Title

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I ABSTRACT

Relatively little research exists estimating the marginal impacts of photovoltaic (PV) energy systems on home sale prices. Using a large dataset of California homes that sold from 2000 through mid-2009, we find strong evidence, despite a variety of robustness checks, that *existing* homes with PV systems sold for a premium over comparable homes without PV systems, implying a near full return on investment. Premiums for *new* homes are found to be considerably lower than those for existing homes, implying, potentially, a tradeoff between price and sales velocity. The results have significant implications for homeowners, builders, appraisers, lenders, and policymakers.

II INTRODUCTION

California has been and continues to be the country's largest market for photovoltaic solar (PV), with nearly 1000 megawatts (MW) of cumulative capacity (SEIA & GTM, 2011). California is also approaching 100,000 individual PV systems installed, more than 90% of which are residential. One of the primary incentives for homeowners to install a PV system on their home, or for home buyers to purchase a home with a PV system already installed, 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 though, relatively little research has been conducted on the existence and level of these returns, though what has been done indicates that a premium does exist.

Farhar et al. (2004a; 2008) 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 these homes over comparable homes (n=12). More recently, Dastrup et al. (2011) used a hedonic analysis to investigate the selling prices of 329 homes with PV installed in the San Diego and Sacramento, California metropolitan areas, finding clear evidence of PV premiums that averaged approximately 3% of the total sales price of 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., Nevin and Watson, 1998; Nevin et al., 1999), 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 (Eichholtz et al., 2009; Brounen and Kok, 2010; Eichholtz et al., 2011), 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 (Barbose et al., 2010).

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 approximately a $1/watt average cost advantage over those on *existing* homes in retrofit applications (Barbose et al., 2010). Further, sellers of *new* homes with PV (i.e., new home developers) might be reluctant to increase home sale prices to the level that would return the full PV investment if, in return, there would be a *positive* impact of PV on product differentiation and sales velocity, as some have postulated (Dakin et al., 2008; SunPower, 2008). On net, it stands to reason that premiums for PV on *new* homes might be lower than those for *existing* homes.

Though a link between selling prices and *some combination* of energy cost savings, green cachet, recouping the net installed cost of PV, and seller behavior likely exists, the existing empirical literature in this area, has largely focused on either energy efficiency in residential and commercial settings (e.g., Nevin and Watson, 1998; Eichholtz et al., 2009), or PV in residential settings, but in a limited geographic area (San Diego and Sacramento), with relatively small sample sizes (e.g., Farhar et al., 2004a; Dastrup et al., 2011). Therefore, to date, establishing a reliable estimate for any existing PV premium across a wide market of homes has not been completed. Moreover, establishing premiums for *new* versus *existing* homes with PV has not yet been addressed.

To explore some of these possible relationships, we investigate the residential selling prices across California of homes with existing PV systems against a comparable set of non-PV homes. It should be stated that this research is *not* intended to disentangle the specific effects of energy savings, green cachet, recovery of the cost of installation, or seller motivations, but rather to establish credible estimates of aggregate PV residential sales price effects.

III METHODS AND STATISTICAL MODELS

A Methodological Overview

Several empirical model specifications, with a high reliance on the hedonic pricing model (Rosen, 1974; Freeman, 1979), are used in this paper to disentangle and control for the potentially competing influences of home, site and neighborhood characteristics in order to determine whether and to what degree PV homes sell for a premium. To test for the impact of PV systems on residential selling prices, a set of "base" models are estimated and coupled with a set of "robustness" models, to test and bound the estimated effects. Before describing these models in more detail, however, a summary of the variables to be included in the models is provided.

B Variables Used in Models

In the base models, four 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 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 (linear and squared), the total square feet of living area, and the relative elevation of the home (in feet) to other homes in the block group; the latter variable serves as a proxy for "scenic vista," a value-influencing characteristic (see e.g., Hoen et al., 2009). Additionally, the size of the property in acres was entered into the model in spline form to account for different valuations of less than one acre and greater than one acre.

The geographic dummy variables control for aggregated "neighborhood" influences, which, in our case, are census block groups. A census block group generally contains between 200 and 3,000 households, and is delineated to never cross boundaries of states, counties, or census tracts, and therefore, in our analysis, serves as a proxy for "neighborhood." To be usable, each block group had to contain at least one PV home and one non-PV home. The estimated coefficients for this group of variables capture the combined effects of school districts, tax rates, crime, distance to central business district and other block group specific characteristics. Because block groups are fairly small geographically, spatial autocorrelation is also, to some degree, dealt with through the inclusion of these variables.

Finally, the temporal dummy variables for each quarter of the study period control for any inaccuracies in the housing inflation adjustment. 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. [2] Although this adjustment is expected to greatly improve the model - relative to using *just* a set of temporal dummy variables 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 model is enhanced with the additional inclusion of these quarterly controls.[3]

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[2] For more info on how the index is constructed see: http://www.caseshiller.fiserv.com/indexes.aspx.

[3] A number of models were tested both with and without these temporal controls and with a variety of different temporal controls (e.g., monthly) and temporal/spatial controls (e.g., quarter and tract interactions). The quarterly dummy variables were the most parsimonious, and none of the other approaches impacted the results substantively.

C Fixed and Continuous Effect Hedonic Models

The analysis begins with the most basic model comparing prices of all of the PV homes (both *new* and *existing*) in the sample to non-PV homes across the dataset. As is common in the literature (e.g., Malpezzi, 2003; Sirmans et al., 2005b; Simons and Saginor, 2006), a semi-log functional form of the hedonic pricing 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 or dummy effect) we estimate the following base model:

$$\ln(\mathrm{P_{itk}}) = \alpha + \beta_1(\mathrm{T_t}) + \beta_2(\mathrm{N_i}) + \sum_{a} \beta_3(\mathrm{X_i}) + \beta_4(\mathrm{PV_i}) + \varepsilon_{\mathrm{itk}} \quad (1)$$

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_i is the quarter in which transaction *i* occurred, N_i is the census 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 indicates the presence of PV on transaction *i* and is measured as either a zero-one dichotomous variable (i.e., a fixed or dummy effect) or by the actual size of the PV system, β_1 through β_4 are parameters to be estimated, and ε_{itk} is a random disturbance term.

The parameter estimate of primary interest is β_4. If differences in selling prices exist between PV and non-PV homes, we would expect the coefficient for this parameter to be positive and statistically significant. The size based (continuous effect) specification of the model may be preferable to the dummy variable (fixed effect) specification 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, as size is related to energy bill savings.[4] Moreover, this specification allows for a direct estimate of any PV home sales premium in dollars per watt ($/watt), which is the form in which other estimates – namely average net installed costs – are reported. Therefore, although both specifications are reported, greater emphasis is placed on the size based (continuous effect) specification in this paper.[5]

D New and Existing Home Models

Although equation (1) is 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*. As discussed earlier, *new* homes with PV might have different premiums than *existing* homes. To try to tease out these possible differences, two additional base hedonic models are estimated using the continuous effect specification of equation 1, one with only *new* homes and the other with only *existing* homes.

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[4] Ideally, the energy bill savings associated with individual PV systems could be entered into the model directly, but these data were not available. Moreover, estimating the savings accurately on a system-by-system basis was not possible because of the myriad of different rate structures in California, the idiosyncratic nature of energy use at the household level, and variations in PV system designs and orientations.

[5] An anonymous reviewer wondered if there was an independent "existence" capitalization effect for solar, such that both the PV_i and PV_i*SIZE_i variables be included in models. We had initially explored this in a variety of models finding the PV_i variable was always insignificant in such specifications. Given these results we opted for the parsimonious alternative thereby eliminating the PV_i variable.

Comparing the coefficients of the SIZE variables (β_4) from these two models elucidates the relative size of the impact of PV systems across the two home types.[6]

IV DATA OVERVIEW

To estimate the models described above, a dataset of California homes is used that joins the following five different sets of data: (1) PV home addresses and system information from three organizations (California Energy Commission, California Public Utilities Commission, and the Sacramento Municipal Utility District) that have offered financial incentives to PV system owners in California; (2) real estate information that is matched to those addresses and that also includes the addresses of and information on a random sample of non-PV homes nearby (Core Logic, Inc); (3) home price index data that allow inflation adjustments of sale prices to 2009 dollars (Fiserv Case-Schiller Index)[7]; (4) locational data to map the homes with respect to nearby neighborhood/environmental influences (Sammamish Data Systems Inc.); and (5) elevation data to be used as a proxy for "scenic vista" (California Environmental Resources Evaluation System). Combining the PV system and real estate data via address allowed us to determine if a home sold after the PV system was installed. This sample of homes is the focus of our analysis. A subset of these data also sold *more* than once, and those that did so prior to the PV system installation were separated out, to be used in the difference-in-difference robustness check discussed below.

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[6] The results of this split model, though, are robust to the alternative specification as a combined new and existing model, as are models that allow each of the controlling parameters to vary by house type or block group, as was the suggestion of an anonymous reviewer.

[7] See link provided in footnote 1.

E Data Summary

The final full dataset includes a total of 72,319 transactions, with 1,894 PV homes and 70,425 non-PV homes. As indicated in Table 1, the average PV home not only has higher sales values (in 2009 $) relative to non-PV homes, but there are also important differences between PV and non-PV homes as regards to other home, site, neighborhood, and market characteristics that could, potentially, be driving differences in value. The dataset (as summarized in Table 2 and Table 3) has sales that: (1) are from 31 of the 58 counties in California; (2) are approximately 60% *existing* home types; (3) occurred over eleven years (1998-2009), with the largest concentration of PV sales occurring in 2007 and 2008; and (4) located primarily within four major utility service areas (Pacific Gas & Electric, Southern California Edison, San Diego Gas & Electric, and Sacramento Municipal Utility District), with the largest concentration in the Pacific Gas & Electric territory.

Table 1: Variable Descriptions and Summary Statistics

		Non-PV Homes (*n* = 70,425)		PV Homes (*n* = 1,894)	
Variable	**Description**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
sp2	most recent sale price (not adjusted for inflation)	$ 584,740	$ 369,116	$ 660,222	$ 435,217
asp2	inflation adjusted most recent sale price (in 2009 dollars)	$ 480,862	$ 348,530	$ 537,442	$ 387,023
lasp2	natural log of asp2	12.9	0.6	13.0	0.6
acre	size of the parcel (in acres)	0.3	0.8	0.4	1.0
acrelt1	number of acres less than one	0.2	0.2	0.2	0.2
ages2	age of home as of sd2	19	23.3	17.3	24.5
ages2sqr	ages2 squared	943	1681	937	1849
bgre_100	relative elevation to other homes in block group (in 100s of feet)	0.0	1.2	0.2	1.3
pvage	age of the PV system at the time of sale	0	0	1.5	2.0
size	size (in STC DC kW) of the PV system	0	0	3.1	1.6
sqft_1000	size of living area (in 1000s of square feet)	2.2	0.9	2.4	0.9
yrbuilt	year the home was built	1986	23	1989	25

Table 2: Frequency Summary by California County

CA County	Non-PV	PV	Total
Alameda	4,826	153	**4,979**
Butte	457	12	**469**
Contra Costa	5,882	138	**6,020**
El Dorado	938	85	**1,023**
Humboldt	7	2	**9**
Kern	2,498	53	**2,551**
Kings	134	5	**139**
Los Angeles	3,368	82	**3,450**
Marin	1,911	61	**1,972**
Merced	48	2	**50**
Monterey	10	2	**12**
Napa	36	1	**37**
Orange	1,581	44	**1,625**
Placer	11,832	159	**11,991**
Riverside	4,262	87	**4,349**
Sacramento	10,928	483	**11,411**
San Bernardino	2,138	50	**2,188**
San Diego	1,083	30	**1,113**
San Francisco	407	16	**423**
San Joaquin	1,807	20	**1,827**
San Luis Obispo	232	1	**233**
San Mateo	2,647	92	**2,739**
Santa Barbara	224	7	**231**
Santa Clara	6,127	157	**6,284**
Santa Cruz	90	1	**91**
Solano	2,413	39	**2,452**
Sonoma	1,246	32	**1,278**
Tulare	774	14	**788**
Ventura	1,643	42	**1,685**
Yolo	16	1	**17**
Yuba	860	23	**883**
Total	**70,425**	**1,894**	**72,319**

Table 3: Frequency Summary by Home Type, Utility and Sale Year

Home Type *	Non-PV	PV	Total
New Home	26,938	935	27,873
Existing Home	43,487	897	44,384
Utility **	**Non-PV**	**PV**	**Total**
Pacific Gas & Electric (PG&E)	36,137	1,019	37,156
Southern California Edison (SCE)	14,502	337	14,839
San Diego Gas & Electric (SDG&E)	8,191	35	8,226
Sacramento Municipal Utility District (SMUD)	11,393	498	11,891
Other	202	5	207
Sale Year	**Non-PV**	**PV**	**Total**
1999	110	0	110
2000	379	1	380
2001	1,335	10	1,345
2002	6,278	37	6,315
2003	8,783	63	8,846
2004	10,888	153	11,041
2005	10,678	168	10,846
2006	9,072	173	9,245
2007	8,794	472	9,266
2008	9,490	642	10,132
2009	4,618	175	4,793

** A portion of the PV homes could not be classified as either new or existing and therefore are not included in these totals*

*** Non-PV utility frequencies were estimated by mapping block groups to utility service areas, and then attributing the utility to all homes that were located in the block group*

V BASE MODEL ESTIMATION RESULTS

Estimation results for four models based on equation 1 are presented in Table 4. The relatively high model performance statistic (i.e., adjusted R^2, which equals 0.94) reflects, in part, the ability of the inflation index and temporal fixed effects variables to adequately control for market conditions, but, as one anonymous reviewer pointed out, is also an indication of the lack of variation inside the census block groups; without these fixed effects the statistic drops to approximately 0.45.[8] 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. For example, each additional 1000 square feet of living area added to a home is estimated to add between 19% and 26% to its value, while the first acre adds approximately 40% to its value with each additional acre adding approximately 1.5%. For each year a home ages, it is estimated that approximately 0.2% of its value is lost, yet at 60 years, age becomes an asset with homes older than that estimated to garner premiums for each additional year in age. Finally, for each additional 100 feet above the median elevation of the other homes in the block group, a home's value is estimated to increase by approximately 0.3%. These results can be benchmarked to other research. Specifically, Sirmans et al. (2005a; 2005b) conducted a meta-analysis of 64 hedonic pricing studies carried out in multiple locations in the U.S. during multiple time periods, and investigated similar characteristics as included in the models presented here, except for relative elevation. As a group, each of the home and site

[8] The results discussed below are robust to the removal of either or both the neighborhood fixed effects variables and the temporal variables.

characteristic estimates in the present study differ from the mean Sirmans et al. estimates by no more than one half of one standard deviation.

In summary, these results suggest that the hedonic models estimated here are effectively capturing many of the drivers to home sales prices in California, and therefore provide increased confidence that those same models can be used to accurately capture any PV effects that may exist.

F Fixed and Continuous Effect Hedonic Model Results

The results from the base hedonic models (equation 1), are shown in Table 4. These models estimate the differences across the full dataset between PV and non-PV homes, using either a dummy variable for the presence of PV system (PV) or the continuous specification using the size of the PV system (SIZE). Regardless of the specification, the variables of interest are positive and significant at the 1% level. The PV coefficient can be directly interpreted as, in the case of the dummy application, or used to determine, in the case of the continuous specification, the percentage increase in the sales price of a PV home over the mean non-PV home sales price in 2009 dollars based on an average sized PV system. By dividing the monetary value of this increase by the number of watts for the average sized system, this premium can be converted to 2009 dollars per watt ($/watt). Therefore, in the Dummy variable PV specification, multiplying the mean non-PV house value of $480,862 by 0.036 and dividing by 3120 watts, yields a premium of $5.5/watt (see bottom of second column in Table 4). Alternatively, the SIZE coefficient directly reflects the percentage increase in selling prices in 2009 dollars for each additional kW added to the PV system. Therefore, to convert the SIZE coefficient to $/watt, the mean house value for non-PV homes is multiplied by the coefficient and divided by 1000. Therefore, for the Continuous model (see third column in Table 4), $480,862 is multiplied by 0.012 and divided by 1000, resulting in an estimate of $5.8/watt.

Table 4: Base Hedonic Model Results

	Dummy	Continuous	New Home	Existing Home
pv	0.036***			
	(0.005)			
size		0.012***	0.006*	0.014***
		(0.002)	(0.003)	(0.002)
sqft_1000	0.253***	0.253***	0.247***	0.256***
	(0.001)	(0.001)	(0.002)	(0.002)
lt1acre	0.417***	0.416***	0.536***	0.373***
	(0.009)	(0.009)	(0.019)	(0.010)
acre	0.016***	0.016***	-0.007	0.019***
	(0.002)	(0.002)	(0.005)	(0.002)
ages2	-0.004***	-0.004***	-0.010	-0.005***
	(0.0002)	(0.0002)	(0.006)	(0.000)
ages2sqr	0.00003***	0.00003***	0.00768***	0.00004***
	(0.000003)	(0.000003)	(0.001676)	(0.000003)
bgre_100	0.003***	0.003***	0.008***	0.002
	(0.001)	(0.001)	(0.001)	(0.001)
intercept	12.703***	12.702***	12.651***	12.820***
	(0.010)	(0.010)	(0.022)	(0.013)
*Numbers in parenthesis are standard errors, *** p<0.01, ** p<0.05, * p<0.1*				
Results for subdivision, block group, and quarterly fixed effect variables are not reported here, but are available upon request from the authors				
Total n	72,319	72,319	27,873	44,384
Adjusted R^2	0.93	0.93	0.94	0.93
n (pv homes)	1,894	1,894	935	897
Mean non-pv asp2	$ 480,862	$ 480,862	$ 397,265	$ 532,645
Mean size (kW)	3.1	3.1	2.5	3.8
Estimated $/Watt	$ 5.5	$ 5.8	$ 2.3	$ 7.7

These results are in line with those found previously by Dastrup, et al. (2011), even though they focused, to some degree, on different geographies. They estimated an average increase in selling price of $15,373, which, when divided by their mean PV system size of 3.37 kW, implies an effect of $4.6/watt, though, their sample, which consisted of 329 PV sales, were focused in San Diego (*n* = 275) and Sacramento, CA (*n* = 54), while our analysis had 35 and 498 sales in those areas, respectively (see Table 3). Additionally, our results are in line with, though slightly higher than, the mean net installed costs of PV on homes in California of approximately $5/watt over the same period (Barbose et al., 2010). This result may indicate that both buyers and sellers are using the net installed cost as a partial basis to value a PV home.

Although not investigated here, one possible reason for sales price premiums that are above net installed costs is that buyers of PV homes may in some cases price in the opportunity cost of avoiding having to do the PV installation themselves, which might be perceived as complex. Moreover, a PV system installation that occurs after the purchase of the home would likely be financed outside the first mortgage and would therefore loose valuable finance and tax benefits, thereby making the purchase of a PV home potentially more attractive that installing a PV system later, even if at the same cost.

G New and Existing Home Model Results

Turning from the full dataset to one specific to the home type, we estimate base models for *new* and *existing* homes, as also shown in Table 4. The coefficient of interest, SIZE, is statistically significant at or below the 10% level in the *new* home model and at the 1% level in the *existing* home model. Estimates for the average $/watt increase in selling prices as a result of PV systems for *new* homes is $2.3/watt, whereas the comparable value for *existing* homes is $7.7/watt.

Though, the apparent discrepancy in premiums between *new* and *existing* homes is consistent with *a priori* expectations, the exact reasons are unclear and warrant future research. They might be explained, in part, by the difference in average net installed costs, which, from 2007 to 2009, were approximately $5.2/watt for *existing* homes and $4.2/watt for *new* homes in California (derived from the dataset used for Barbose et al., 2010). The gap in net installed costs between *new* and *existing* homes is not wide enough to fully account for these findings, however.

Several alternative explanations for the disparity between *new* and *existing* home premiums exist. There is some evidence that builders of *new* homes might discount premiums for PV if, in exchange, PV systems provide other benefits for new home developers, such as greater product differentiation and increased sales velocity, thus decreasing overall carrying costs, as some case studies (Dakin et al., 2008) and industry reports (SunPower, 2008) have suggested. Further, sellers of *new* homes with PV might be reluctant to try to fully recoup installed PV system costs because of the burgeoning state of the market for PV homes and concern that more aggressive pricing could slow home sales. Also, because many builders of *new* homes began offering PV as a standard feature (rather than an option) over the last few years (Farhar et al., 2004b; Dakin et al., 2008) PV premiums might have been more difficult to maximize. For example, because sales agents for the *new* PV homes have been found to either not be well versed in the specifics of PV and felt that selling a PV system was a new sales pitch (Farhar et al., 2004b) or to have combined the discussion of PV with a set of other energy features (Dakin et al., 2008), up-selling the full value of the PV system as a standard product feature might not have been possible. A final postulate for the relatively small *new* home premium exists: because the average sales price of *new* PV homes in our dataset is lower than the average sales price of *existing* PV homes, and PV is considered a luxury good, it may be somewhat less-highly valued for the buyers of the *new* homes.[9]

These downward influences for *new* homes might potentially contrast with analogous upward influences for *existing* homes, creating a larger disparity. For example, buyers of *existing* homes with PV may, to a greater degree than buyers of the less expensive *new* homes in our sample, be self-selected towards those who place particular value on a PV home, and therefore value the investment more. Additionally, in contrast to *new* home sellers, who might not be familiar with the intricacies and benefits of the PV system, *existing* home sellers are likely to be very familiar with the particulars of the system and its benefits, and therefore might be able to "up-sell" it more effectively.

[9] In addition to the alternative explanations offered herein, an anonymous reviewer suggested two other possibilities: (1) developers install solar on enough homes in the neighborhood to make the visible panels effective advertising of the target buyer types and since we are using within-neighborhood comparisons this would tend to equalize solar and non-solar prices in new communities; and (2) a new development may feature some homes with PVs, other homes in the neighborhood with extras not observable in our dataset (e.g., passive lighting), and maybe some homes with both thus making an omitted variables problem more likely in new subdivisions. Sorting through these many possibilities is beyond the scope of this paper.

These possible influences, in combination, may explain the difference in average PV premiums between *new* and *existing* homes. Evaluating the effect on sale price premiums of these specific drivers is beyond the scope of this work, but warrants further study.

H Robustness Tests

For each base model we explore a number of different robustness models to better understand if and to what degree the results are potentially biased. Although an abbreviated discussion is included here, a full discussion of these tests and their results is available in Hoen at al., 2011.

Two areas of bias are of particular concern: omitted variable bias and sample selection bias, and therefore robustness tests are created to address these biases. To potentially mitigate the issue of omitted variable bias, two methods were explored: 1) a variety of other home and site characteristics, that were not fully populated across our sample, are tested, such as the condition of the home, the number of bathrooms, the number of fireplaces, and if the home had a garage and/or a pool; and 2) a subdivision dummy variable is substituted, where available, as a proxy for "neighborhood" in place of the block-group dummy variables. To mitigate the issue of selection bias, a "coarsened exact matched" dataset is used (King et al., 2010; Iacus et al., 2011), instead of the full dataset. These two sets of robustness models are also applied to both the *new* and *existing* home models, and an additional set of robustness tests is estimated for the *existing* homes in the form of a difference-in-difference model.

The results from these models similarly estimate a relatively large statistically significant premium for PV homes, but indicate that the base models might be overstating the effect and that the true effect might instead be in the range of $3.9/watt to $4.8/watt for an average PV home. The robustness results for *new* and *existing* homes imply that the actual premiums, respectively, might be slightly larger ($2.6/watt) and slightly smaller (between $6.0 and $6.5/watt) than what was estimated in the base models. Regardless of the absolute magnitude, a sizable premium for PV homes over non-PV homes is clearly evident in the results, as is the premium for *existing* PV homes over that garnered by *new* PV homes.

VI COMPARISON TO ENERGY SAVINGS 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., Horowitz and Haeri, 1990), to approximately 20:1 (e.g., Nevin et al., 1999; Eichholtz et al., 2009) to as high as 31:1 (e.g., Nevin and Watson, 1998). In the absence of similar studies for PV, practitioners have sometimes referred to these ratios for EE as also applicable to PV (e.g., Black, 2010).

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 (Barbose et al., 2010; 2010),[10] which offsets electricity use at an average rate of $0.20/kWh (AC) (Darghouth et al., 2010), 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. Thus, 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.

VII CONCLUSIONS

The market for solar PV is expanding rapidly in the U.S. Almost 100,000 PV systems have been installed in California alone, more than 90% of which are residential. Some of those "PV homes" have sold, yet little research existed estimating if those homes sold for significantly more than similar non-PV homes. This research has used a dataset of approximately 72,000 California homes, approximately 2,000 of which had PV systems installed at the time of sale, and has

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[10] 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 (2010), and an 0.86 conversion factor between CEC-AC kW and DC kW (Barbose et al., 2010).

estimated a variety of different hedonic and difference-in-difference models to directly address this question.

The research finds strong evidence that homes with PV systems in California have sold for a premium over comparable homes without PV systems. More specifically, estimates for average PV premiums range from approximately $3.9 to $5.8 per installed watt (DC), among a variety of different model specifications that coalesce near $5.5/watt. That value corresponds to a premium of approximately $17,000 for a relatively new 3,100 watt PV system (the average size of PV systems in the study). This implies an approximate near-full return on homeowner investment (i.e., after state and federal incentives) given average net installed costs of PV systems in California during the study period of near $5/watt.

When the dataset is split among *new* and *existing* homes, PV system premiums are found to be markedly affected, with *new* homes demonstrating average premiums of $2.3-2.6/watt, while *existing* homes are found to have average premiums of $6-7.7/watt. The *new* home findings imply, potentially, a trade-off between sales price and sales velocity.

These results have potentially significant implications for stakeholders in the PV arena, including homeowners, builders, appraisers, lenders, and even state and federal policymakers. Solar PV investments are sizable, and must be made under uncertainty, as future electricity rates, electrical output, and on-going maintenance requirements cannot be known with precision. Given the possibility that a homeowner might not reside in their home for long enough to experience the full returns of electricity bill savings from their PV investment, uncertainty over the impact of

PV on home resale value could further dissuade investment in PV and thereby slow solar deployment. State and federal policymakers, meanwhile, have developed a variety of incentive programs to try to overcome these barriers and to increase solar deployment. Our results strongly suggest that, on average at least, PV systems have substantial value upon home sale, thereby reducing this source of uncertainty for buyers, sellers, and developers, and potentially facilitating increased deployment of solar systems. If popularized, these results could reduce the amount of state and federal incentives that might otherwise be needed to support a given amount of solar deployment. To make such an outcome possible, however, homeowners would need to include resale value considerations when making investment decisions, which requires more-comprehensive life-cycle costing approaches rather than the simple payback calculations that are often used but that ignore resale value. Acceptance by appraisers and lenders of the resale value of PV could further reinforce to homeowners that such impacts are real, and such changes seem to be underfoot (e.g., Appraisal Institute, 2011). Finally, though our results suggest that new home builders can also expect a premium for solar homes, the average premium has not – to this point – been sufficient to cover the net cost of PV systems. Encouraging greater uptake of solar in new homes may therefore require higher state and federal incentive levels and/or greater customer education, or for homebuilders to more-fully recognize the other possible benefits of PV in the form of sales velocity and other considerations.

Finally, this research uncovers a number of possible future areas of research, most notably: 1) future research would ideally include more-recent sales (the present sample was limited to mid-2009) from a broader geographic area to better understand any regional/national differences that may exist including differences in net installed costs and therefore increase external validity, and also to better understand how/if the recent housing market crash affected PV premiums; and 2) comparing sales price premiums to actual annual home energy cost savings, to not only 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 that would be expected from energy cost savings alone.

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IX DATA APPENDIX

I Data Processing

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.

To focus our analysis on more-typical California homes, sales transactions were required to meet the following criteria (see Table 1 for variable descriptions and summary statistics):

- an inflation adjusted most recent sale price between $85,000 and $2,500,000;
- living area in square feet greater than 750;
- price per square feet of living area between $40 and $1,000;
- lot size greater than living area but less than 25 acres;
- year built more recent than 1900;
- age of the home (in years) at the time of the most recent sale greater than or equal to negative one;
- number of bathrooms greater than zero and less than ten;
- size of the PV system greater than 0.5 and less than 10 kilowatts (kW); and
- total assessed value less than or equal to the predicted assessed value, where the latter equal the most recent sale price*1.02^(2010-year of sale). (This screen was intended to help ensure that homes that had significant improvements since the most recent sale, which would

be reflected in a higher assessed value than would otherwise be the maximum allowable under California property tax law, were removed from the dataset. The screen was not applied to homes that sold in 2009, however, because, in those cases, assessed values often had not been updated to reflect the most recent sale.)

In addition, each census block group in the study was required to contain at least one PV home sale and one non-PV home sale. In total, these screens removed 213 PV homes and 8,418 non-PV homes from the sample. The results are robust to their individual and collective inclusion. In addition to the screens listed, a number of alternatives were tested, such as limiting the sample to only homes with sale prices less than $1 million or $600,000, or to homes that had smaller "footprints", none of which influenced the results significantly.

J New and Existing Homes

New and existing homes were determined in an iterative process. For PV homes, the type of home was often specified by the data provider. It was also discovered that virtually all of the new PV homes (as specified by the PV data providers) had ages, at the time of sale, between negative one and two years, inclusive, whereas the existing PV homes (as specified by the PV data providers) had ages greater than two years in virtually every case. The small percentage (3%) of PV homes that did not fit these criteria was excluded from the models. For non-PV homes, no data specifying the home type were available, therefore, groupings were created following the age at sale criteria used for PV homes (e.g., ages between negative one and two years apply to new non-PV homes).

The approximately 50:50 ratio of new homes to existing homes occurs because our sampling procedure begins with solar home sales and is then augmented with a random sample of comparable homes. This suggests that the sample may not be truly representative of the overall population of home sales, which would have a higher proportion of existing homes, nor of the population of PV homes, which are heavily weighted toward existing homes (see Barbose et al. 2011).