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Exploring the Influence of Solar Panels on Housing Values:
A Preliminary Review of the Literature and Potential Data

Abstract: Through a collaboration with the Lawrence Berkeley National Laboratory (LBNL), we are leveraging a unique opportunity to combine Fannie Mae's Collateral Underwriter® data with LBNL data on solar panel installations. Our initial match between the two datasets includes 126,622 unique single-family homes with solar panels in California, and 6,409 of these properties received repeat appraisals pre- and post-solar panel installation. This initial research brief provides a detailed overview of the prior literature exploring the relationship between property values and solar panels, as well as a descriptive summary of the sample characteristics for this merged sample of appraisal data and solar panel characteristics. In the final section we discuss the next steps in our data work, the methodology we expect to follow to explore the relationship between solar panels and housing values, and our plans to exploit some unique features of the data in our final research design.

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PRELIMINARY RESEARCH: PLEASE DO NOT CITE WITHOUT THE AUTHOR'S PERMISSION.

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Introduction

Solar is an increasingly popular green home energy feature, with residential solar panel installations growing at 59% annually in the decade after the 2006 Solar Investment Tax Credit according to the Solar Energy Industries Association (SEIA) (SEIA 2018A, SEIA 2018B).[1] Solar energy is part of a larger global movement to increase the number of high performance dwellings, and these efforts are reflected in the building industry, in government policies, and in the investment community. The growing popularity of green improvements is partially due to the many benefits of renewable energy and energy efficient investments: zero or reduced energy housing provides cost-savings to households, reduces infrastructure burdens for municipalities, and reduces stress on the environment. In fact, California recently implemented a statewide policy mandating solar in all new construction starting in 2020, noting that consumers will experience cost-savings, grids will experience improved reliability, and greenhouse gas emissions will be reduced (California Energy Commission 2018). California is also the clear leader in solar panel installations with 40% of the total residential solar panel market share in 2017 (SEIA 2018A).

These two facts make California a unique and important housing market for studying green features, and although there are a number of studies looking at the success of solar panels in California, none have access to the depth and breadth of data necessarily to fully understand the market. Through a collaboration between Fannie Mae and Lawrence Berkeley National Laboratory (LBNL), we were able to merge data on solar properties in California with residential property appraisal information. This data match provides a vast amount of detailed information on both housing and solar panels originating from industry data used for transactions and lending decisions, which means we have more details as well as more accurate data than other studies that rely on public records data. This is a unique opportunity to learn more about the relationship between solar panels and housing values as reflected in residential appraisals.

Our merged dataset includes information on solar panel adoptions, housing characteristics, sales comparables, property valuations, and in some cases, homeowner characteristics (for the subset of loans that are ultimately purchased by Fannie Mae). With this wealth of data, we hope to establish salient facts about the housing experience of solar homes, which can be used for better decisions surrounding solar panel property financing, development, and public policy. We also hope to offer a better understanding of whether and how the appraisal community treats solar panels in their appraisal processes given our unique view of appraisal documentation.[2]

Our initial match of the two datasets includes 126,622 unique single-family homes with solar in California, and 6,409 properties that have repeat observations pre- and post-solar panel installation. This initial research brief provides a detailed overview of our matched sample, and explores patterns in appraised property values before and after solar installations. In the final section we discuss the next steps in our data work, including the

[1] This is a 30% nonrefundable investment tax credit based on solar panel installation investment costs (SEIA 2018B, US Department of Treasury 2017).

[2] Our findings will correspond to aggregate trends, and will not be individual-property-specific.

methodology we plan to follow to test the robustness of our preliminary findings, and our plans to exploit some unique features of the data in our final research design.

Prior research

Not surprisingly, the majority of the solar homes literature focuses on California's experience, although a handful of studies also incorporate other states as well. In general, the research finds housing value premiums for properties with solar panels, although the study sample sizes are often small or have limited geographic scope. For example, Dastrup et al (2013), analyzing just solar in San Diego, estimate a 3% premium for solar homes based on housing values and repeat sales indices from the late 1990s through the late 2000s. Similarly, Hoen et al (2013) also find a price premium for solar properties in California using data through 2009, but find that this premium is smaller for new homes. Looking more closely at differences in values based on solar ownership structure, Hoen, Rand, and Adomatis (2017) find premiums for household-owned solar panels, but they are unable to find similar premiums for leased solar panels in their data on housing transactions in California between 2011 and 2013.[3, 4]

Additionally, the California literature on incentives, savings, and adoption suggests that the local policy and socioeconomic context matters a great deal. Exploring peer effects in solar adoption, Bollinger and Gillingham (2012), find evidence of a "causal" relationship—an additional solar installation within a zip code increases the probability of new solar panel adoption by 0.78 percentage points. Similarly, Borenstein (2015) finds that more affluent households in California install solar panels, and the average solar user since 2010 likely saved money over the life of the system within the context of the state and federal incentive structures. Also looking at adoption and incentives, Hughes and Podelesfky (2014) find that upfront rebates have a large effect on solar installations, and they predict almost 60% fewer installations would have occurred without state subsidies.[5]

Research outside of the California-context also finds solar premiums in housing values. In a multistate study, Adomatis and Hoen (2016) use appraisal methods to estimate price premiums for a small sample of single family solar homes across six states and consistently find evidence of premiums, regardless of state. In a larger study incorporating eight states, Hoen et al (2017) again find evidence of solar premiums, this time amounting to about $15,000 or $4/watt, with similar estimates of the premium regardless of the methodological approach (i.e., they estimate savings using hedonic models, the present value of saved energy, and a replacement cost approach). They also explore how difference solar panel characteristics affect values: such as, system size, age, and ownership. Qiu, Wang, and Wang (2017), focusing only on a small sample in Arizona, estimate larger premiums, and also find differential results for housing values (i.e., the whole owner-occupied housing stock) compared with housing transaction prices (i.e., only properties that sell during their sample timeframe): they

[3] A closer look at the solar lease payments noted that they may potentially offset any value derived from solar savings.
[4] However, a Texas-based analysis of solar ownership structure finds that the leasing model can provide important benefits and options to homeowners interested in adopting solar energy, particularly those with less available disposable income (Rai and Sigrin 2013).
[5] Dargouth, Barbose, Wiser (2010) provide a detailed review of the California-specific electricity metering and incentive nuances, including how these features relate to disparate solar savings based on installation-type and metering structure.

estimate the housing value premium for solar panels is about $45,000, while the premium on houses that are actually transacting is closer to $28,000. Wee (2016) finds a result of similar magnitude ($35,000) for solar home transactions in Hawai'i.[6]

Studies looking more broadly at the green housing investment experience tend to focus on the value of the green premium on housing prices or values or the financial return on energy investments. Looking at the premiums associated with green labels more broadly (not just solar), Kahn and Kok (2013) estimate a 2.1% premium on home transaction prices in California. Similarly, Shewmake and Viscusi (2014) find a 5.0% premium, on average, for green label homes in Austin, and Bardhan et al (2014) highlight a number of recent studies that also find the potential for positive returns on energy efficient investments. On the other hand, a recent study exploring the costs and benefits of energy efficient home improvements made through the federal Weatherization Assistance Program found that the returns to investment do not justify the upfront costs. However, their analysis does not incorporate increases in property value due to the energy efficient improvements, and thus potentially understates overall returns to homeowners (Fowlie, Greenstone, and Wolfram 2018).

Data

This collaboration between Fannie Mae and Lawrence Berkeley National Laboratory allows for a unique opportunity for detailed exploration of solar panel installations in California. The LBNL data includes property-level solar panel installations for California, which they collect through their Tracking the Sun (TTS) initiative.[7] The data LBNL provided to Fannie Mae includes all residential solar installations from 1999 through 2017 in the three investor-owned utility service areas of the state, which is 93% of the total systems and 5% of the total housing units in the state,[8] with 654,340 unique installation addresses. The Fannie Mae data came from its Collateral Underwriter® (CU) database, a proprietary internal Fannie Mae appraisal review database. The universe of CU is Fannie Mae loan applications (purchase and refinance) for properties between 2012 and the 2018, with a smaller sample of property data collected from 2011. In addition to the property-specific appraisal information for each home, these data also include a set of property-specific comparables for each property with analogous property information for the comparables. Matching the CU and the LBNL solar data was conducted using Melissa Data's (MD) address verification service.[9] MD provides United States Postal Service address standardization and verification, and returns a unique persistent all-numerical address ID that can be used in place of matching address strings between the datasets. We presented MD with the set of CU and LBNL addresses and, once returned, were able to match them using the MD standardized ID.

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[6] Although they note the premium is partially due to supply restrictions affecting on permit availability in these neighborhoods.

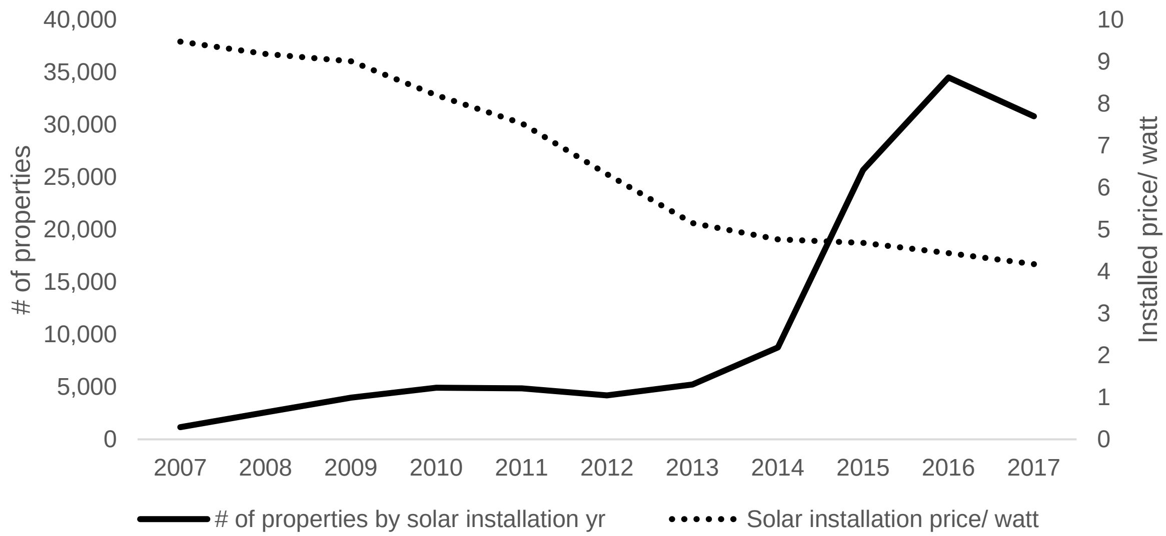
[7] A public version of the LBNL data, with addresses redacted is available here: https://emp.lbl.gov/tracking-the-sun/. For more information about the California-specific data collection process, see Barbose and Darghouth (2018).

[8] The solar panel data only includes solar homes in investor-owned utility service areas, so it does not include the two municipal utility districts: the Los Angeles Department of Water and Power and the Sacramento Municipal Utility District.

[9] For more information, please see: https://www.melissa.com/address-verification.

The merge of the Fannie CU data with the LBNL TTS data yielded 323,308 unique properties, of which 126,622 are single-family, fee-simple homes with owner-purchased solar panels installed.[10] The solar installation dates and solar installation price for the 126,622 properties are shown in Figure 1, reflecting the sharp increase in solar panel installations over time, which coincides with a decrease in the installed solar panel price per watt over time as reported in the LBNL data (in 2017$s).[11] Both of these patterns are consistent with general industry trends (SEIA 2018B).

Figure 1: Solar property installations and solar panel price/ watt (2017$s)



Source: Author calculations from LBNL and Fannie Mae matched dataset.

Table 1 shows the summary statistics for the 126,622 individual properties in the merged dataset. The summary statistics offer a few different views of the sample, with variables such as "appraised market value" representing the market value of the property provided by an appraisal, and the "contract price" representing the reported sale price of the property as provided by the appraisal (if used in the appraisal). The first panel in Table 1 represents the full set of properties, using the earliest observation for each property for properties that are appraised more than once in the sample. All of the $ amounts are nominal, with the exception of the solar panel installed price/ watt. The mean year of solar installation and appraisal is 2015, with a mean appraised property value of $712,177, a median property appraised value of $575,000,[12] and a mean installation price per watt for the solar panels of $5.12. Most of the properties are also fairly new and large (with 4 bedrooms and an average year built of 1982). The summary statistics reflect considerable variation across properties with

[10] We drop properties with contract prices of greater than $5M and less than $10,000. We also eliminate homes with leased solar systems (as well as ones with unclear solar ownership) because Fannie Mae's Selling Guide does not allow for leased solar panels to be considered in the appraised value of the property (Fannie Mae 2018, pg. 277). This accounted for 54% of the initial matched sample.

[11] Prices represent the gross installed costs and do not include federal, state or utility incentives. Therefore price the property owner pays is lower because for virtually every installation some or all of these incentives applies.

[12] In contrast, the median value of a single-family home in California in December 2017 as estimated by Zillow was $530,500.

respect to property size, age, and values. This is in part due to the diverse geographic representation of cities, and differences within local housing markets in the state.

A number of properties in these data are observed prior to their solar installation, and the descriptive characteristics for these properties are in the second panel of Table 1. Not surprisingly, these properties were appraised earlier, in 2013 on average, and their solar panels were installed slightly later, in 2015 on average. Finally, the last panel reflects properties for which we have complete information, including reported contract prices in the appraisal data. In general, these properties look similar to the rest of the sample.

Table 1: Summary Statistics for the matched sample

Variable	N	Median	Mean	Std. Dev.	Min	Max
First observation, all properties						
Property characteristics						
Year appraised	126,605	2015	2015	2	2011	2018
Contract price	22,207	550,000	671,587	455,160	100,000	4,850,000
Appraised market value	126,622	575,000	712,177	535,347	27,000	9,900,000
Year built/ renovated	126,544	1986	1982	23	1801	2018
Square footage	126,584	2,293	2,438	941	216	21,440
# of rooms	126,606	8	8	2	2	20
# of bedrooms	126,606	4	4	1	0	10
Solar characteristics						
Year panels installed	126,622	2016	2015	2	1999	2017
Panel size (kilowatts)	126,622	5.67	6.10	2.80	1.00	20.00
Price/ watt (2017$)	114,467	4.64	5.12	2.13	1.00	19.98
Pre-solar installation						
Property characteristics						
Year appraised	53,555	2013	2013	1	2011	2016
Contract price	9,251	525,000	626,624	417,294	100,000	4,800,000
Appraised market value	53,572	550,000	652,380	437,861	52,000	9,500,000
Year built/ renovated	53,512	1984	1980	22	1860	2016
Square footage	53,545	2,271	2,405	905	216	21,440
# of rooms	53,558	8	8	2	2	18
# of bedrooms	53,559	4	4	1	0	10
All fields populated						
Property characteristics						
Year appraised	20,340	2015	2015	2	2012	2018
Contract price	20,340	554,300	672,412	453,726	100,000	4,800,000
Appraised market value	20,340	559,000	676,648	454,172	80,000	4,800,000
Year built/ renovated	20,340	1990	1986	21	1860	2018
Square footage	20,340	2,340	2,474	920	442	9,804
# of rooms	20,340	8	8	2	3	19
# of bedrooms	20,340	4	4	1	1	10
Solar characteristics						
Year panels installed	20,340	2016	2015	2	2001	2017
Panel size (kilowatts)	20,340	5.98	6.33	2.93	1.00	19.95
Price/ watt (2017$)	20,340	4.43	4.83	1.93	1.00	19.86

Source: Author calculations from LBNL and Fannie Mae matched dataset.

Table 2 reflects the top 10 cities by property volume in these data, these cities collectively represent about 20.8% of the sample, with the largest share, 6.5%, or 8,166 properties, located in San Diego. The majority of these cities are in Southern California and the Central Valley.

Table 2: Geographic distribution of top 10 cities in matched sample

	City	N	%
1	San Diego	8,166	6.5
2	San Jose	3,913	3.1
3	Bakersfield	2,766	2.2
4	Fresno	2,376	1.9
5	Escondido	1,831	1.5
6	Clovis	1,559	1.2
7	El Cajon	1,496	1.2
8	Carlsbad	1,445	1.1
9	Corona	1,420	1.1
10	Chula Vista	1,345	1.1
	Sum	26,317	20.8%

Source: Author calculations from LBNL and Fannie Mae matched dataset.

Finally, our matched dataset also offers the opportunity to look at repeat-appraisals for the same property across different time periods. For some properties we have property appraisals both pre- and post-solar installation. We can potentially use these repeated property observations to isolate the influence of solar panels on property values. In our current sample, we have 6,409 properties where we observe appraisals both pre- and post-solar installation.[13]

Next Steps

In the next phase of this project, we intend to undertake a number of additional steps to understand the relationship between solar panels and property values. First, we plan to econometrically model the influence of solar panels on property values using the variables available to us in the data; such as property size, construction quality, appraisal date, solar panel installation date, and number of bedrooms, among others. We also plan to merge in local housing price indices to capture disparities in local housing market growth over this time period. Controlling for property characteristics, local housing market growth, and appraisal timing will help to statistically isolate the relationship between solar installations and property values. We also hope that it will allow us to answer more detailed questions about solar panels, such as: whether solar panel premiums changing over time and whether there are specific aspects of solar panel characteristics that are correlated with either the presence or magnitude of premiums.

Second, we plan to use the appraisal data to better understand how appraisers factor the presence of solar panels into their valuations. The merged dataset has the advantage of providing appraiser-specific property inputs, demonstrating whether the appraiser flagged the property and its comparables as having solar or other energy-efficient features. We can use this information to gauge whether appraisers are explicitly considering/documenting solar panels in their property valuations. We can also use this information to get a

[13] Given potential delays in the recording of solar installations, we eliminate observations where the solar panel installation is within 11 months from the appraisal date.

more comprehensive understanding of how energy efficient features are bundled at the property-level, and to explore the influence of interactions between solar panels and other types of green upgrades on property values.

Third, we plan to exploit some unique features of the data to further isolate the relationship between solar panel installation and property values. We intend to employ a quasi-experimental research design that will incorporate the comparable property information we have in our data. We can use these comparables as an additional comparison group for our sample, and they are an ideal control group for each property because they have already been chosen by professionals as similar to the subject property for valuation purposes. We will also be able to compare similar properties with and without solar panels to hedonically establish another estimate of the contribution of solar panels to property values. Moreover, in our dataset, we will be able to see whether these properties also have solar panels. If so, we can compare the specific features of the solar panels (e.g., age, size, price per watt), which will allow us to decompose the influence of solar panels based on these components. These quasi-experimental designs will not eliminate selection biases in our sample, but they will help to provide robustness checks to improve confidence in results and to verify statistically-significant findings in the literature.

Finally, we plan to extend the analysis to additional states. Currently, we have data on solar panel installations for the majority of California and all of Massachusetts, and we are working to incorporate data from a number of other states that collect solar panel data. We have currently received some data from New Mexico, Oregon, Pennsylvania, and Vermont, and we are hoping to receive in the future data for Connecticut, North Carolina, Nevada, New York, and Rhode Island. The additional information we glean from these states will be particularly beneficial to establishing the generalizability of our findings and to identify disparate relationships between solar panels and property values across states. The addition of these data also adds the potential for exploiting exogenous changes in energy policy across states, which will help us to isolate a causal effect of solar panel installations on property values.

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