DO PHOTOVOLTAIC ENERGY SYSTEMS AFFECT RESIDENTIAL SELLING PRICES? RESULTS FROM A CALIFORNIA STATEWIDE INVESTIGATION

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ABSTRACT

An increasing number of homes in the U.S. have sold with photovoltaic (PV) energy systems installed at the time of sale, yet relatively little research exists that provides estimates of the marginal impacts of those PV systems on home sale prices. This research analyzes a large dataset of California homes that sold from 2000 through mid-2009 with PV installed. We find strong evidence that homes with PV systems sold for a premium over comparable homes without PV systems during this time frame. Estimates for this premium expressed in dollars per watt of installed PV range, from roughly \$4 to \$6.4/watt across the full dataset, to approximately \$2.3/watt for new homes, to more than \$6/watt for existing homes. A number of ideas for further research are suggested.

1. INTRODUCTION

California has been and continues to be the country's largest market for PV, and is approaching 100,000 individual PV systems installed, approximately 90% of which are residential [18]. One of the incentives for homeowners to install a PV system on their home, for home buyers to purchase a home with a PV system already installed, or for new home builders to consider installing PV as a standard feature, is the possibility that a portion of any incremental investment in PV will be returned at the time of the home's subsequent sale. To this point, relatively little research has been conducted on the existence and level of those returns at the time of sale, though what has been done indicates that a premium exists.

Farhar et al. [10; 9] tracked repeat sales of 15 "high performance" energy efficient homes with PV installed from one subdivision in San Diego and found evidence of higher appreciation rates, using simple averages, for PV homes over non-PV (n=12) comparable homes. More recently, Dastrop et al. [7] used a hedonic analysis to investigate the selling prices of 279 homes with PV installed in the San Diego, CA metropolitan area, finding clear evidence of PV premiums that averaged roughly 3% of the total sales price (roughly \$4.4/watt) over non-PV homes.

A portion of the sales price premium that a PV system generates is expected to be related to energy cost savings. Although no studies exist investigating this link directly, potentially analogous evidence does exist from the energy efficiency literature [e.g., 16], which convincingly shows this correlation, thereby implying the same might exist for PV. Other energy efficiency studies have gone further, finding a premium over and above what would be predicted for energy savings alone, implying the potential of a "green cachet" driver to selling prices [3; 7], which might exist for PV homes too. Another driver to PV home premiums might be the net installed costs (i.e., after available state and federal incentives) of the PV systems. Buyers, in considering the appropriate premium for PV, might consider the opportunity cost of purchasing a home without PV and installing the system themselves. Similarly, sellers might use the net installed cost as a benchmark against which to negotiate the premium. In California, the net installed costs of PV have hovered around \$5/watt over the last decade [1]. Adding slightly to the complexity, the installed costs of PV systems are not the same across home types, with net installed costs on *new* homes in CA enjoying roughly a \$1/watt average cost advantage over those on *existing* homes in retrofit applications [1].

Though a link between selling prices and some combination of energy cost savings, green cachet, and the net installed cost of PV likely exists, the existing empirical literature in this area, as discussed earlier, has largely focused on a limited geographic area (San Diego) with relatively small sample sizes. Therefore, to this point, establishing a transferable estimate for the PV premiums that may exist across a wide market of homes has not been possible. Moreover, establishing premiums for *new* versus *existing* homes has not yet been addressed.

To explore these possible relationships, though not to disentangle them, we investigate the residential selling prices across the state of California of roughly 2,000 homes with PV systems against a comparable set of roughly 70,000 non-PV homes. All home sales occured during the period of 2000 through mid-2009. We apply a variety of hedonic pricing (and repeat sales) models and sample sets, to test and bound the possible effects of PV on residential sales prices and increase the confidence of the findings.

The paper begins with a discussion of the data used for the analyses. This is followed by a discussion of the empirical basis for the study, where the variety of models and sample sets are detailed. The paper then turns to a discussion of the results and their potential implications, and finally offers some concluding remarks with recommendations for future research.

2. DATA OVERVIEW

To estimate the models described later, a dataset of California homes was amassed from five different data sources. Those data include: PV home addresses and system information (from CEC, CPUC & SMUD); real estate information (from Core Logic, www.corelogic.com); home sales price index data (from Fiserv, www.caseshiller.fiserv.com); locational data (from Sammamish, www.sammdata.com); and elevation data (from CERES, www.ceres.ca.gov).

Data cleaning and preparation for final analysis was a multifaceted process involving the exclusion of homes because of missing core real-estate characteristic data (e.g., sale date, year built, square feet), sales occurring outside the range of the index (January 1970 to June 2009), and screening the data of outliers and potentially erroneous data.[1]

2.1. Data Summary

The final full sample dataset included a total of 72,319 sales, 1,894 of which were PV homes and 70,425 of which were non-PV. The homes with PV systems were distributed approximately evenly between *new* and *existing* home types.

A subset of these data, which sold both before and after the PV system was installed, were also available. These "repeat sales" totaled 28,313 homes, of which 394 were PV and 27,919 were non-PV.

The average non-PV home in the full sample (not the repeat sales sample) sold for $584,740 (unadjusted), which corresponds to $480,862 (adjusted) in 2009 dollars.[2] This "average" non-PV home was built in 1986, was 19 years old at the time of sale, had 2,200 square feet of living space, had 2.6 bathrooms, was situated on a parcel of 0.3 acres, and was located at the mean elevation of the other homes in the block group. On the other hand, the average PV home in the full sample sold for $660,222, which corresponds to $537,442 in 2009 dollars. Therefore, this "average" PV home, as compared to the "average" non-PV home, is higher in value. This difference might be explained, in part, by the fact that the average PV home is slightly younger at the time of sale (by two years), slightly bigger (by 200 square feet), has more bathrooms (by 0.3), is located on a parcel that is slightly larger (by 0.06 acres), and, of course, has a PV system (which is, on average, 3,100 watts and 1.5 years old). The repeat sale dataset, though not discussed here, shows similar modest disparities between PV and non-PV homes.

The full dataset has sales that are (1) from 31 of the 58 counties in California, (2) occurred over eleven years (1998-2009), with the largest concentration of PV sales occurring in 2007 and 2008, and (3) are located primarily within four major utility service areas (Pacific Gas & Electric (PG&E), Southern California Edison, San Diego Gas & Electric, and Sacramento Municipal Utility District), with the largest concentration in the PG&E territory

3. METHODOLOGICAL OVERVIEW

The data, as outlined above, not only show higher sales values for PV homes (in 2009 $) over non-PV homes, but also important differences between PV and non-PV homes as regards other home, site, neighborhood, and market characteristics that could, potentially, be driving these differences in value. A total of 16 empirical model specifications, with a high reliance on the hedonic pricing method [17], are used in this paper to disentangle these potentially competing influences in order to determine whether and to what degree PV homes sell for a premium.

A variant of the hedonic model, a difference-in-difference model [19], is also used, which uses only the "repeat sales" as its dataset.

[1] A full description of the data sources, cleaning and processing is available from the authors.

[2] This decrease in inflation adjusted values is an indication of the housing price deflation that occurred between 2005 and 2006, when most of the sales in the sample occurred, and 2009.

For each set of estimation methods, a base model is estimated that is coupled with a set of robustness models. Before describing these models in more detail, however, a summary of the variables to be included in the models is provided.

3.1. Variables Used in Models

In each base model, be it hedonic or difference-in-difference, four similar sets of parameters are estimated, namely coefficients on the variables of interest - the focus of the research (e.g., if the home has PV or not, and the size of the PV system), and coefficients for three sets of controls that include: 1) home and site characteristics; 2) geographic (census block group) fixed effects; and 3) temporal (year and quarter) fixed effects. The base models differ in their specification and testing of the variables of interest, as discussed later, but use the same three sets of controls.

The first of these sets of control variables accounts for differences across the dataset in home and site-specific characteristics, including the age of the home, the total square feet of living area, the size of the property in acres, and the relative elevation of the home to other homes in the block group.

The second set of controls, the geographic fixed effects variables, includes dummy variables that control for aggregated "neighborhood" influences, which, in our case, are census block groups. To be usable, each block group has to contain at least one PV home and one non-PV home. Because block groups are fairly small geographically, spatial autocorrelation is also, to some degree, dealt with through the inclusion of these variables.

Finally, the third set of controls, the temporal fixed effect variables, includes dummy variables for each quarter of the study period to control for any inaccuracies in the housing inflation adjustment that was used. A housing inflation index is used to adjust the sales prices throughout the study period to 2009 prices at a zip code level across as many as three price tiers. Although that adjustment is expected to greatly improve the estimation - relative to using *just* a temporal fixed effect with an unadjusted price - it is also assumed that because of the volatility of the housing market, the index may not capture price changes perfectly and therefore the estimation is enhanced with the additional inclusion of these quarterly controls.[3]

[3] A number of less-parsimonious temporal/spatial approaches were also tested with no substantive impact on the results.

3.2. Fixed and Continuous Effect Hedonic Models

The analysis begins with the most basic model comparing prices of all of the PV homes in the sample (whether new or existing) to non-PV homes across the full dataset. As is common in the literature, a semi-log functional form of the hedonic model is used where the dependent variable, the (natural log of) sales price (P), is measured in zip code-specific inflation-adjusted (2009) dollars. To determine if an average sized PV system has an effect on the sale price of PV homes (i.e. a fixed effect) we estimate the following base fixed effect hedonic model:

$$\ln(P_{itk}) = \alpha + \beta_1(T_t) + \beta_2(N_k) + \sum_a \beta_3(X_i) + \beta_4(PV_i) + \varepsilon_{itk} \quad (1)$$

where: P_{itk} represents the inflation adjusted sale price for transaction *i*, in quarter *t*, in block group *k*; α is the constant or intercept across the full sample; T_t is the quarter in which transaction *i* occurred; N_k is the block group in which transaction *i* occurred; X_i is a vector of *a* home characteristics for transaction *i* (e.g., acres, square feet, age, etc.); PV_i is a fixed effect variable indicating if a PV system is installed on the home in transaction *i*; and, ε_{itk} is a random disturbance term for transaction *i*.

The parameter estimate of primary interest in this model is β_4, which represents the marginal percentage change in sale price with the addition of an average sized PV system. If differences in selling prices exist between PV and non-PV homes, we would expect the coefficient to be positive and statistically significant.

An alternative to equation (1) is to interact the PV fixed effect variable (PV_i) with the size (in kW) of the PV system as installed on the home at the time of sale ($SIZE_i$) thereby producing an estimate for the differences in sales prices as a function of size of the PV system (i.e., a continuous effect). This base continuous effect model takes the form:

$$\ln(P_{itk}) = \alpha + \beta_1(T_t) + \beta_2(N_k) + \sum_a \beta_3(X_i) + \beta_4(PV_i \cdot SIZE_i) + \varepsilon_{itk} \quad (2)$$

where, β_4 is a parameter estimate for the percentage change in sale price for each additional kW added to a PV system, and all other terms are as were defined for equation (1). This "continuous effect" specification may be preferable to the PV "fixed effect" model because one would expect that the impact of PV systems on residential selling prices would be based, at least partially, on the size of the system because size is related to energy bill savings. Therefore, in this paper, greater emphasis is placed on the continuous effect specification in place of the fixed effect specification.

As mentioned earlier, for each base model we explore a number of different robustness models to better understand if and to what degree the results are unbiased. In the present research, two areas of bias are of particular concern: omitted variable bias and sample selection bias.

The omitted variables that are of specific concern are any that might be correlated with the presence of PV, and that might affect sales prices. With respect to selection bias, the concern is that the distribution of homes that have installed PV may be different from the broad sample of homes on which PV is not installed.

To mitigate the issue of omitted variable bias, one robustness model uses the same data sample as the base model but a different model specification. Specifically, a combined subdivision-block group fixed effect variable is substituted, where available, in place of the block group fixed effect variable as an alternative proxy for "neighborhood." Potentially omitted variables are likely to be more similar between PV and non-PV homes at the subdivision level than at the block level. Therefore, this model may more-effectively control for omitted variables. [4]

To mitigate the issue of selection bias, the robustness model uses the same model specification as the base model but with an alternative (subset) of the data sample. Specifically, instead of using the full dataset with equations (1) and (2), a coarsened exact matched dataset can be used [14].[5] Because the PV and non-PV data sets are statistically equal on their covariates after the matching process, differences between them, and biases related to selection, are minimized.

Finally, specific to equation (2), a robustness model to address both omitted variable and selection bias is constructed in which the sample is restricted to *only* include PV homes (in place of the full sample of PV *and* non-PV homes). Because PV system size effects are estimated without the use of non-PV homes in this model, it provides an important comparison to the base models, while also directly addressing any concerns about the inherent differences between PV and non-PV homes and therefore omitted variable and sample selection bias.

3.3. New and Existing Home Models

Although equations (1) and (2) are used to estimate whether a PV system, on average, affects selling prices across the entire data sample, they do not allow one to distinguish any such effects as a function of house type, specifically whether the home is *new* or *existing*. To try to tease out these possible differences two base hedonic models are estimated using equation (2), one with only *new* homes drawn from the full sample and the other with only *existing* homes. Comparing the coefficient of the variable of interest (β_4) between these two models allows for an assessment of the relative size of the impact of PV systems across the two home types.

Additionally, two sets of robustness models for the *new* and *existing* home specifications are explored, one using the coarsened exact matched dataset and, the other, using the combined subdivision-block group delineations. Although it is discussed separately as a base model in the following subsection, the difference-in-difference model, using repeat sales of *existing* homes, also doubly serves as a robustness test to the *existing* homes base model.

3.3.1. Difference-in-Difference Model

One classic alternative to estimating a hedonic model is to estimate a difference-in-difference (DD) model. This model uses a set of homes that have sold twice, both with and without PV, and provides estimates of the effect of adding PV to a subset of those homes as of the second sale. Repeat sales models of this type are particularly effective in controlling for selection and omitted variable bias. Estimates derived from this model, apply to - while also serving as a robustness tests for - the *existing* home models as specified above. The base DD model is estimated as follows:

$$\ln(P_{itk}) = \alpha + \beta_1(T_t) + \beta_2(N_k) + \sum_a \beta_3(X_i) + \beta_4(PVH_i) + \beta_5(SALE2_i) + \beta_6(PVS_i) + \varepsilon_{itk} \quad (3)$$

where, PVH_i is a fixed effect variable indicating if a PV system is or will be installed on the home in transaction *i*, $SALE2_i$ is a fixed effect variable indicating if transaction *i* is the second of the two sales, PVS_i is a fixed effect variable (an interaction between PVH_i and $SALE2_i$) indicating if transaction *i* is both the second of the two sales and contained a PV system at the time of sale, and all other terms are as were defined for equation (1).

[4] Homes in the same subdivision are often built at similar times using similar materials and therefore serve as a control for a variety of house specific characteristics that are not controlled for elsewhere in the model. For homes not situated in a subdivision, the block group delineation is used. Therefore these fixed effects are entitled "combined subdivision-block group" delineations.

[5] The matching procedure creates statistically matched sets of PV and non-PV homes in each block group, based on a set of covariates, which, for this research, include the number of square feet, acres, and baths, as well as the age of the home, its elevation, and the date at which it sold. 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 80% non-PV and 20% PV) are *not* included in the resulting dataset.

To further attempt to mitigate the potential for omitted variable bias, two robustness models are estimated for the base DD model: one with the combined subdivision-block group delineations and a second with a limitation of five years applied on the length of time between the first and second sales. The second robustness model accounts for the potential problem of the age of the first sale, which can be as much as 20 years before the second sale.

4. ESTIMATION RESULTS[6]

Although not shown here, the adjusted R^2 for all models is high, ranging from 0.93 to 0.95. Further, the sign and magnitude of the home and site control variables are consistent with *a priori* expectations, are largely stable across all models, and are statistically significant at the 1% level in most models.[7]

4.1. Fixed and Continuous Effect Hedonic Model Results

The results from the base hedonic models (equations 1 and 2) and their respective robustness models are summarized in Fig. 1, where the results are converted to 2009 dollars per watt of installed PV ($/watt). The premiums shown represent the statistically significant difference (90% confidence intervals shown) in inflation adjusted selling prices between PV and non-PV homes divided by the size of the PV system, after controlling for various home and site characteristics, the location of the home, and the market conditions at the time.

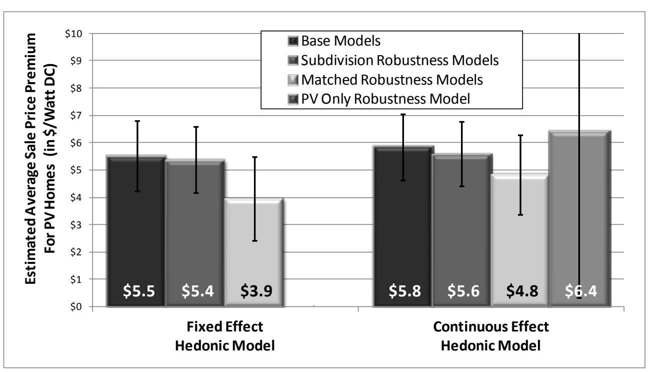

Fig. 1: Fixed and Continuous Effect Models

Despite the various model specifications, the results are fairly consistent ranging from $3.9 to $6.4/watt on average. These sale price premiums are in-line with the historical mean net installed costs of residential PV systems in CA of approximately $5/watt from 2001 through 2009 [1], and results found previously by Dastrop et al. [7]. They estimated an average increase in selling price of $14,069, which, when divided by their mean PV system size of 3.2 kW, implies an effect of approximately $4.4/watt.

4.2. New and Existing Home Model Results

Turning from the full dataset to one specific to the home type, we estimated continuous effects models for *new* and *existing* homes as well as their various robustness models. Estimates for the average $/watt increase in selling prices (as summarized in Fig. 2, which also includes the base continuous model results for reference) for *new* homes are quite stable, ranging from $2.3 to $2.6. In comparison, for PV sold with *existing* homes, not only are the selling price impacts found to be higher, but their range across the three models is greater, ranging from $ 6.4 to $7.7/watt.

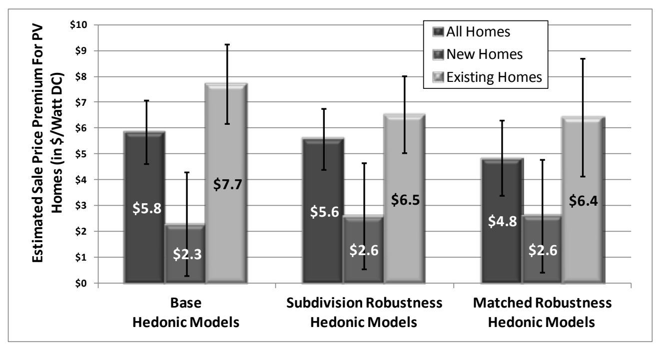

Fig. 2: New and Existing Home Models

Delving deeper into PV system impacts on *existing* homes, Fig. 3 shows the results of the base Difference-in-Difference (DD) Model with its two robustness tests in combination with the *existing* home hedonic model results discussed above. The premium for *existing* PV homes, as estimated in the DD Models, are between $6 and $6.3/watt, very similar to that estimated in the robustness tests for the hedonic model. Each of these five models are in-line with - though slightly higher than - the mean net installed costs of PV on existing homes of approximately $5.2/watt from 2007 to 2009.

The reasons for the apparent discrepancy in selling price impacts between *new* and *existing* homes could be related to a variety of complimentary drivers. Part of the difference might be explained by the difference in average net installed costs, which, from 2007 to 2009, were roughly $5.2/watt for *existing* homes and $4.2/watt for *new* homes [data obtained from authors of 1].

[6] All models were estimated with Stata SE Version 11.1 using the "areg" procedure with corrections for heteroskedasticity.

[7] Only a portion of model results are shown here. All results are available upon request from the authors.

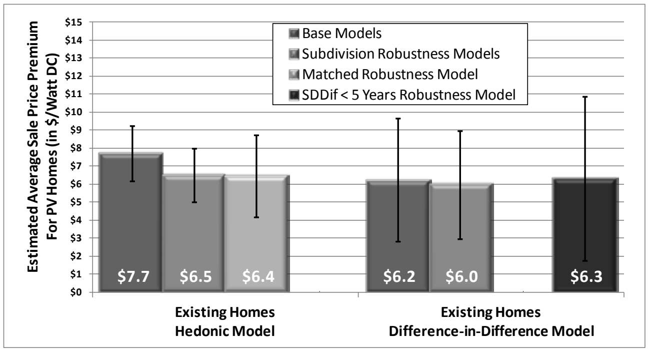

Fig. 3: Existing Home Hedonic and Difference-in-Difference Models

Additionally, there is evidence that builders of *new* homes might discount premiums for PV if, in exchange, the home is differentiated from its competition, allowing the builder to increase sales velocity and therefore minimize carrying costs [5; 12]. Further, buyers of *new* homes, which were lower in value, might also have less of an appetite for PV, if it was considered a luxury good.

Finally, it has been discovered, sales agents for the *new* PV containing homes are sometimes not well versed in the specifics of PV [11], or downplay the unique characteristics of the PV system by discussing it with a suite of energy efficient features [12], which might have made the up-selling of the PV feature more difficult.[8] This set of postulates, although reasonable, are not investigated directly here, and therefore should be the focus of future research.

5. COMPARISON TO ENERGY SAVING ESTIMATES

As discussed earlier, premiums for PV (and other energy related features) are expected to be related to energy savings. In the energy efficiency (EE) literature, a ratio is often used to clarify this relationship, namely the ratio of the home sale price premium to the annual energy savings. These ratios have ranged from approximately 7:1 [e.g., 13], to approximately 20:1 [e.g., 15; 8] to as high as 31:1 [e.g., 16]. In the absence of similar studies for PV, practitioners have sometimes referred to these ratios for EE as also applicable to PV [e.g., 2], therefore comparing them might be fruitful.

Although actual home energy bill savings from PV for the sample of homes used for this research were not available, a rough estimate is possible, allowing for a comparison of our results to the previous results for EE. Specifically, assuming that 1,425 kWh (AC) are produced per year per kW (DC) of installed PV on a home [1; 4],[9] which offsets electricity use at an average rate of $0.20/kWh (AC) [6], each watt (DC) of installed PV can be estimated to save $0.29 in annual energy costs. Using these assumptions, the $/watt PV premium estimates reported earlier can be converted to sale price to energy savings ratios (see Fig. 4).

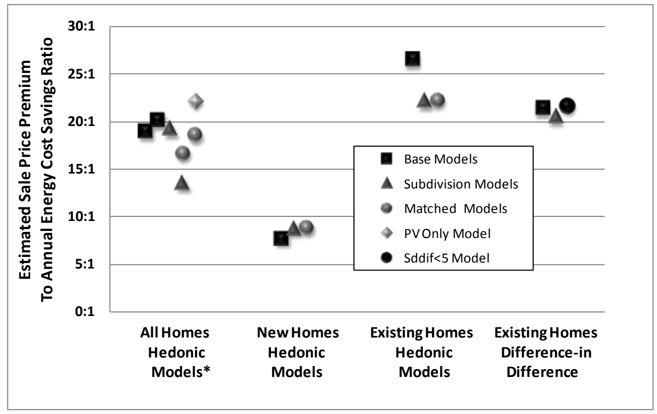

Fig. 4: Estimated Ratios of Sale Price Premium to Annual Energy Cost Savings

A $3.9 to $6.4/watt premium in selling price for an average CA home with PV installed equates to a 14:1 to 22:1 sale price to energy savings ratio, respectively. For *new* homes, with a $2.3-2.6/watt sale price premium, this ratio is estimated to be 8:1 or 9:1, and for *existing* homes, with an overall sale price premium range of $6-7.6/watt, the ratio is estimated to range from 21:1 to 26:1. Without actual energy bill savings, these estimates are somewhat speculative, but nonetheless are broadly consistent with the previous research that has focused on EE-based home energy improvement.

6. CONCLUSIONS

The market for solar PV is expanding rapidly in the U.S. Yet, one of the incentives (or barriers) for solar homes, namely the potential that a portion of the investment in PV will (or will not) be returned at the time of the eventual sale of the home, has not been well researched to date. Past research has focused on smaller sets of PV homes concentrated in one geographic area. Moreover, the effect of installing PV on a *new* versus an *existing* home has not previously been the subject of research.

[8] This scenario potentially stands in contrast to the emphasis existing home sellers might place on the PV system. Being intimately aware of the installation of the system and it benefits, the seller of existing homes might be able to more effectively up-sell the PV system.

[9] The 1,425 kWh (AC) estimate is a combination of a 0.19 capacity factor (Based on AC kWh and CEC-AC kW) from CPUC [4], and an 0.86 conversion factor between CEC-AC kW and DC kW [1].

This research has used a large dataset of approximately 72,000 California homes, approximately 2,000 of which had PV systems installed at the time of sale, and has estimated a variety of different hedonic, difference-in-difference, and robustness models to address the questions outlined above.

The research finds strong evidence that homes with PV systems have sold for a premium over comparable homes without PV systems, with estimates for the PV premiums ranging from roughly $3.9 to $6.4/watt. This average increase in sales price is coincident with the net installed cost of California PV systems from 2001-2009 [1], and also a recent study of PV home sales premiums in the San Diego metropolitan area [7], and also seems to be in-line with energy cost savings estimates found elsewhere.

When the dataset is split among *new* and *existing* homes, however, PV system premiums are found to be markedly affected, with *new* homes showing premiums of $2.3-2.6/watt, while *existing* homes often show premiums of $6-7.7/watt. *New* home sale price premiums are estimated to be below net installed PV system costs, whereas *existing* home premiums are above net installed costs. The reasons for this disparity for *new* PV homes, among others, might be a discounting of the PV system to favorably differentiate the product, which might lead to increased sales velocity and therefore decreased carrying costs, though further research is warranted.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

Although this research provides a robust estimate for sale price premiums for California homes with PV, additional questions remain that merit further research. Perhaps most importantly, although the dataset used for this analysis consists of almost 2,000 PV homes, the study period was limited to sales occurring prior to mid-2009 and the dataset was limited to California, therefore future research would ideally include more-recent sales from a broader geographic area. More research should also be conducted for *new* versus *existing* homes to better understand the differential discovered in this research, which could also include interviewing/surveying home builders and buyers, and investigating time-on-the-market (i.e. sales velocity) impacts.

Additionally, future research might compare actual home energy cost savings to sale price premiums, not only to explore the sale price to annual energy cost savings ratio directly, but also to explore if a green cachet exists over and above any sale price premiums would be expected from energy savings alone.

Further, house-by-house PV system and other information not included in the present study could be included in future studies, such as actual net installed costs of PV for individual homes, system age, rack-mounted or roof-integrated distinctions, and whether the PV system was customer or 3rd party owned at the time of sale, as well as the level of energy efficiency of the home.

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