on property value.

One might hypothesize that if a house has more bathrooms and/or a pool, the demand for water heating would be higher, making solar water heater a more attractive investment. As a result, houses with more bathrooms or a pool would increase the marginal value of solar water heater. To test this hypothesis, we add two interaction terms, one between number of bathrooms and solar water heater, and one between the pool variable and solar water heater. The results are listed in Table 4. The results suggest that if a house has more bathrooms, it does increase the marginal value of solar water heater, based on historical transaction price. However, for a house with a pool, it does not increase the marginal value of such investment. In fact, based on estimated market value, having a pool reduces the marginal value of solar water heater. First, most pools in the Phoenix metropolitan area are non-heated. In a normal year, non-heated pools can be enjoyed for about 10 months out of the year, thus lowering the marginal return of adding the heated feature. This should explain why having a pool does not increase the marginal value of a solar water heater. Second, as to why the empirical result actually shows a negative impact, we offer the following economic rational. Heated and non-heated water are substitutes to an extent, especially in an area known for its high temperature. When usage of non-heated water goes up (which it does when the house has a non-heated pool), it lowers the fraction of heated water usage for the household, and hence also increases the opportunity costs of the solar-heater. A non-heated pool should not increase a household's demand for heated water, but it does increase the demand for electricity. This is because many standard pool-features (self-cleaning robot, automatic water filtering and refiling) run on electricity. A solar water heater cannot mitigate this increase in demand. Hence, its marginal value to the house value should be lower even though the absolute demand for heated-

Table 4
Hedonic regression results for solar hot water treatment and control groups.

Dependent variable	Estimated value				Last sold price			
	Coefficient	Clustered standard error	Coefficient	Clustered standard error	Coefficient	Clustered standard error	Coefficient	Clustered standard error
Solar hot water	−4841.791	8133.668	82,066.281	49,642.254	−28,041.556	15,105.409	−605,811.268**	174,101.608
Solar hot water * Pool			−55,622.293***	18,193.803			−54,803.702	98,399.573
Solar hot water * # of bathrooms			−27,417.194	21,502.855			268,194.042**	78,089.101
# of bedrooms	−31,591.655**	14,716.715	−30,199.604**	14,897.209	79,227.092	42,577.726	107,796.005***	29,062.021
# of bathrooms	67,603.218**	25,950.807	80,853.178***	25,798.770	17,493.703	19,492.608	−230,414.006**	82,644.522
Sqft2	144.640***	17.290	143.141***	16.725	68.788	41.402	92.880	59.859
Lot sqft2	0.228	0.209	0.237	0.174	0.024	0.130	−0.120	0.281
Pool	46,034.244**	17,542.703	74,559.492***	21,934.114	32,601.406	41,630.223	−7980.972	59,321.175
Year built	−692.651	621.922	−714.890	634.445	−5798.353	4617.064	−6398.166*	2891.490
View	54,222.384***	18,127.009	54,956.646***	17,243.614	51,718.921	84,176.372	111,737.842	89,767.014
Constant	1,248,215.748	1,236,064.280	1,247,831.189	1,253,477.268	11,339,680.798	9,175,053.278	12,921,387.077*	5,782,875.895
N	142		142		16		16	
R-squared	0.7702		0.7815		0.9001		0.9647	
	Std. Err. adjusted for 48 clusters in zipcode				Std. Err. adjusted for 7 clusters in zipcode			

Definitions of variables: Solar hot water – whether a house has a solar water heater installed, # of bedrooms – number of bedrooms, # of bathrooms – number of bathrooms, Sqft2 – square footage of the house, Lot sqft2 – square footage of the lot, Pool – indicator variable of whether a house has a pool, Year built – the year the house was built, View – indicator variable of whether a house has good views such as mountain views, city light views, park views, lake views, or golf course views.

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

water remains unchanged, because the relative demand for heated-water has decreased.

The fact that the impact on estimated value of a property by the number of bedrooms is significantly negative upon controlling for square footage is consistent with other studies. Although counter intuitive at first glance in light of the fact that having more bedrooms means more living space, but given a fixed amount of living space (captured by square footage), having more bedrooms means that the average size of each bedroom is smaller and hence less desirable. Number of bathrooms, square footage, lot size and having a desirable view have statistically significant positive impacts on property values.

5. Discussions and conclusions

Fully acknowledging the lack of time dimensionality of the analysis, the restriction of location, and the limitation of a relatively small sample, the results provide empirical evidence that the benefits of having solar panels are indeed being recognized by market participants in Arizona, an important state for solar energy development given its abundant solar resources and its recent regulatory debate on increasing fixed charges for solar homes. Findings are consistent with the notion that properties with electricity-generating solar panels do enjoy a premium in terms of property value relative to their non-solar counterparts. Less conclusive evidence is also present that such a premium is also present in transaction prices.

This finding functions as a confirmation that installing solar panels can indeed be viewed as an investment that increases property value. The estimated premium enjoyed by properties with electricity-generating solar panels is approximately \$45,000, and at a medium home value of control groups in the sample, this represents a premium of 15%. The transaction sales price premium found in this paper is \$28,000 or 17% increase at medium sales price. Given that on average the installation of rooftop solar panels costs about \$23,000 in 2013 and it is projected that the cost will continue to fall (USC, 2014), the findings indicate that installing electricity generating solar panels is a cash-flow positive investment with a non-trivial return.

Compared to the few existing studies outside Arizona (mostly California) which find sales price premium of \$15,000 ~ \$23,000 of solar PV homes, the \$28,000 transaction sales price premium found in this paper is close but on the higher end. One explanation is that Arizona has cheaper land and housing prices, and thus residents can afford larger houses with larger rooftops to install larger size PV systems. Regarding percentage premium, the 17% premium found in this study is higher than existing studies, which again could be due to the lower base housing prices in Arizona. The much higher percentage premium of solar homes in Arizona also imply that investment in solar PV systems in Arizona can generate better return for investors.

On the other hand, properties with solar water heaters do not appear to enjoy any positive premium. The lack of premium empirically can be a result of the limited sample size and/or from the notion that having solar energy systems that restricts the energy usage is less desirable to market participants because these solar water heaters reduce the option value of installing electricity-generating solar panels by increasing the cost of installation (e.g., lack of space, removal cost). Consequently, the implication for property owners and developers is that solar water heaters do not enjoy a noticeable premium and hence are likely a less attractive investment option.

For policy makers trying to encourage the usage of renewable energy (especially solar energy) by residential properties, this suggests that providing subsidies to electricity-generating solar panels (thus lowering the upfront investment cost faced by the property decision makers) is likely to generate a higher welfare and monetary surplus than subsidizing solar water heaters. From a policy maker's perspective and assuming that the environmental benefit of solar panels and solar water heaters are comparable on a per kWh basis, it is more cost effective and hence more rational to subsidize the option that has a higher probability of adoption by home owners given a fixed amount of subsidization. Finally, additional investigation on the premium enjoyed by properties with solar panels are needed and are reserved for future research as more data become available.

Acknowledgements

Funding for this research was provided by the National Science Foundation under grant NO. 1652696.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2017.07.001.

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