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SELLING INTO THE SUN: PRICE PREMIUM ANALYSIS OF A MULTI-STATE DATASET OF SOLAR HOMES

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Abstract

Capturing the value that solar photovoltaic (PV) systems may add to home sales transactions is increasingly important. Our study enhances the PV-home-valuation literature by more than doubling the number of PV home sales analyzed (22,822 homes in total, 3,951 of which are PV) and examining transactions in eight states that span the years 2002–2013. We find that home buyers are consistently willing to pay PV home premiums across various states, housing and PV markets, and home types; average premiums across the full sample equate to approximately $4/W or $15,000 for an average-sized 3.6-kW PV system. Only a small and non-statistically significant difference exists between PV premiums for new and existing homes, though some evidence exists of new home PV system discounting. A PV green cachet might exist, i.e., home buyers might pay a certain amount for any size of PV system and some increment more depending on system size. The market appears to depreciate the value of PV systems in their first 10 years at a rate exceeding the rate of PV efficiency losses and the rate of straight-line depreciation over the asset's useful life. Net cost estimates—which account for government and utility PV incentives—may be the best proxy for market premiums, but income-based estimates may perform equally well if they accurately account for the complicated retail rate structures that exist in some states. Although this study focuses only on host-owned PV systems, future analysis should focus on homes with third-party-owned PV systems.

Key words: photovoltaic, PV, solar, homes, residential, property value, selling price, premium, hedonic, California, new homes, existing homes, host-owned

Table of Contents

List of Tables

List of Figures

1. Introduction

As of the second quarter (Q2) of 2014, solar photovoltaic (PV) energy systems have been installed on more than a half million homes in the United States; more than 42,000 systems were installed in Q2 alone, roughly four times the number installed in the same quarter in 2010 (SEIA & GTM, 2014). This growth is in part related to the dramatic decrease in installed PV costs over the last 10 years (Barbose et al., 2014) as well as the increase in financing options for property owners installing PV, such as leased PV systems and other zero-money-down purchase options (SEIA & GTM, 2014).

As PV installations have proliferated, so has the number of transactions involving homes with PV (Hoen et al., 2013b). Because of this, the real estate sales and valuation communities have been working to enable a better understanding of the valuation of PV systems and green features more generally (Adomatis, 2014). For example, courses on the marketing and valuation of green features are available through the Appraisal Institute and the NATIONAL ASSOCIATION OF REALTORS® (NAR)[1]; green attributes for a multiple listing services data dictionary have been recommended by a working group of the NAR (2014); the Appraisal Institute has developed a "Residential Green & Energy Efficient Addendum" to capture green attributes during an appraisal[2]; PV Value®, a web-based tool specifically designed for the valuation of PV systems, has been developed (Klise et al., 2013); the National Home Performance Council and CNT Energy developed a blueprint to make energy improvements more visible in the real estate market (CNT Energy & NHPC, 2014); Fannie Mae, in its updated standards for conforming loans it will repurchase, now mentions homes with solar panels and the need to "adjust" the appraised value of the home if the market warrants it (Fannie Mae, 2014); and, finally, the Federal Housing Administration has proposed requirements for valuing "Special Energy Related Building Components" in its *Draft Single Family Housing Handbook*, which governs conforming loans for homes with PV systems (FHA, 2014).

Despite the activity around valuing (and marketing) PV homes, little research documents the premiums for these homes. Farhar and Coburn (2008) first documented the apparent increase in values for 15 PV homes inside a San Diego subdivision. This was later corroborated by strong empirical evidence from greater San Diego and Sacramento (Dastrup et al., 2012) and from a relatively large dataset of approximately 1,900 California PV homes (Hoen et al., 2011; 2013a; 2013b); these studies employed hedonic pricing models to estimate premiums. Finally, a case study of 30 PV homes that sold in the Denver metro area found evidence of premiums (Desmarais, 2013). Because the evidence that PV homes garner a premium has focused on a relatively small number of California homes and a few in Colorado, there is need for further evidence of premiums outside of California and even inside California. There is also a need to analyze transactions that occurred after the recent housing bubble, the period from which most previous data had been collected and analyzed (Hoen et al., 2011; 2013a; 2013b).

In most local markets, few PV home sales occur, thus appraisers and other real estate professionals (real estate agents, lenders, underwriters, etc.) often cannot compare similar PV and non-PV home sales to derive a PV premium. Because of this, valuation professionals often use other methods to value PV systems, including the income and cost methods (Adomatis, 2014; FHA, 2014). Hoen et al. (2013b) used hedonic (regression) modeling, employing similar methods as the sales-comparison approach, and found premiums larger than the contributory values generated with the cost and income approaches—a counterintuitive result. Possible reasons for this result include issues with the underlying dataset, which

[1] See, e.g., http://www.appraisalinstitute.org/education/education-resources/green-building-resources/ and http://www.greenresourcecouncil.org/.

[2] See http://www.appraisalinstitute.org/professional-practice/professional-practice-documents/new-residential-green-energy-efficient-addendum/.

included sales from homes with a very wide range of prices and sales that occurred largely during the housing boom. In addition to that California-based study, Desmarais (2013) compared the three methods in her analysis of 30 Colorado sales but did not use statistical tests. Therefore, additional comparison of the various methods—using a more recent dataset, statistical methods, and a broader group of transactions—would be a valuable contribution to the literature.

Other considerations are important as well. The gross installed costs (i.e., costs before state and federal incentives) of PV systems have declined steadily in recent years, while net costs (i.e., with incentives included) have remained fairly stable (Barbose et al., 2014). Examining premium changes over this period might indicate how the market responds to signals from gross and net costs. Moreover, over the same period, the housing market saw significant swings: the housing bubble, the subsequent crash, and then the recovery. Understanding whether observed PV premiums varied over this period would help illuminate how enduring these premiums might be. There also has been evidence that the new home market in California heavily discounted PV homes during the housing boom and bust (through 2009) in comparison to the premiums garnered by existing home sellers (Hoen et al., 2011; 2013a).[3] Therefore, examining how new home PV premiums fared in relation to existing home premiums within an expanded dataset would be of interest.

In addition, others have explored the existence of a green cachet, such as the "Prius effect" and other forms of "conspicuous (non)consumption," where buyers appear to pay more for a "green" item than they will save over its life in decreased energy costs (White, 1978; Kahn, 2007; Sexton, 2011). Dastrup et al. (2012) find larger PV premiums where more Prius hybrid vehicles are registered, which they use as a proxy for environmental leanings. This analysis concentrated on only the San Diego and Sacramento areas, thus analysis of a broader dataset is warranted.

Finally, previous literature suggests the need for more research on the market's depreciation of aging PV systems, especially for systems greater than 6 years old, which have not been well studied because of the immaturity of the PV market (Hoen et al., 2011; 2013a; 2013b). A clearer understanding of how the market depreciates PV systems would likely enhance appraisal techniques.

In summary, there are a number of gaps in the literature, each of which the present research seeks to address:

1. Are PV home premiums evident for a broader group of PV homes than has been studied previously both inside and outside of California and through 2013?
2. Are PV home premiums outside of California similar to those within California?
3. How do PV home premiums compare to contributory values estimated using cost and income methods?
4. How did the size of the premium change over the study period, as gross PV system prices decreased and during housing market swings?
5. Are premiums for new PV homes similar to existing PV home premiums?
6. Is there evidence of a "green cachet" for PV homes above the amount paid for each additional watt added?
7. How does the age of the PV system influence the size of the PV premium?

[3] These discounts, it was assumed, were offset by decreased marketing times (i.e., "sales velocity") for these homes, a priority for home builders as the market for new homes slowed and inventories increased (Dakin et al., 2008; Farhar and Coburn, 2008; SunPower, 2008).

It is important to clarify that this research focuses on only host-owned PV systems and therefore excludes third-party-owned systems, which, we recommend, should be the focus of future research.

The remainder of this report is organized as follows: Section 2 discusses our methodological approach; Section 3 details the data used for the analysis; and Section 4 presents the results, followed by a discussion of the results in Section 5 and conclusions in Section 6. An appendix detailing cost estimate preparation follows the references.

2. Methodological Approach

To examine the questions above, this research relies on a hedonic pricing model—the "Base Model"—against which a series of other models are compared. Those other models use a subset of the data (e.g., new or existing homes), an interaction term(s) (e.g., age of the PV system), or other variants to examine the various research questions and test the overall robustness of the results.

The basic theory behind the hedonic pricing model starts with the concept that a house can be thought of as a bundle of characteristics. When a price is agreed upon between a buyer and seller, there is an implicit understanding that those characteristics have value. When data from a number of sales are available, the average marginal contribution to the sales price of each characteristic can be estimated with a hedonic regression model (Rosen, 1974; Freeman, 1979; Sirmans et al., 2005). This relationship takes the basic form:

Sales price = f (home and site, neighborhood, and market characteristics)

"Home and site characteristics" might include, but are not limited to, the number of square feet of living area and the presence of a PV system. "Neighborhood" characteristics might include such variables as the crime rate and the distance to a central business district. Finally, "market characteristics" might include, but are not limited to, temporal effects such as housing market inflation/deflation.

2.1 Base Model

The "Base Model" to which other models are compared uses a relatively simple set of home and site characteristics: size of the home (i.e., square feet of living area); age of the home at the time of sale (in years); age of the home squared (in years); size of the parcel (in acres) up to 1 acre; and any additional acres more than 1 (in acres).[4] It also includes the presence and size of the PV systems. To control for neighborhood, we include a census block group fixed effect, which, in all cases, includes at least one PV home and one non-PV home.[5] Finally, market characteristics are accounted for by including a dummy variable for the quarter and year (e.g., 2013 Q2, 2009 Q1, etc.) in which the sale occurred. This model form was chosen for its relative parsimony, its high adjusted R^2, and its transparency.[6] It is estimated as follows:

$$\ln(\mathrm{P}_{\mathrm{itk}}) = \alpha + \beta_1(\mathrm{T}_{\mathrm{i}}) + \beta_2(\mathrm{K}_{\mathrm{i}}) + \sum_{\mathrm{a}} \beta_3(\mathrm{X}_{\mathrm{i}}) + \beta_4(\mathrm{PV}_{\mathrm{i}} \cdot \mathrm{SIZE}_{\mathrm{i}}) + \varepsilon_{\mathrm{itk}} \quad (1)$$

[4] Acres is entered into the model as a spline function using two variables, up to 1 acre (*acreslt1*) and any additional acres above 1 (*acresgt1*), to capture the different values of up to the first and additional acres of parcels in the sample. Therefore *acreslt1 = acres* if *acres* ≤ 1 and 1 otherwise, while *acresgt1 = acres*-1 if *acres* > 1 and 0 otherwise. Additionally, square feet and age squared are entered into the model in 1,000s to allow for easier interpretation of the coefficients.

[5] A census block group contains approximately 600 to 3,000 people. By including this fixed effect, and requiring each to contain at least one PV and one non-PV home, the PV estimates are, therefore, essentially a comparison of those two home types within the block group, while controlling for temporal and characteristic differences between them.

[6] Model choice for this work was based on extensive robustness model exploration in previous analysis (Hoen et al., 2011; 2013a; 2013b). Other models were explored but are not presented here. They include adding other home and site parameters such as number of bathrooms, condition of the home, and if a pool is present, all of which further limited the dataset but did not substantively affect the results. Similarly, instead of using a fixed effect for sale year and quarter, interacting sale year and, separately, sale quarter, with a geographic variable, such as county, to control for geographic variation in market inflation/deflation was explored with no change to the results.

where

P_{itk} represents the sale price for transaction *i*, in quarter *t*, in block group *k*,

α is the constant or intercept across the full sample,

T_i is the quarter *t* in which transaction *i* occurred,

K_i is the census block group *k* in which transaction *i* occurred,

X_i is a vector of *a* home and site characteristics for transaction *i*,

PV_i is a fixed-effect variable indicating a PV system is installed on the home in transaction *i*,

$SIZE_i$ is a continuous variable for the size (in kW) of the PV system installed on the home prior to transaction *i*,[7]

β_1 is a parameter estimate for the quarter in which transaction *i* occurred,

β_2 is a parameter estimate for the census block group in which transaction *i* occurred,

β_3 is a vector of parameter estimates for home and site characteristics *a*,

β_4 is a parameter estimate for the change in sale price for each kilowatt added to a PV system, and

ε_{itk} is a random disturbance term for transaction *i*, in quarter *t*, in block group *k*.

The parameter estimate of primary interest in this model is β_4, which represents approximately the marginal percentage change in sale price over the average sale price of the comparable set of non-PV homes within the same census block group, with the addition of each kilowatt of PV.[8] If differences in selling prices exist between PV and non-PV homes, we would expect the coefficient to be positive and statistically significant.

This model allows an examination of many of the research questions depending on the dataset that is used. If the full dataset is used, the first question can be answered. If a subset of the dataset is used, many of the other questions can be answered. For example, if homes within and outside California are used, the second question can be explored. Similarly, if the data are restricted to particular subsets of the study period (e.g., 2002–2007, 2008–2009, 2010–2011, or 2012–2013), the fourth research question could be examined. To explore if new or existing homes had similar premiums (the fifth question), the data could be restricted to those subsets. Finally, if only PV systems of particular ages were used, the seventh question could be answered. Therefore, almost all of the research questions can be answered using subsets of the data, leaving only the sixth question regarding green cachet, which requires a slightly altered model and will be discussed next, and the third question, which can use either the full dataset or subsets of the data but also requires calculations of comparison valuation estimates using the cost or income method.[9]

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[7] All references to the size of PV systems in this paper, unless otherwise noted, are reported in terms of direct-current watts or kilowatts under standard test conditions. A discussion of this convention is offered in Appendix A of Barbose et al. (2014).

[8] To be exact, the conversion to percent is actually EXP(β_4)-1, but the differences are often *de minimis*.

[9] Although the preferred method is to estimate a separate model using a subset of the data, which allows all of the controlling parameters to take different values for each subset, we also explored estimating models with a categorical variable for each of the subsets interacted with either the variable of interest only <u>or</u> both the variable of interest and the other controlling parameters, with no substantive change in the results.

2.2 Base Model Variation: Size of PV System Model

Although the Base Model and variations to the subsets of data allow examination of almost all the research questions, the sixth question requires a slightly altered model: the Size of PV System Model. If the market exhibits a green cachet, theoretically a fixed amount might be added to the value of a home with PV regardless of the size of that PV system. Therefore, for smaller systems, a premium expressed in dollars per installed watt would be larger than it would be for larger systems, representing a decreasing marginal premium for each watt added to a PV system. To examine decreasing marginal returns, a second-order polynomial is added, and therefore we estimate the following model:

$$\ln(\mathrm{P_{itk}}) = \alpha + \beta_1(\mathrm{T_i}) + \beta_2(\mathrm{K_i}) + \sum_{a}\beta_3(\mathrm{X_i}) + \beta_4(\mathrm{PV_i} \cdot \mathrm{SIZE_i}) + \beta_5(\mathrm{PV_i} \cdot \mathrm{SIZE_i}^2) + \varepsilon_{\mathrm{itk}} \qquad (2)$$

where

$SIZE_i^2$ is a continuous variable for the squared size (in kilowatts) of the PV system installed on the home prior to transaction *i*, and

β_5 is a parameter estimate for the change in sale price for each additional squared kilowatt added to a PV system, and all other variables are as shown in Equation (1).

The parameter estimates of primary interest in this model are β_4 and β_5. If decreasing marginal returns exist for increasing sizes of PV systems, we would expect the β_4 coefficient to be positive and larger and the β_5 coefficient to be negative and smaller.

2.3 Model Summary

Combining the Base Model, the use of various subsets of data, and the Size of PV System Model allows examination of the seven research questions listed in Section 1. The full set of research questions, models, and sample sets are described in Table 1.

Table 1: Summary of Research Questions, Models, and Sample Sets

Research Question	Equation	Model Name	Sample Set(s)
1. Are PV home premiums evident for a broader group of PV homes than has been studied previously both inside and outside of California and through 2013?	Equation (1)	Base Model	All Data
2. Are PV home premiums outside of California similar to those within California?	Equation (1)	Location Models	CA vs. Non-CA Homes
3. How do PV home premiums compare to contributory values estimated using the cost and income methods?	Equation (1)	Various Models	All Data, or Subsets of Data, But Compare Results To Income and Cost Methods
4. How did the size of the premium change over the study period, as gross PV system prices decreased and during housing market swings?	Equation (1)	Year of Sale Models	Subsets of Years in Sample Period (e.g., Pre-'08; 08-09, 10-11, Post 11)
5. Are premiums for new PV homes similar to existing PV home premiums?	Equation (1)	Home Type Models	New vs. Existing Homes
6. Is there evidence that there is a "green cachet" for PV homes over and above the amount paid for each additional watt added?	Equation (2)	Size of PV System Model	All Data
7. How does the age of the PV system influence the size of the PV premium?	Equation (1)	Age of PV System Models	Subsets of PV System Ages (e.g., < 2 years; 2-4; 5-6; 7-14 years)

2.4 Robustness Models

We also explore the robustness of our results with two alternative model specifications.

2.4.1 PV Only Model

It has been well documented that PV homes often have a suite of additional energy-efficiency (EE) features (CPUC, 2010; Hee et al., 2013; Langheim et al., 2014). Further, it has been theorized that PV home owners, who have the financial resources to install a PV system, might also make other (non-EE) upgrades, such as a new kitchen or bathroom, or may alternatively replace their roof contemporaneously with PV system installation. Therefore, the premium estimated from Equation (1) could also include effects of EE and other features and therefore overestimate the effect related to PV alone.

To test this, PV homes are compared to other PV homes based on system size. While the Base Model estimates a difference in sales prices between PV and non-PV homes, all else being equal, the PV Only Model compares the difference between PV homes and PV homes based on differences in their PV system size, all else being equal. Assuming all PV homes have the same frequency of EE and other features among them, an effect free of those influences can be estimated and then compared to the results in Equation (1).[10]

One complication of this model concerns possible collinearities of the block group fixed effects and PV when a single or small number of PV homes exist within a single block group. While in the Base Model the use of the block group fixed effect is appropriate, because each contains at least one PV and one non-PV home, in the PV Only Model collinearities might exist for block groups with only one or a few PV homes, or those that might have only similarly sized PV systems. In those block groups, the fixed effect might absorb the contributory effect of the PV variable. Therefore, this model uses the county as the fixed effect and is restricted to counties that have two or more PV homes, to allow more heterogeneity between the PV homes within the fixed effect delineation and therefore less collinearity between them and the PV variable; otherwise the model is identical to Equation (1).[11]

2.4.2 Repeat PV Home Model

A common concern with hedonic modeling, such as the Base Model, is that a suite of home and site characteristics are not controlled for, which could be driving the results. These omitted variables could include any manner of home features, such as granite countertops, a newly renovated basement, and Jacuzzi, as well as neighborhood features, such as location on a cul-de-sac, a scenic vista, or location next to a major road. These variables could be present for PV and non-PV homes. Although the assumption is that these unobserved features are randomly distributed among PV and non-PV homes, and therefore are not correlated with the presence of PV, this might not be the case. This can be tested using the Repeat PV Home Model.

The Base Model estimates a difference in sales prices between PV and non-PV homes all else being equal, but the Repeat PV Home Model compares sales prices of homes before they had PV installed to prices of the same homes after they had PV installed. Because many of the characteristics controlled for

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[10] It is at least conceivable that EE and other features are correlated with PV system size, with a larger PV system correlated with more EE and other features. We expect, however, that this would likely be more correlated with the size of the home, which is controlled for in this and the Base Model.

[11] Although not shown here, using county fixed effects in the Base Model in place of block group fixed effects has no apparent effect on the premium estimate, and therefore this PV Only Model can be compared directly to the Base Model results. Also, this model assumes a tradeoff with being able to compare PV homes to PV homes, and therefore controlling for the unobservables associated with PV, versus controlling for the unobservables associated with the localized neighborhood effects that the block group fixed effect controls for.

in the Base Model are held constant in the Repeat PV Home Model, such as block group and size of the home and parcel, they do not need to be controlled for.[12] Therefore, the following greatly simplified model can be estimated:

$$\ln(\mathrm{P_{itk}}) = \alpha + \beta_1\left(\mathrm{T_i}\right) + \sum_{\mathrm{a}} \beta_2\left(\mathrm{X_i}\right) + \beta_3\left(\mathrm{PV_i} \cdot \mathrm{SIZE_i}\right) + \varepsilon_{\mathrm{itk}} \tag{3}$$

where

X_i is a vector of age of the home and age squared for transaction *i*,

β_2 is a vector of parameter estimates for age and age squared,

β_3 is a parameter estimate for the change in sale price for each additional kilowatt added to a PV system, and all other variables are as defined in Equation (1).

[12] Ideally we would have information on the size of the home as of the first sale and the second sale, but we only have information from the most recent assessment and therefore can only assume that it has not changed between sales. If it has changed, however, it would have likely increased the home's value, thus the second sale would include the increase in related value. If this were the case, the PV premium would capture this increase. Our results do not exhibit this increase, so it is assumed that the Repeat PV Home Model results are free of this influence.

3. Data Preparation and Summary

This section describes the underlying data used for this analysis—including PV home and non-PV home data, cost estimates, and income estimates—followed by a data summary.

3.1 PV and Non-PV Home Data

For the Tracking the Sun (TTS) report series (e.g., Barbose et al., 2013), Lawrence Berkeley National Laboratory was provided a set of approximately 150,000 host-owned (i.e., not third-party-owned) PV home addresses by various state and utility incentive providers, along with information on PV system size, date the incentive was applied for, date the system was put into service, and the average tilt and azimuth of the PV system, where available.[13] These data span the years 2002–2012 and stretch across eight states: California, Connecticut, Florida, Massachusetts, Maryland, North Carolina, New York, and Pennsylvania.[14]

These PV home addresses were matched to addresses maintained by CoreLogic,[15] which CoreLogic aggregates from county-level assessment and deed recorder offices. Once the addresses were matched, CoreLogic provided, when available, real estate information on each of the PV homes as well as similar information on approximately 200,000 non-PV homes located in the same (census) block group as the PV homes. The data for both of these sets of homes included, but were not limited to:

- address (e.g., street, street number, city, state and zip+4 code);
- most recent and previous (if applicable) sale date and amount;
- home characteristics (e.g., acres, square feet of living area, bathrooms, pool, and year built[16]);
- assessed value of land and improvements;
- parcel land use (e.g., commercial, residential);
- structure type (e.g., single-family residence, condominium, duplex); and,
- x/y coordinates.

These data were cleaned to ensure all data were populated and appropriately valued.[17] Using these data, along with the PV incentive provider data, we determined if a home sold after a PV system was installed, significantly reducing the usable sample because the majority of PV homes have not yet sold. We also culled a subset of these data for which previous sale information was available and for which a PV system

[13] For a full discussion of how these data are obtained, cleaned, and prepared, see Barbose et al. (2013).

[14] The TTS dataset also included data on PV homes from other states, including Illinois, New Mexico, New Hampshire, Oregon, Texas, and Vermont. However, after matching to the CoreLogic sales transaction dataset and cleaning to ensure all the homes that did sell had data that were fully populated and appropriately signed, no PV home sales existed from these states.

[15] More information about this product can be obtained from http://www.corelogic.com/.

[16] Year built, along with previous sales information and a CoreLogic-provided flag on new homes, allowed for a determination of whether the home was newly built or existing at the time of sale.

[17] Because the CoreLogic data sometimes are missing or miscoded, the cleaning and preparation of these data were extensive and therefore not detailed here, but the process included the following screens: sale price greater than $165,000 and less than $900,000, size of the home between 1,000 and 5,000 square feet, sale price per square foot between $8 and $800, sale year after 2001, and size of the parcel between 0.05 and 10 acres.

had not yet been installed as of this previous sale. These "repeat sales" were used in the Repeat PV Home Model described in Section 2.4.2 .

Ideally, for each PV home transaction, we would have a set of identical (i.e., all else being equal) non-PV home transactions for comparison. This theory underlies the comparable-sales method used by appraisers and other valuation professionals (Adomatis, 2014), where comparable homes are chosen that are as similar as possible, and then adjustments are made to account for the observable differences.

To emulate the comparable-sales method, we employed the Coarsened Exact Matching (CEM) process (King et al., 2010), which finds a matched sample of PV and non-PV homes that are statistically equal on their covariates.[18] The covariates include being within the same block group, selling in the same year, and having similar values for size of the home, age of the home, size of the parcel, and ratio of assessed value of land to total assessed value.[19] This procedure results in a reduced sample of homes to analyze, but biases related to the selection of PV and non-PV homes are minimized.[20] The unmatched dataset has 173,982 non-PV homes and 5,373 PV homes, while the matched dataset—the one used for the analysis—has 18,871 non-PV homes and 3,951 PV homes. Various models, as described above, use subsets of the PV homes and therefore will need matching non-PV homes. For most of the subsets this is straightforward, because we divide the PV and non-PV homes along the same lines used for the CEM matching, such as whether the homes are located in California or the rest of the United States, or if they are newly built homes or existing. For the Age of PV Systems models, though, there is not an intuitive division for the non-PV homes, because age of the PV system was not used for matching. Therefore, for these models the CEM process was employed again for each set of PV homes. The resulting matched non-PV homes were not necessarily mutually exclusive between the sets of PV homes, but most importantly each block group contained at least one PV home and one non-PV home.

3.2 Cost Estimates

In this analysis, as in previous studies (Hoen et al., 2011; 2013a; 2013b), we compare the market premiums we find using our Base Model and alternative models to cost and income contributory-value estimates to illuminate how the market might be reacting to various signals. A cost estimate refers to the cost to replace an asset with a new equivalent. Appraisal theory posits that cost estimates are likely important price signals in the marketplace, and market values normally should not exceed the replacement cost of an asset. This might mean, for example, that a buyer of a PV system already installed on a home is not willing to pay more for it than the cost of a new system (i.e., its replacement cost).

For this analysis, we prepared two sets of cost estimates: gross costs and net costs, the detailed preparation of which is described in Appendix A. In this context "net" implies a cost after federal and state tax incentives and state rebates are factored in, while "gross" estimates do not factor these incentives

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[18] The procedure used, as described in the referenced paper, is CEM in Stata, available at: http://ideas.repec.org/c/boc/bocode/s457127.html. Because this matching process excludes non-PV homes that are without a statistically similar PV match (and vice versa), a large percentage of homes (approximately 90% of non-PV and 33% of PV) are *not* included in the resulting dataset. Pre-matching Multivariate Distance (0.95) compares favorably to post-matching Distance (0.82).

[19] The assessed value of land to total value ratio is expected to capture the unexplained within-block group locational variation that often is present, for example, due to being on a quiet road, abutting a park, or being on the waterfront. Assessed values, it is assumed, are consistently applied within the block group.

[20] Although the preferred model is one with a matched dataset, the Base Model was also estimated using the unmatched dataset, which results in a slightly higher estimated premium. We attribute this change to the heterogeneity of the unmatched PV and non-PV homes and the fact that the unmatched non-PV homes have lower-valued unobserved characteristics.

in.[21] We distinguish between the two because the ability of the homeowner to benefit from the incentives depends somewhat on their tax obligations. For example, the federal incentive for PV comes in the form of a reduced federal tax obligation (formally known as the Internal Revenue Code Section 25D: Residential Energy Efficient Property Credit). If a homeowner expects to pay very little in taxes (e.g., because they have a mortgage and very little taxable income), then the federal tax incentive might not be realized immediately (it can be carried over year to year). A similar scenario exists if state tax incentives are present. More generally, incentive availability changes with time, so home buyers may have some uncertainty about what incentives might be available, and their value. Because of these different scenarios, it is not immediately clear if the market would fully capitalize the incentives calculated as part of the net cost, thus net cost can serve as the low cost estimate for our purposes. Similarly, we expect that buyers would not be willing to pay more than the gross cost, which thereby serves as the high cost estimate.

Finally, in previous analyses, we prepared cost estimates depreciated using a straight-line 20-year depreciation schedule, assuming this would be roughly equivalent to the usable life of a PV system (Hoen et al., 2011; 2013a; 2013b). For the present analysis we use, instead, the un-depreciated amount. In doing so, we do not presuppose how the market depreciates PV systems and/or the replacement costs of those systems; rather, we allow the market to dictate how best to depreciate their values, if at all. This is the customary approach of appraisers (Adomatis, 2014).

3.3 Income Estimates Using the PV Value Algorithm

As with cost estimates, appraisal theory posits that income estimates—a discounted stream of income derived from an asset over time, such as rent—are likely important price signals in the marketplace. For example, an apartment seller might not be willing to sell a property for significantly less than the present value of rent (minus costs) it receives for that property. Similarly, the buyer and seller of a home with a PV system might use the discounted value of the system's energy cost savings as a key factor in determining any PV premium.

For each of the PV homes in our sample, we prepared data to estimate the present value of energy bill savings (income estimates) using the size and age of the system, the zip code of the home, and the estimated tilt and azimuth of the system.[22] These inputs were fed through the PV Value algorithm (Klise et al., 2013) to produce estimates for utility bill savings for a similarly sized system as of the time of sale.[23]

The algorithm is outlined by Klise and Johnson (2012), and the inputs for our current research effort are based on the following: the expected energy output of the PV system after the sale date and assuming a life span not greater than the warranty life of the panels (usually 25 years); an electricity retail rate at the time of sale and an escalation of the rate similar to the historical escalation over the previous years; discount rates as of the time of sale, which, for the purposes of this study, are equivalent to 100 basis points above the 30-year, fixed mortgage, 60-day Fannie Mae lock-in rate at the time of sale; a system

[21] Other incentives exist, such as state renewable energy credits, feed-in tariffs, and performance-based incentives, but these are rare throughout the analysis dataset and therefore are not considered. Understanding how to value them appropriately should be the subject of future research, however, because their value can be significant in certain circumstances.

[22] Because tilt and azimuth were not available for all PV systems (the data were not provided during the TTS data-collection effort), they were estimated via a cascading approach, based on systems with those data in the same census block group if available, then, if not available, census tract or, finally, county when needed.

[23] The estimation procedure produces a set of low, average, and high estimates of the present value of the expected energy output, based on a risk premium of 50, 100, and 200 basis points, respectively. Only the average value was used for this analysis.

direct current-to-alternating current derate factor of 0.77%; a module degradation factor of 0.5% per year; and an expected inverter replacement at 15 years. Tiered rates, which are prevalent in California, are not considered here, but instead an average zip-code level rate is used, as is the default for PV Value. We return to this issue in Section 5, where we discuss results from the model estimation in comparison to the income estimates.

The descriptions of the income estimation procedure are contained elsewhere (Klise and Johnson, 2012; Appendix A in Hoen et al., 2013b; Klise et al., 2013) and therefore are not detailed here.

3.4 Data Summary

The final dataset includes 22,822 transactions, consisting of matched PV (n = 3,951) and non-PV (n = 18,871) homes. This full matched dataset is composed of transactions occurring across eight states (Table 2) from 2002 to 2013 (Table 3), with the vast majority in California. All PV systems in this dataset are homeowner owned as opposed to third-party owned (leased or under a power-purchase agreement).

Table 2: Frequency Summary of PV and Non-PV Homes by State

State	Non-PV Homes	PV Homes	Total
CA	18,207	3,828	22,035
FL	317	25	342
Mid-Atlantic Region: MD, NC, PA	288	77	365
Northeast Region: CT, MA, NY	59	21	80
Total	18,871	3,951	22,822

Table 3: Frequency Summary of PV and Non-PV Homes by Sale Year

Sale Year	Non-PV Homes	PV Homes	Total
2002	107	18	125
2003	196	31	227
2004	238	53	291
2005	197	56	253
2006	348	64	412
2007	818	242	1,060
2008	1,251	453	1,704
2009	1,762	429	2,191
2010	2,751	504	3,255
2011	3,341	642	3,983
2012	3,928	694	4,622
2013	3,934	765	4,699
Total	18,871	3,951	22,822

Summary statistics for the PV and non-PV homes are shown, respectively, in Table 4 and Table 5. The mean sale price (*sp*) of the PV homes in the sample is $473,373 and ranges from a minimum of $165,500 to a maximum of $899,500. The average PV home in the sample has 2,334 square feet of living area (*sfla*), is located on a parcel of 0.45 acres (*acres*), and was 17 years old (*age*) when it sold in 2010 (*sy*).[24] It has a 3.6-kW PV system (*size*), which was installed 2.7 years before the home was sold (*pvage*). The gross installed cost for a similarly sized PV system in the same county at the time of sale was $6.90/W (*grosscost*), while the net cost (after incentives) was $4.14/W (*netcost*). The present value of the stream of energy produced by the PV system, as calculated by the PV Value algorithm, is $2.93/W (*income*). PV systems in the sample range in size from 0.1 kW to 14.9 kW, with a median of 2.8 kW (*size*). The age of the PV systems at the time of sale ranges from new to more than 13 years, with a median of 2.2 years (*pvage*). For the 18,871 non-PV homes, we find a mean sale price of $456,378, which is $16,995 lower than that of the matching PV homes. The average non-PV home is slightly smaller than the average PV home (2,319 square feet), occupies a smaller parcel (0.41 acres), and is equivalent in age. The dataset contains 7,480 newly built homes and 15,342 existing homes, of which 1,444 and 2,507, respectively, are PV homes.

Table 4: Summary Statistics for All PV Homes

variable	description	N	mean	sd	min	median	max
sy	year of sale	3951	2010	2	2002	2011	2013
syq	year and quarter of sale (yyyyq)	3951	20103	23	20021	20111	20134
sp	price of sale (dollars)	3951	$ 473,373	$ 196,451	$ 165,500	$ 433,000	$ 899,500
lnsp	natural log of sale price	3951	12.98	0.43	12.02	12.98	13.71
sfla	living area (square feet)	3951	2,334	702	1,006	2,244	4,981
sfla1000	living area (in 1000s of square feet)	3951	2.3	0.7	1.0	2.2	5.0
acres	size of parcel (in acres)	3951	0.45	0.95	0.05	0.18	9.99
age	age of the home at time of sale (years)	3951	17	21	(2)	7	100
agesq1000	age of the home squared (in 1000s of years)	3951	0.7	1.3	0	0.0	10.0
pv	if the home has a PV system (1 if yes)	3951	1	-	1	1	1
size	size of the PV system (kilowatts)	3951	3.6	2.0	0.1	2.8	14.9
pvage	age of the PV system at time of sale (years)	3951	2.7	2.9	(0.5)	2.2	13.4
income	average PV Value estimate ($/watt)	3951	$ 2.93	$ 0.57	$ 1.18	$ 2.92	$ 4.98
netcost	net cost estimate ($/watt)	3951	$ 4.14	$ 0.93	$ 1.07	$ 4.04	$ 7.95
grosscost	gross cost estimate ($/watt)	3951	$ 6.90	$ 1.50	$ 3.15	$ 6.92	$ 11.83

Table 5: Summary Statistics for All Non-PV Homes

variable	description	N	mean	sd	min	median	max
sy	year of sale	18871	2010	2	2002	2011	2013
syq	year and quarter of sale	18871	20103	23	20021	20112	20134
sp	price of sale (dollars)	18871	$ 456,378	$ 197,004	$ 165,500	$ 413,000	$ 899,500
lnsp	natural log of sale price	18871	12.94	0.44	12.02	12.93	13.71
sfla	living area (square feet)	18871	2,319	714	1,001	2,200	4,990
sfla1000	living area (in 1000s of square feet)	18871	2.3	0.7	1.0	2.2	5.0
acres	size of parcel (in acres)	18871	0.41	0.86	0.05	0.18	9.8
age	age of the home at time of sale (years)	18871	17	21	(2)	8	100
agesq1000	age of the home squared (in 1000s of years)	18871	0.7	1.3	0	0.1	10.0
pv	if the home has a PV system (1 if yes)	18871	0	0	0	0	0

[24] Negative values for the minimum age of a home (e.g., -2) apply to newly built homes in the sample and occur when the sale date is prior to the date of home completion, as might occur when a home is purchased on spec. Similarly, for PV system age, a negative minimum value occurs when the completion date of the PV system occurred before the home sale date, which happens sometimes for new homes. Additionally, although acres is shown in the tables, it is entered in the model as a spline function of up to 1 acre <u>and</u> any additional acres above 1 (see Section 2.1). Finally, age of the home squared is not shown in the tables.

4. Results

This section presents results, starting with the Base Model, which addresses the first research question: Are PV home premiums evident for a broader group of PV homes than has been studied previously? This is followed by results for the various other models, which explore the remainder of the research questions (Table 1 shows the full set of questions), and the two robustness models.

4.1 Base Model Results

The Base Model estimates, over the entire dataset, the marginal return to each kilowatt of PV installed on a home as defined in Equation (1). The model is summarized in Table 6, with full results shown in Table 7.[25] Overall the model performs well, with an adjusted R^2 of 0.92, indicating that it captures approximately 92% of the price variation within the 22,822 home sales located in the 1,830 census block groups that make up the sample.

Table 6: Base Model Results Summary

Total *n*	22,822
PV *n*	3,951
Non-PV *n*	18,871
Adjusted R^2	0.92
Dependent Variable	lnsp
Block Group Fixed Effects	1,830

The full set of results is shown in Table 7. The controlling variables that account for size (*sfla1000*) and age of the home (*age, agesq1000*) and size of the parcel (*lt1acres*, for each acre up to 1, and *gt1acres*, for each acre over 1) are all highly statistically significant (i.e., *p*-value < 0.001). The model indicates that, in our sample, each additional 1,000 square feet adds approximately 21% to the selling price, while each acre up to 1 adds 39% and each additional acre beyond 1 adds 3%.[26] Each year a home ages initially takes approximately 0.7% off its value, but this annual value reduction declines with time, and homes over approximately 60 years in age appreciate in value as they age.[27] Using the fourth quarter of 2013 as the reference category, in our sample, prices start approximately 44% lower (Q1 2002) and then increase to approximately 20% higher (2005), before falling again to lows in early 2012 and then increasing to levels present in late 2013. This rise, fall, and eventual recovery are entirely consistent with the national trends in housing prices.[28] Combined, the various controlling characteristics are appropriately signed and leveled based on our expectations, giving us confidence that the model is acting appropriately and adequately capturing price differences across the sample.

Turning to the variable of interest, *pv*size*, the model estimates that, for each kilowatt of installed PV, sale prices increase by 0.91%, and this estimate is highly statistically significant (*p*-value < 0.001).

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[25] All models are estimated in Stata using *areg*, with block groups as the absorbed fixed effect and with robust standard errors.

[26] The exact percentage interpretation of coefficients in a semi-log model is as follows: exp(coefficient)-1, but the differences in this context are *de minimis*.

[27] Approximately 60 years is determined by dividing the age coefficient by the first derivative of the square term's (*agesq*) coefficient.

[28] As noted previously, we also explored interacting the year of sale with the county, to capture regional price trends, with no substantive change to the results.

Accordingly, at the 95% confidence interval, average price increases are estimated to vary between approximately 0.78% and 1.05% per kilowatt, a relatively precise estimate. This sample of approximately 4,000 PV homes shows a clear premium for each kilowatt of PV installed above the sale prices of comparable non-PV homes.

By using the mean sale price (in dollars) for non-PV homes, we can convert this percentage estimate into dollars per watt.[29] Doing so leads to an estimated premium of $4.18/W, with a 95% confidence interval of +/- $0.62/W, which corresponds to a premium of approximately $15,000 for an average-sized system of 3.6 kW. From Table 4, we see that, for these PV homes, the mean gross cost estimate is $6.90/W, while the net cost estimate is $4.14/W, and the average PV Value (income) estimate is $2.93/W. Therefore, the premium in our sample is almost identical to the average net cost for a similarly sized system as of the time of sale, is approximately $2.70/W less than the gross cost, and is $1.25/W higher than the PV Value income estimate.

4.2 Base Model Variations Using Subsamples

As shown in Table 1, many of the research questions can be investigated using variations of the Base Model that use subsamples of the data in place of the full sample. The following sections describe those model sets and include: Location Models, for California and the rest of the United States; Home Type Models, for newly built and existing homes; Age of PV System Models; and Year of Sale Models.

4.2.1 Location Model Results

Our Location Models estimate premiums for either the subset of homes located in California or those located in the rest of the United States; Table 8 shows the results, along with results for the Home Type Models (which are discussed in the next subsection).[30] Also shown in the table, for reference purposes, are the results for the Base Model using the full sample. Results shown for each model include the *pv*size* coefficient, standard error, and *p*-value; the mean non-PV home sale price; the $/W premium and its 95% confidence interval; and estimates for the net and gross costs and PV Value income. Finally, for each model, the table shows the total, PV, and non-PV sample sizes; the adjusted R^2; and the number of block groups represented by the sample.

The coefficient for the variable of interest for the California subsample is 0.0091, which is highly statistically significant and equates to a $4.21/W premium and a 95% confidence interval of +/- $0.64/W. Not surprisingly, the PV premium is very close to the premium estimated for the full sample, because California PV homes make up 97% of that sample. The PV premium can be compared to the net, gross, and PV Value estimates of $4.16/W, $6.94/W, and $2.95/W, respectively.

For homes outside of California where we have data (in Connecticut, Florida, Massachusetts, Maryland, North Carolina, New York, and Pennsylvania), the PV premium is estimated to be $3.11/W and highly statistically significant (*p*-value < 0.01), but with a 95% confidence interval of $2.33. This indicates that, in this broader sample of homes, a premium for PV homes is evident, but that the smaller sample of homes outside California does not allow for a very precise estimate of the effect size. The estimated premium is very similar to the net cost estimate for this subset of $3.09/W, and it is not statistically different from the premium estimated for California homes.

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[29] The formula for doing so is: $/W premium = ((exp (*pv*size* coefficient)-1)* *mean sale price in dollars for non-PV homes*)/1,000.

[30] For brevity, only the variable of interest is shown for the remainder of the report. Results for the controlling variables were similarly signed and leveled across the various models as they are in the Base Model. The full set of results is available upon request.

Table 7: Base Model Results

Variable	Coefficient	Standard Error	*t* Statistic	*p*-value	- 95% CI	+ 95% CI
intercept	12.498	0.016	758.00	0.000	12.465	12.530
pv*size	0.0091	0.0007	13.12	0.000	0.0078	0.0105
sfla1000	0.213	0.004	51.70	0.000	0.205	0.221
lt1acre	0.386	0.028	13.73	0.000	0.331	0.441
gt1acre	0.029	0.006	5.08	0.000	0.018	0.040
age	-0.007	0.001	-7.86	0.000	-0.008	-0.005
agesq1000	0.056	0.009	6.63	0.000	0.040	0.073
syq						
20021	-0.441	0.034	-13.100	0.000	-0.507	-0.375
20022	-0.379	0.038	-10.060	0.000	-0.453	-0.305
20023	-0.375	0.036	-10.480	0.000	-0.446	-0.305
20024	-0.306	0.073	-4.220	0.000	-0.448	-0.164
20031	-0.087	0.056	-1.560	0.118	-0.196	0.022
20032	-0.077	0.037	-2.050	0.040	-0.150	-0.004
20033	-0.025	0.038	-0.670	0.505	-0.100	0.049
20034	-0.035	0.037	-0.950	0.343	-0.108	0.037
20041	0.001	0.031	0.040	0.972	-0.060	0.062
20042	0.095	0.021	4.430	0.000	0.053	0.137
20043	0.121	0.024	5.120	0.000	0.075	0.168
20044	0.124	0.028	4.340	0.000	0.068	0.179
20051	0.137	0.047	2.910	0.004	0.045	0.230
20052	0.204	0.039	5.170	0.000	0.127	0.281
20053	0.164	0.062	2.640	0.008	0.042	0.285
20054	0.202	0.038	5.340	0.000	0.128	0.276
20061	0.159	0.021	7.710	0.000	0.119	0.200
20062	0.163	0.021	7.900	0.000	0.123	0.204
20063	0.160	0.022	7.300	0.000	0.117	0.203
20064	0.071	0.022	3.240	0.001	0.028	0.114
20071	0.162	0.017	9.700	0.000	0.129	0.195
20072	0.124	0.020	6.170	0.000	0.085	0.163
20073	0.074	0.016	4.580	0.000	0.042	0.106
20074	0.002	0.018	0.100	0.919	-0.034	0.038
20081	0.022	0.016	1.360	0.175	-0.010	0.054
20082	-0.005	0.013	-0.380	0.707	-0.031	0.021
20083	-0.050	0.014	-3.690	0.000	-0.077	-0.023
20084	-0.066	0.014	-4.630	0.000	-0.094	-0.038
20091	-0.113	0.014	-8.070	0.000	-0.141	-0.086
20092	-0.116	0.012	-9.800	0.000	-0.139	-0.092
20093	-0.124	0.012	-10.610	0.000	-0.147	-0.101
20094	-0.120	0.012	-9.700	0.000	-0.144	-0.096
20101	-0.121	0.013	-9.030	0.000	-0.147	-0.095
20102	-0.124	0.012	-10.750	0.000	-0.147	-0.102
20103	-0.144	0.012	-11.660	0.000	-0.168	-0.120
20104	-0.171	0.012	-14.070	0.000	-0.194	-0.147
20111	-0.173	0.011	-15.170	0.000	-0.196	-0.151
20112	-0.189	0.011	-17.360	0.000	-0.211	-0.168
20113	-0.190	0.011	-17.040	0.000	-0.212	-0.168
20114	-0.205	0.011	-18.360	0.000	-0.227	-0.183
20121	-0.212	0.011	-19.000	0.000	-0.234	-0.190
20122	-0.176	0.012	-15.180	0.000	-0.199	-0.153
20123	-0.154	0.011	-13.660	0.000	-0.176	-0.132
20124	-0.123	0.012	-10.220	0.000	-0.147	-0.099
20131	-0.090	0.010	-9.480	0.000	-0.109	-0.072
20132	-0.038	0.009	-4.150	0.000	-0.056	-0.020
20133	-0.009	0.009	-1.000	0.317	-0.027	0.009
20134			--- omitted ---			

Table 8: Location and Home Type Model Results[31]

	All Homes	Location: California	Location: Rest of US	Home Type: New Homes	Home Type: Existing Homes
PV Premium Estimates					
PV*Size Coefficient	0.0091	0.0091	0.0085	0.0084	0.0094
PV*Size Standard Error	0.0007	0.0007	0.0032	0.0012	0.0008
PV*Size *p*-value	*0.000*	*0.000*	*0.009*	*0.000*	*0.000*
Mean Sale Price Non-PV ($)	$ 456,378	$ 459,366	$ 364,854	$ 422,001	$ 476,124
PV Premium ($/watt)	$ 4.18	$ 4.21	$ 3.11	$ 3.58	$ 4.51
95% CI ($/watt)	$ 0.62	$ 0.64	$ 2.33	$ 1.00	$ 0.71
Contributory Value Estimates					
PV Value - Income ($/watt)	$ 2.93	$ 2.95	$ 2.15	$ 3.04	$ 2.86
Net Cost ($/watt)	$ 4.14	$ 4.16	$ 3.09	$ 3.85	$ 4.29
Gross Cost ($/watt)	$ 6.90	$ 6.94	$ 5.64	$ 7.34	$ 6.65
Model Info					
Total *n*	22,822	22,035	787	7,480	15,342
PV *n*	3,951	3,828	123	1,444	2,507
Non-PV *n*	18,871	18,207	664	6,036	12,835
Adjusted R^2	0.92	0.93	0.88	0.97	0.91
Dependent Variable	lnsp	lnsp	lnsp	lnsp	lnsp
Block Group Fixed Effects *n*	1,830	1,721	109	155	1,766

4.2.2 Home Type Model Results

Dividing the data by the type of home, specifically whether the home was newly built or existing at the time of sale, allows examination of the differences between these subgroups. In previous analyses, premiums for existing homes were found to be significantly larger than those for newly built homes, but the sample used was smaller, only for homes in California, only extended through 2009, and included homes with sales prices up to almost $3 million (Hoen et al., 2011; 2013a). The present analysis enables a reexamination of this question by using a sample that is larger, more broadly distributed geographically, has more recent data, and uses homes no more expensive than $900,000.

The results from the Home Type Models that used the new and existing home subsamples are shown in Table 8. New homes have a premium of $3.58/W, while existing homes have a premium of $4.51/W, a difference of approximately $1/W. Both estimates are highly statistically significant (*p*-values < 0.001) by themselves, but they are not statistically different from each other (difference in coefficients = 0.001, *p*-value = 0.46; not shown in table). Therefore, we are unable to uncover a difference in premiums between those subgroups with the larger, more geographically diverse and recent dataset. Nonetheless, the differences between these two sets of estimates mimic the different net costs, which are higher for existing homes than for newly built homes.

4.2.3 Age of PV System Model Results

Dividing the full sample into subsamples consisting of four quartiles based on PV system age (0.5–2.4 years, 2.4–3.8 years, 3.8–5.9 years, and 5.9–14 years) allows us to explore if the market accounts for PV system age when valuing PV systems. For this set of quartiles, only existing homes are used, because all

[31] Here, as in other results tables, the numbers of block groups for subsets of data do not always sum to 1,830. This occurs when the block groups are not mutually exclusive between the subsets, e.g., with new or existing homes.

newly built homes have PV systems that are also new. Table 9 contains the results for the full set of existing homes and the four other quartile models. Each of the four quartile models uses a different set of PV homes and a set of non-mutually exclusive CEM matched non-PV homes, to which the PV homes are compared.[32]

The coefficients for each progressively older subset of PV systems are monotonically ordered, going from 0.0123 for the systems 0.5–2.4 years old to 0.0055 for systems 5.9–14 years old. These translate into premiums of $5.90/W for the newest systems and $2.60/W for the oldest systems, with relatively stable 95% confidence intervals of approximately $1.40/W and somewhat decreasing cost and income estimates. Clearly home buyers and sellers place greater value on newer systems than on older systems, all else being equal. Although not shown here, additional models were estimated with additional older age groups (e.g., 10–14 years), but the confidence intervals around those estimates increased such that the results were not any more revealing than what is presented here. In none of the models, however, did we find an estimate close to zero. This seems to indicate that, as systems age, their value flattens out, but additional analysis in future years is needed to understand this trend better.[33]

Finally, it appears that the premiums, as systems age, start well above what would be predicted by the net cost estimates for young systems and then fall well below what would be predicted by the net cost estimates for older systems. This is an artifact of how the net cost estimates are calculated. As discussed in Section 3.2 the cost estimates are prepared without any depreciation and therefore are estimates of a new system. Of course new systems likely would not have the same value as otherwise identical older systems, but knowing the correct amount of depreciation to apply to these estimates is beyond the scope of this work.

[32] As described above, because the characteristics on which the PV homes are matched to the non-PV homes are exclusive of PV system age, the set of non-PV homes (and the block groups in which they are located) are not mutually exclusive across the models, but the same rules apply to these subsets in that for each block group that contains a PV home at least one matched non-PV home is present.

[33] Additionally, we calculated a linear estimate of age of PV interacted with PV system size, which was, not surprisingly, negative and highly statistically significant. Although this reaffirms that increasing age of PV systems is highly correlated with lower premiums, by its very nature it implies that PV systems lose 100% of their value at some point in time. This was calculated to be about 13 years, but it is at the end of our dataset and is not borne out in other tests (e.g., bins shown above, polynomial interactions, and additional binning for older systems). Therefore, we conclude that older systems are of lower value, but not of no value, at least given the age distribution of 0 to 14 years contained in the sample.

Table 9: Age of PV System Model Results

	Existing Homes		Age of PV System Groups 0.5-2.4	2.4-3.8	3.8-5.9	5.9-14
PV Premium Estimates						
PV*Size Coefficient	0.0094		0.0123	0.0113	0.0076	0.0055
PV*Size Standard Error	0.0008		0.0014	0.0014	0.0015	0.0016
PV*Size *p* -value	*0.000*		*0.000*	*0.000*	*0.000*	*0.001*
Mean Sale Price Non-PV ($)	$ 476,124		$ 477,737	$ 474,560	$ 478,634	$ 474,476
PV Premium ($/watt)	$ 4.51		$ 5.90	$ 5.40	$ 3.67	$ 2.60
95% CI ($/watt)	$ 0.71		$ 1.30	$ 1.33	$ 1.37	$ 1.51
Contributory Value Estimates						
PV Value - Income ($/watt)	$ 2.86		$ 3.06	$ 3.03	$ 2.83	$ 2.52
Net Cost ($/watt)	$ 4.29		$ 4.49	$ 4.27	$ 4.24	$ 4.16
Gross Cost ($/watt)	$ 6.65		$ 7.08	$ 6.65	$ 6.54	$ 6.34
Model Info						
Total *n*	15,342		4,398	3,865	4,100	3,607
PV *n*	2,507		633	613	635	626
Non-PV *n*	12,835		3,765	3,252	3,465	2,981
Adjusted R^2	0.91		0.93	0.93	0.92	0.90
Dependent Variable	lnsp		lnsp	lnsp	lnsp	lnsp
Block Group Fixed Effects *n*	1,766		574	504	509	540

4.2.4 Year of Sale Model Results

Because the dataset spans the period from 2002 through 2013, we can examine how premiums change over time. This is especially interesting given that, in the same period, the costs for PV modules dropped (Barbose et al., 2013) and housing market prices saw a rapid rise, fall, and recovery. We break the data into four subsamples roughly consistent with these broad changes (2002–2007, 2008–2009, 2010–2011, and 2012–2013) and estimate the Base Model specification for each subsample.

Results from these models are contained in Table 10. The model results for the full dataset are also contained in Table 10 for reference. In each model, the coefficient of the variable of interest, *pv*size*, is highly statistically significant (*p*-value ≤ 0.001), with relatively stable standard errors ranging from 0.002 to 0.001, or a tenth of a percent. Despite varying levels of non-PV homes prices, which range from $512,170 to $440,495, premiums are relatively stable, ranging from $3.41/W to $4.54/W, with none being statistically different from each other over the various periods.

During this period, we see mean gross costs descend from a high of $8.97/W in 2002–2007 to a low of $5.45/W in 2012–2013. Net costs fall much less between these two periods, from $5.39/W to $3.58/W, while PV Value income estimates remain near, or slightly below, $3/W. Despite falling gross costs, and shifts in the overall housing market, premiums remain fairly flat and not statistically different from the net costs in all periods and from the PV Value income estimates in two out of four periods.

Table 10: Year of Sale Model Results

		Year of Sale Groups			
	All Homes	2002-2007	2008-2009	2010-2011	2012-2013
PV Premium Estimates					
PV*Size Coefficient	0.0091	0.0066	0.0103	0.0083	0.0093
PV*Size Standard Error	0.0007	0.0020	0.0016	0.0011	0.0010
PV*Size *p*-value	*0.000*	*0.001*	*0.000*	*0.000*	*0.000*
Mean Sale Price Non-PV ($)	$ 456,378	$ 512,170	$ 440,495	$ 448,976	$ 453,988
PV Premium ($/watt)	$ 4.18	$ 3.41	$ 4.54	$ 3.73	$ 4.23
95% CI ($/watt)	$ 0.62	$ 2.03	$ 1.34	$ 0.97	$ 0.88
Contributory Value Estimates					
PV Value - Income ($/watt)	$ 2.93	$ 2.79	$ 2.73	$ 3.00	$ 3.02
Net Cost ($/watt)	$ 4.14	$ 5.39	$ 4.56	$ 4.00	$ 3.58
Gross Cost ($/watt)	$ 6.90	$ 8.97	$ 8.25	$ 6.88	$ 5.45
Model Info					
Total *n*	22,822	2,368	3,895	7,238	9,321
PV *n*	3,951	464	882	1,146	1,459
Non-PV *n*	18,871	1,904	3,013	6,092	7,862
Adjusted R^2	0.92	0.96	0.96	0.95	0.91
Dependent Variable	lnsp	lnsp	lnsp	lnsp	lnsp
Block Group Fixed Effects *n*	1,830	259	313	630	1,022

4.3 Size of PV System Model

To examine if larger PV systems garner an equal, lower, or higher marginal price premium than smaller systems, we estimate a polynomial model as described in Equation (2) with parameters for *pv*size* and $pv*size^2$. Abbreviated results from this model are shown in Table 11. Coefficients for the first- and second-order polynomials are highly statistically significant (p-value < 0.02) and indicate decreasing marginal returns to increasing PV system size. The *pv*size* coefficient equates to a premium of $5.86/W, while the $pv*size^2$ coefficient corresponds to a decrease in value of $0.53/W. Therefore, the model estimates that, up to approximately 10 kW, each increase in PV system size adds value to a home, but progressively less value for each addition. Beyond 10 kW, premium increases with increasing system size seem to flatten out, but we are less confident of the results because of the relatively few observations in this size range.[34]

[34] We also estimated models using subsets of data, each containing progressively larger systems, and find a similar pattern, with decreasing $/W premiums for increasing sizes.

Table 11: Size of PV System Model Results

	PV*Size	PV*Size^2
Coefficient	0.0128	-0.0006
Standard Error	0.0015	0.0002
p -value	0.0000	0.0130
Mean Sale Price Non-PV ($)	$ 456,377	$ 456,377
PV Premium ($/watt)	$ 5.86	$ (0.53)
95% CI ($/watt)	$ 1.35	$ 0.42
Model Info		
Total *n*	22,822	
PV *n*	3,951	
Non-PV *n*	18,871	
Adjusted R^2	0.92	
Dependent Variable	lnsp	
Block Group Fixed Effects *n*	1,830	

4.4 Robustness Models

The various models estimated above, which mostly are based on the Base Model and subsets of the data, compare PV home prices to non-PV home prices. Here we estimate two Robustness Models, which allow us to examine the robustness of the results under alternative specifications: the PV Only Model and the Repeat Sales Model. The PV Only Model compares selling prices of only PV homes, while the Repeat Sales Model examines the selling prices of the same home for homes sold once before the PV system was installed and again after it was installed, as described by Equation (3). These models use both different sets or subsets of the data and different specifications of the model, which allows them to control for possible specification biases in the Base Model. They, therefore, serve as valuable comparisons to and, potentially, validations of the Base Model results.

4.4.1 PV Only Model

Results for the PV Only Model are shown in Table 12. The coefficient for *pv*size* is effectively identical to that estimated for the Base Model with the full dataset, and it is highly statistically significant (*p*-value ≤ 0.001). The fact that the coefficient is identical to the Base Model coefficient is remarkable given that it is derived from a model that uses county fixed effects, rather than the more geographically precise block group fixed effect used in the Base Model. The estimated premium is $4.37/W, although the 95% confidence interval is considerably larger at $2.62/W vs. the Base Model's $0.62/W, indicating considerably less precision in the PV Only Model estimate.

4.4.2 Repeat PV Home Model

Results from the Repeat PV Home Model are also shown in Table 12. The coefficient for *pv*size* is very similar to that estimated for the Base Model with the full dataset, but it is not statistically significant (*p*-value = 0.113). The estimated premium is $4.60/W, which is also very similar to that of the Base Model, although the 95% confidence interval, at $5.69/W, is considerably larger than those for the Base and PV Only Models.

4.4.3 Summary of Robustness Checks

Because of the large margins of error, we cannot say the three estimates are statistically different from each other. Despite this, none of the results appear markedly different from that estimated using the Base

Model where PV homes are compared to non-PV homes. When comparing PV homes to other PV homes, as in the PV Only Model, or the same PV home to itself over multiple transactions, as in the Repeat PV Home Model, we find little evidence to support the claim that the Base Model PV premium estimate is biased. Therefore, there appears to be no evidence that the PV estimate also contains the effects of other omitted features such as EE upgrades.

Table 12: Robustness Model Results

PV Premium Estimates	**All Homes**	**PV Only**	**Repeat**
PV*Size Coefficient	0.0091	0.0092	0.0087
PV*Size Standard Error	0.0007	0.0028	0.0055
PV*Size *p* -value	*0.000*	*0.001*	*0.113*
Mean Sale Price Non-PV ($)	$ 456,377	$ 474,529	$ 528,368
PV Premium ($/watt)	$ 4.18	$ 4.37	$ 4.60
95% CI ($/watt)	$ 0.62	$ 2.62	$ 5.69
Contributory Value Estimates			
PV Value - Income ($/watt)	$ 2.93	$ 2.93	$ 2.15
Net Cost ($/watt)	$ 4.14	$ 4.14	$ 3.09
Gross Cost ($/watt)	$ 6.90	$ 6.91	$ 5.64
Model Info			
Total *n*	22,822	3,915	1,698
PV *n*	3,951	3,915	849
Non-PV *n*	18,871	-	849
Adjusted R^2	0.92	0.68	0.23
Dependent Variable	lnsp	lnsp	lnsp
Fixed Effects *n*	1,830	65	n/a

5. Discussion of Research Questions

This section explores in more detail the seven research questions listed in Table 1, building on the full set of results described above.

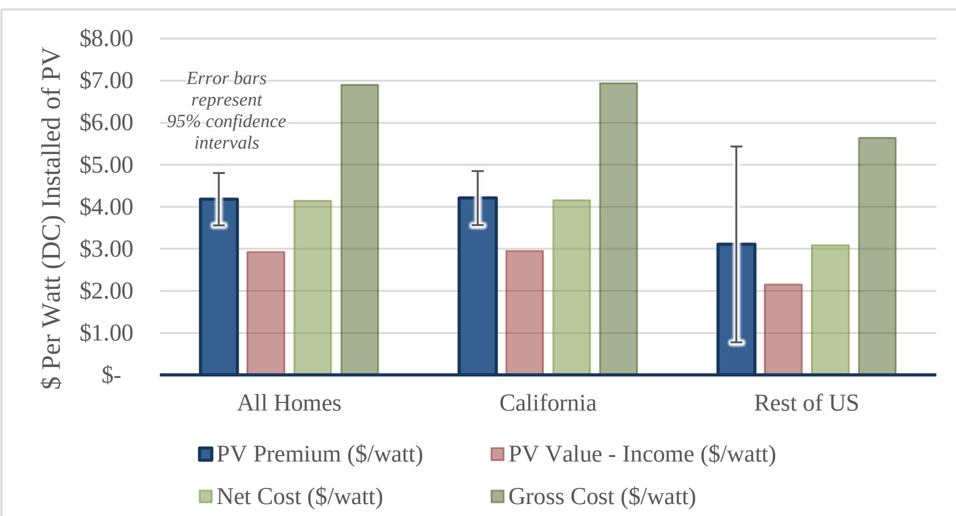
Are PV home premiums evident for a broader group of PV homes than has been studied previously both inside and outside of California and through 2013?

PV home premiums have been found by previous research of transactions of 15 PV homes in one California subdivision from 2001–2006 (Farhar and Coburn, 2008), of 594 PV homes in the San Diego and Sacramento metro areas between 1997–2010 (Dastrup et al., 2012), of approximately 1,900 PV homes in 31 California counties between 1999–2009 (Hoen et al., 2011; 2013a), and of 30 PV homes in the Denver metro area between 2011–2013 (Desmarais, 2013).

This analysis more than doubles the number of transactions analyzed, with data on almost 4,000 PV home transactions across 102 different counties in eight different states, including California, Connecticut, Florida, Massachusetts, Maryland, North Carolina, New York, and Pennsylvania. The data span the period from 2002 to 2013, with more than a third from 2012 and 2013 alone.

The Base Model and Location Models (Table 8 and Figure 1) show a consistent difference in PV home prices compared to matched non-PV homes across the dataset, with premiums ranging from a bit more than $4/W in California to approximately $3/W outside of California, both of which are highly statistically significant.[35] Moreover, this premium, as shown in the Year of Sale Models (Table 10 and Figure 2), survived both the dramatic decrease in installed costs over the study period as well as the market tumult which was the housing bubble, subsequent crash, and recovery. Clearly buyers of homes with PV are willing to pay a premium for PV, and this trend has continued despite dramatic changes in both the PV and housing markets. Finally, similarly sized premiums are found for the two robustness models—the PV Only Model and the Repeat PV Home Model—which further validates these results.

Figure 1: Base and Location Model Results



[35] The standard error for the Base Model of 0.0007 is 35% of the standard error found in the previous analysis of California PV homes of 0.0018 (Hoen et al. 2011; 2013a), indicating the increased precision of this estimate.

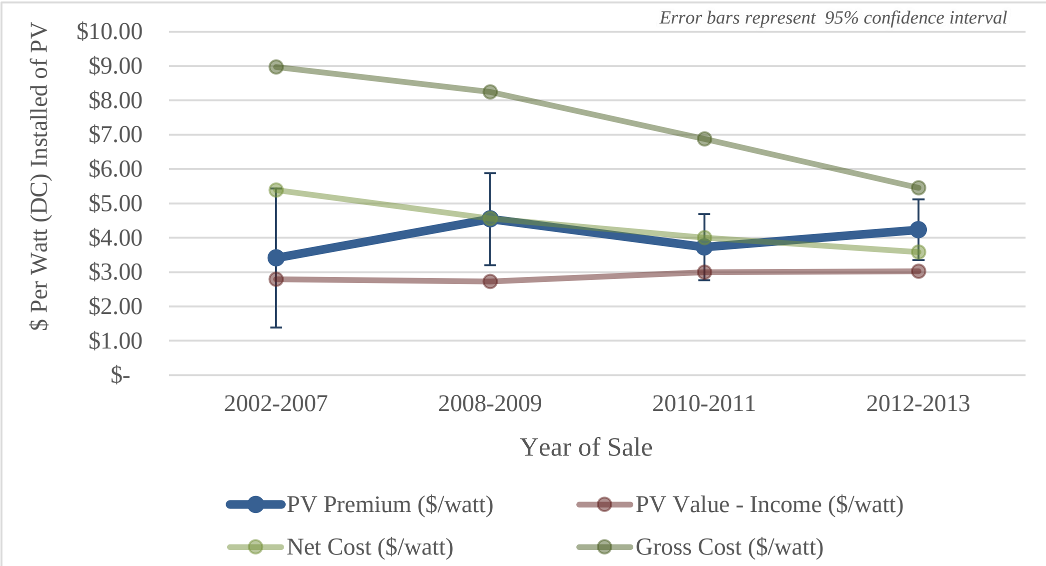
Are PV home premiums outside of California similar to those within California?

As shown in Table 8 and Figure 1, premiums for PV homes are estimated, on average, to be $1.10/W larger in California than outside of California. However, this difference, given the relatively large margin of error around the Rest of U.S. estimate, is not statistically significant. That notwithstanding, the apparent difference seems to echo decreases in each of the three other contributory value estimates we derived. For example, the gross and net costs in California are $1.30/W and $1.07/W higher than outside of California. Similarly, the PV Value income estimate is $0.80/W lower outside of California. In any case, these findings should give stakeholders outside of California greater confidence that PV adds value to homes in their markets.

How do PV home premiums compare to contributory values estimated using the cost and income methods?

The market premiums estimated from our suite of models seem to follow, at least to some degree, the contributory-value net cost estimates and, to a lesser degree, the PV Value estimates using the income approach, but not the gross cost estimates. For example, as shown in Figure 1, both the California and Rest of U.S. estimates are within a few pennies of the net cost estimates, but they are more than $2.50/W less than the gross cost estimates. Similarly, the Year of Sale Model results show PV premiums that are not statistically different in any period from the net cost estimates (Table 10 and Figure 2) despite widely changing gross cost estimates and underlying housing market tumult. Therefore, the net cost estimates—which account for the federal, state, and local incentives available at the time of sale—seem reasonably related to the value added (PV premiums) at least among average PV systems in our sample. Since the data indicate that, for the average systems in our sample, the PV premium is similar to the net cost estimate, it is reasonable to conclude the incentives are offsetting the influence of depreciation for those systems. At the same time and as discussed in further detail later, net cost estimates diverge from the calculated market premiums for those PV systems that are considerably newer or considerably older at the time of home sale. Depreciation in PV premiums is therefore apparent when other PV system ages are considered. As such, adjustments to net cost estimates may be required to account for market-derived depreciation. In this instance, it may be necessary for appraisers to estimate physical deterioration and functional obsolescence in situations where replacement costs exceed the contributory market value of older systems.

Figure 2: Year of Sale Model Results



Curiously, the PV Value income estimates are consistently lower than the premiums found in the market, while theory holds that cost savings should be a strong price signal. One reason for this disparity, which is especially evident in the California subset, might be related to the PV Value inputs that we used in this study, which were based on the average retail electricity rate. In California, tiered volumetric rates, which are based on the customer's consumption, are normal for most of the state's residential PV customers (CPUC, 2013). If customers consume more than the average retail customer, then they will be moved into higher-priced tiers. These tiers can be dramatic, with a doubling or even tripling of rates, depending on which tier the consumer falls into (CPUC, 2013). PV customers tend to be larger consumers of electricity than the average retail customer in California, thus they often pay more than the average (Darghouth et al., 2011; CPUC, 2013) and, with a PV system, may avoid higher-cost tiers altogether, increasing the value of the avoided costs. We cannot determine the exact level of this increase for the specific PV homes in our sample, but even a $0.05/kWh increase in the rate, which is well within the range proposed by others for PV customers (CPUC, 2013), would result in a substantial increase in the income estimate. The mean default electricity rate we entered into PV Value for the California portion of our sample is $0.1543/kWh. If that rate increased by $0.05/kWh, it would increase the PV Value estimate from $2.93/W to almost $4/W, within the margin of error of our premium estimate. Therefore, it seems possible that buyers and sellers might be using the cost savings as an important price signal, but they are estimating those savings at a slightly higher rate than the tool's default average retail rate. It is recommended that, when tiered rates are present that deviate substantially from the default average rate and normal consumption for a particular home would put the homeowner in higher tiers, users of the PV Value tool should input a custom rate that is more appropriate.[36]

How did the size of the premium change over the study period, as gross PV system prices decreased and during housing market swings?

While gross costs decreased dramatically over the study period, dropping 40% from $8.97/W in the 2002–2007 period to $5.45/W in the 2012–2013 period, PV premiums remained fairly consistent around

[36] For example, for California customers where tiered rates are common, weighting based on the tiers and the usage within each tier for particular PV homes might result in a more appropriate input rate.

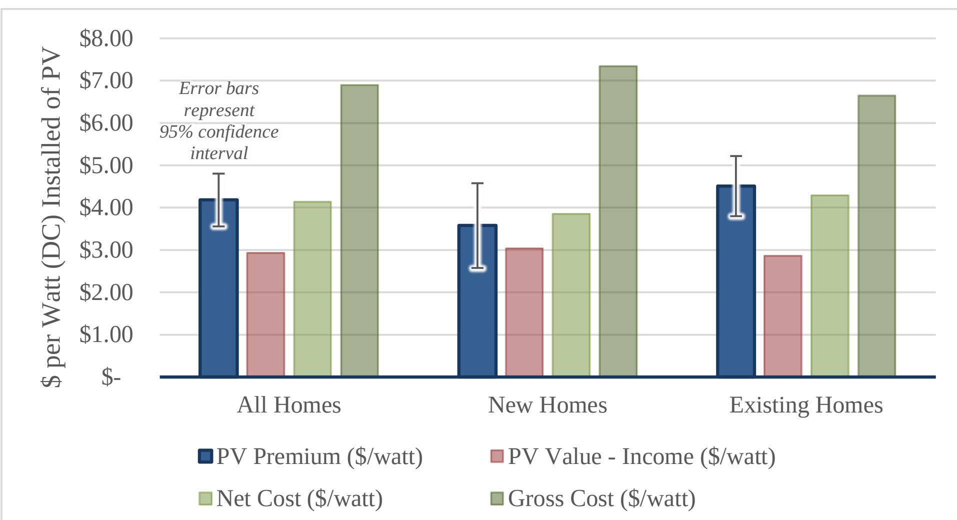
$4/W (see Figure 2). During this same period, the housing market was in upheaval, with a sizable rise, a subsequent crash, and then a recovery. This seems to show, first, that the gross cost is not a strong market signal. Rather, net cost, which over all periods was not statistically different from the premium, seems to be the more significant price signal. Moreover, it shows that the PV premium has been reasonably consistent during widely varying housing market conditions.

Are premiums for new PV homes similar to existing PV home premiums?

The results from the Home Type Model, which explores differences between new and existing home premiums, are shown in Table 8 and Figure 3. The average new home premiums of $3.58/W are lower than the existing home premiums of $4.51/W, a non-statistically significant difference of $0.93/W (*p*-value = 0.46). The net cost estimates for new homes are also lower (by $0.44/W) than those of existing homes, potentially explaining some of the difference.

Previous analyses found large, statistically significant differences between new and existing home premiums (Hoen et al., 2011; 2013a; 2013b). These differences occurred because existing home estimates were larger (near $6.50/W) and new home estimates were smaller (near $2.5/W) than found in the present analysis. It appears, based on analysis not shown here, that high-priced homes (e.g., over $1 million), which were included in the past analyses (up to $3.3 million) but excluded from this analysis, might explain a large portion of the differences. Including those homes in our analysis increased the existing home premiums and lowered the new home premiums, although not to the extent found previously. Including these homes also increased the margin of error around the estimates, however, implying that our models did a poorer job of explaining price differences and that many home and site characteristics for these homes likely are not included in the models. Further, the previous analyses included home transactions only through 2009, but this analysis included transactions through 2013, with two thirds occurring after 2009. In summation, this analysis is likely a better representation of the current market for most PV homes because it included many more recent sales, had more sales in total, and excluded high-priced homes (over $1 million) that were difficult to model, but it does not find a statistically significant difference between new and existing homes.

Figure 3: Home Type Model Results



One additional nuance to the present findings involves the new home premium and the net cost estimate. As discussed in Section 3.2, the net cost estimates (e.g., shown in Figure 3) represent the gross cost estimates less the appropriate federal and state incentives (and rebates where appropriate). The federal incentive, which normally comes in the form of an investment tax credit (ITC), is calculated as 30% of the gross cost of a PV system after state and utility incentives are applied. Interestingly, this incentive cannot be claimed by new home builders but instead only by the buyer of the home.[37] Therefore, the new home buyer not only receives the PV system on the home, but will also be able to receive a tax credit. Correspondingly, the net cost of the builder should not include this federal ITC reduction and, therefore, should be approximately $1.26/W higher and should affect the premium the buyer paid. This is interesting because we do not see a premium that reflects this incentive. If we did, the premium would be approximately $1.26/W higher or $4.84/W; instead we find a premium of $3.58/W.[38] Understanding the exact reasons for this discounting is beyond the scope of this work, but several plausible explanations exist: home builder discounting—the builder discounts the home for other reasons, for example to sell the home more rapidly (e.g., Dakin et al., 2008; SunPower, 2008), which has the effect of obscuring the premium related to the federal ITC; buyer discounting—the buyer is not willing to pay the full cost of the tax credit because it cannot be claimed until the following year when taxes are filed and might not be able to be claimed fully because of a lack of tax appetite by the homeowner; and lack of market clarity—because tax rules related to the federal ITC only recently were clarified (US IRS, 2013), both the home builder and buyer might not have consistently known if the ITC could be claimed.

Is there evidence of a "green cachet" for PV homes above the amount paid for each additional watt added?

Results from the Size of PV System Model suggest that the systems with the highest marginal premiums, in terms of dollars per watt, were the smallest systems, and as system size increased the dollar-per-watt premium decreased (Table 11). This decreasing slope is estimated in Figure 4 for PV systems from 1 to 10 kW, which shows both the decreasing dollar-per-watt value of each additional kilowatt added (left axis) and the total PV system premium (right axis). This indicates, potentially, that there is a fixed component of PV home premiums that occurs regardless of system size. This might indicate that a green cachet exists for PV homes in our sample. In other words, buyers might be willing to pay something for having any size of PV system on their homes and then some increment more depending on the size of the system. These findings echo those found previously (Dastrup et al., 2012).

How does the age of the PV system influence the size of the PV premium?

The results from the Age of PV System Models, which explore how premiums change as PV systems age, are shown in Table 9 and Figure 5. For systems installed on homes just before they were resold, larger premiums were garnered, with premiums falling by almost 60% in the oldest age group compared with the newest group.[39] This indicates that the market quickly depreciates PV systems in their first 10 years at a rate exceeding an average rate of PV efficiency losses, e.g., 0.5%/year (Dobos, 2014), and also exceeding the depreciation expected were straight-line depreciation applied over the asset's life; this might indicate functional obsolescence setting in. Because the mean age for the oldest quartile (5.9–14 years) is only 7.8 years (Figure 5), however, we cannot describe PV system values as they age into their second decade. Does their value level out and decrease at the rate of system degradation? Or do they lose 100% of their value before that? Those questions are recommended for future analyses.

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[37] In this instance we are referring to the federal ITC under Title 26 Section 25D of the Internal Revenue code (see: http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US37F).

[38] The portion of the difference between net and gross cost attributable to the federal ITC ranges from approximately $0.80/W to as high as $1.84/W, with a mean of $1.26/W.

[39] Although not shown here, the average size of PV systems was very similar in all four age bins, at approximately 4.2 kW. We hypothesize that this larger premium for nearly new systems is related to additional nearly new features installed coincidently or the homeowner not fully taking advantage of tax incentives if they had planned on selling the home soon after the installation.

Figure 4: Estimated Dollar Per Watt Premium for Increasingly Larger PV Systems

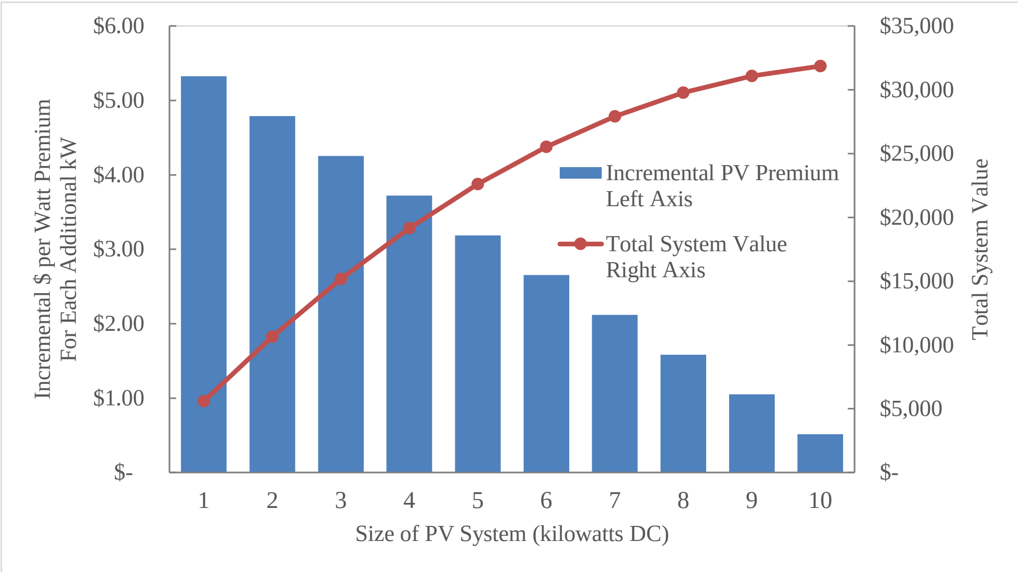
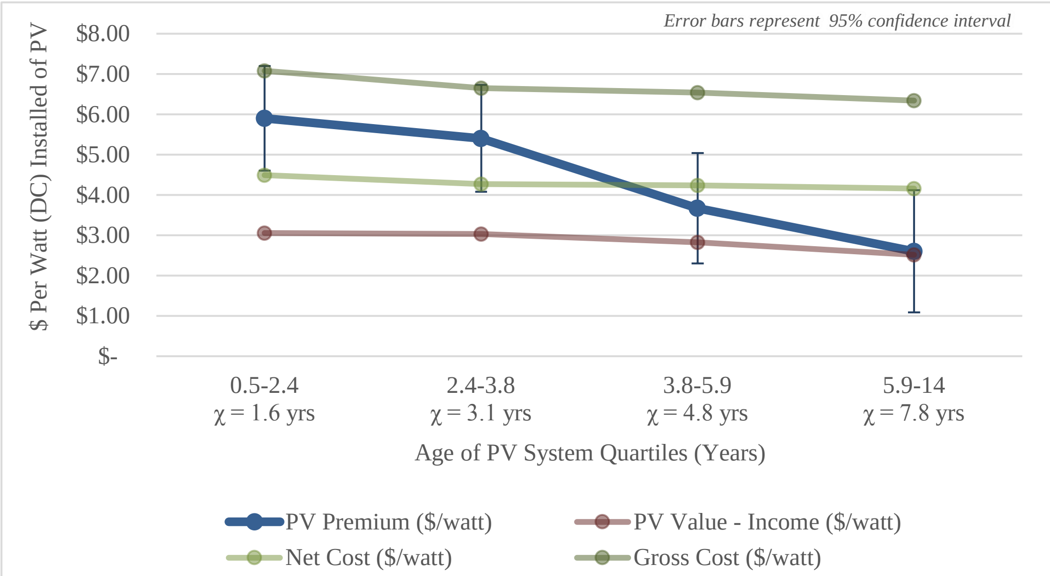


Figure 5: Age of PV System Model Results



6. Conclusion

As solar photovoltaic (PV) systems become an increasingly common feature of U.S. homes, the ability to value homes with these systems appropriately will become increasingly important. The U.S. Department of Energy estimates that achieving its SunShot PV system price-reduction targets could result in 108 GW of residential rooftop PV installed by 2050—equivalent to 30 million American homes with PV (US DOE, 2012).[40] Conversely, capturing the value of PV to residential properties is important for enabling a robust rooftop PV market.

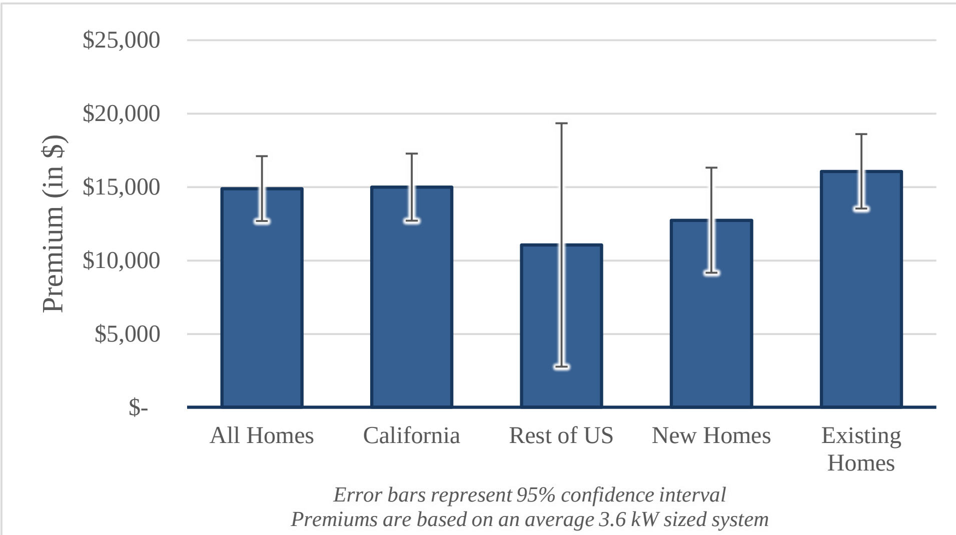
Appraisers, sales agents, and others tasked with property valuation have made strides toward valuing PV homes, and several limited studies suggest the presence of PV home premiums, particularly in California. Our study fills important gaps in this literature and illuminates various factors that might influence U.S. PV home premiums. The study more than doubles the number of PV home sales previously analyzed, examines transactions in eight different states, and spans the years 2002–2013, thus encompassing the recent housing boom, bust, and recovery. Based on our results, we draw the following major conclusions:

- Home buyers consistently have been willing to pay more for a property with PV across a variety of states, housing and PV markets, and home types. Average market premiums across the full sample of homes analyzed here are about $4/W or $15,000 for an average-sized 3.6-kW PV system (Figure 6).
- Our findings should provide greater confidence that PV adds value to non-California homes. Premiums for PV homes are $1.10/W larger in California than outside of California (respectively equating to $16,000 and $12,700 for an average-sized system – Figure 6), but this difference is not statistically significant: somewhat lower premiums outside of California are consistent with lower net cost and income estimates.
- Net cost estimates—which account for government and utility PV incentives—seem to be generally consistent with incremental market value premiums for the average PV home in our sample, but they do not appear to account accurately for market-based depreciation (the difference between value and cost). PV Value income estimates—which for this study used the default average retail rates—were consistently lower than the calculated market premiums, which seems to indicate that a higher retail rate would be more appropriate for that portion of the sample where tiered rates were present.
- PV premiums remained fairly consistent even as PV gross costs decreased dramatically over the study period and the housing market went through upheaval. This suggests that net cost, rather than gross cost, may be the more dominant market signal. It also suggests that PV premiums are robust to housing market conditions.
- In contrast to previous studies, our study found a relatively small and non-statistically significant difference between PV premiums for new and existing homes (respectively equating to $12,700 and $16,000 for an average-sized system – Figure 6), likely because our study includes many more sales and recent sales while excluding very-high-priced homes. That notwithstanding, there might be some evidence of either home builder or buyer discounting of new home PV systems.
- A green cachet might exist for PV homes; that is, buyers might be willing to pay a certain amount for having any size of PV system on their homes and then some increment more depending on the size of the system.
- The market appears to depreciate PV systems in their first 10 years at a rate exceeding the rate of PV efficiency losses and of straight-line depreciation over the asset's life. Our data do not allow analysis

[40] Assuming the average PV system size of 3.6 kW found for all PV homes in this study.

of depreciation into the second decade of PV systems' operation—this is an area for future research.

Figure 6: Estimated Premiums Based on an Average-Sized 3.6 kW System



This study focuses only on homes with host-owned PV systems, as opposed to those with leased PV systems. Future analysis should focus on leased systems, because they are a growing portion of the PV home market and have not been studied. In addition, although our sample indicates that, as PV systems age, the size of the premium diminishes, our data are not robust to systems in their second decade; such older systems should be the focus of future study, as should the appropriate deprecation to place on PV systems throughout their lives.

Although this work allows for a robust analysis of average system premiums across the full dataset, and subsets of the data, the results are not necessarily applicable to individual markets and states that might have unique characteristics. Therefore, any market-specific ("small scale") analysis, especially one that employs appraisers and other valuers in those local markets, would be beneficial. Similarly, collecting and analyzing more data in a wide variety of states individually would be useful.

Because premium differences related to the availability of PV homes are unclear, investigating both buyer's markets (with many PV homes available) and seller's markets (with few PV homes available) would add clarity to PV home valuation. Finally, very large PV systems and systems on commercial properties were not represented in our data; both could have unique valuation characteristics and are thus areas for further study.

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8. Appendix A: Cost Estimate Preparation

To calculate both the net and gross cost estimates for each of the PV home transactions at the time of sale, we estimate a two-stage regression as used previously (Hoen et al., 2011; 2013a; 2013b). This procedure starts with the extensive dataset of more than 150,000 PV homes collected for TTS VI and their respective gross installed costs as reported (Barbose et al., 2013), for which the respective net installed costs (i.e., net of federal and state incentives) are calculated using the procedure outlined in Appendix C of Barbose et al. (2010). The first stage uses the net costs as the dependent variable and county, year, system size, and home type (new or existing) as the independent variables, in the following model:

$$C_{itsc} = \alpha + \beta_1(T_i) + \beta_2(S_i) + \beta_3(N_i) + \beta_4(C_i) + \varepsilon_{itsc} \tag{4}$$

where

C_{itsc} is the "net installed cost" of PV system *i* after state and federal incentives from the full TTS dataset,

T_i is a vector of variables representing the year *t* in which the system was installed,

S_i is a vector of variables representing the size *s* of the system in rounded kilowatts (e.g., 1 kW, 2 kW, 3 kW…),

N_i is a fixed-effect variable indicating if the home was newly built when the system was installed,

C_i is a vector of variables representing the county *c* in which the system was installed,

α is the constant,

$\beta_{1\text{-}4}$ are coefficients for the parameters, and

ε_{itsc} is the error term.

The model accounts for the different state incentives and system component prices over the study period (via T_i), economies of scale (via S_i), different installed costs between new and existing homes (N_i), and the variety of rate structures, installer competitive prices, and market development (via C_i).

Using the predicted coefficients from this model, the data for the set of PV home transactions (county in which the home is located, PV system size, if the home is newly built, and substituting the sale year for the installation year *t*) are fed into the model to produce predicted net cost estimates. These represent, as of the time of sale, the approximate cost to replace a similarly sized system new on the same home.

An identical procedure is followed for gross cost estimates, except, for the first stage, C_{itsc} is the "gross installed cost" of PV system *i* <u>before</u> state and federal incentives from the full TTS VI dataset.