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ABSTRACT

This study uses a large sample of homes in the San Diego area and Sacramento, California area to provide some of the first capitalization estimates of the sales value of homes with solar panels relative to comparable homes without solar panels. Although the residential solar home market continues to grow, there is little direct evidence on the market capitalization effect. Using both hedonics and a repeat sales index approach we find that solar panels are capitalized at roughly a 3.5% premium. This premium is larger in communities with a greater share of college graduates and of registered Prius hybrid vehicles.

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I. Introduction

On a per-capita basis, California has the most installed residential solar capacity in the United States. Solar homes are expensive. It can cost $30,000 to install such a system. Several state and federal programs actively subsidize this investment. Judged on strictly efficiency criteria (foregone electricity expenditure per dollar of investment), solar panels may be a bad investment. Borenstein (2008) finds that the cost of a solar photovoltaic system is about 80 percent greater than the value of the electricity it will produce.

Solar panels bundle both investment opportunities (the net present value of the flow of electricity they generate) and conspicuous consumption opportunities (that it is common knowledge that your home is "green"). Kotchen (2006) provides a theoretical analysis of the case in which individuals have the option of consuming "impure" public goods that generate private and public goods as a joint product. Outside of the Toyota Prius, solar homes are perhaps the best known "green products" sold on the market.

The owner of a solar home faces low electricity bills and, if an environmentalist, enjoys the "warm glow" for "doing his duty" and producing minimal greenhouse gases (Andreoni 1990). Because the presence of solar panels on most roofs is readily apparent, the solar home owner knows that others in the same community know that the home owner has solar panels. This community level re-enforcement may further increase the demand for this green product. This "observability" is likely to be even more valued in an environmentalist community (i.e a Berkeley) than in a community that dismisses climate change concerns. The recent political divide between Democrats and Republicans over climate change mitigation efforts (see Cragg, Zhou, Gurney and Kahn 2011) highlights that in conservative communities solar panels may offer less "warm glow" utility to its owners.

We examine two facets of solar purchases in this paper. Our primary empirical contribution is to provide new hedonic marginal valuation estimates for a large sample of solar homes based on recent real estate transactions in San Diego County. We test the robustness of our results using data from Sacramento County. We document evidence of a solar price premium and find that this premium is larger in environmentalist communities. In most mature housing markets, we expect that the econometrician knows less about the market than the decision makers. In the case of solar panels, our interactions with professionals in the field suggests that these professionals have little basis for estimating the pecuniary benefits of solar installation.

Our second empirical contribution is to document what types of people, in terms of education, political ideology and demographic attributes do and do not live in solar homes. Most hedonic studies which use sales data (rather than Census data) have little information about the household living in the home, but we can observe household characteristics for a single year.

Our hedonic study contributes to two literatures. The real estate hedonics literature explores how different housing attributes are capitalized into home prices. Solar installation can be thought of as a quality improvement in the home. Recent studies have used longitudinal data sets such as the American Housing Survey (which tracks the same homes over time) to study how home upgrades such as new bathrooms and other home improvements are capitalized into resale values (Harding, Rosenthal and Sirmans 2007, Wilhelmsson 2008). A distinctive feature of solar panels is that on a day to day basis they have no "use value" as compared to a new bathroom or kitchen. Solar panels reduce your household's need to purchase electricity but from an investment standpoint they represent an intermediate good that indirectly provides utility to households. For those households who derive pleasure from knowing that they are generating their own electricity, the solar panels will yield "existence value". Such households will recognize that they have reduced their greenhouse gas emissions and thus are providing world public goods. In their local communities, such households may be recognized by neighbors for their civic virtue. Households who take pride in engaging in "voluntary restraint" will especially value this investment (Kotchen and Moore 2008).

A recent literature in environmental economics has examined the demand for green products. Most of these studies have focused on hybrid vehicle demand such as Kahn (2007), Kahn and Vaughn (2009) and Heutel and Muehlegger (2010) or the diffusion of solar panels across communities (Dastrup 2010 and Bollinger and Gillingham 2010). By using hedonic methods to estimate the price premium for green attributes our study shares a common research design with several recent studies that have used hedonic methods to infer the "green product" price premium such as Delmas and Grant's (2010) study the demand for organic wine, Eichholtz, Kok, and Quigley's (2010) work on the capitalization of Energy Star and LEED status for commercial buildings, and Brounen and Kok's (2010) investigation of the capitalization of residential energy efficiency when Dutch homes are certified with regards to this criterion.

II. The Hedonic Pricing Equilibrium and the Make versus Buy Decision over Solar Installation

A household who wants to live in a solar home can either buy such a home or buy another home that does not have solar panels and pay a contractor to install these solar panels. This option to "make" versus "buy" should impose cross-restrictions on the size of the capitalization effect. Consider an extreme case in which all homes are identical and there is a constant cost of $c to install solar panels. By a no arbitrage argument, in the hedonic equilibrium, we would recover a price premium of "c" for the solar homes. Over time, any supply innovations that lead to a lower installation cost or higher quality of the new solar panels would be immediately reflected in the hedonic price premium.

In reality, homes are differentiated products that differ along many dimensions. No home has a "twin". The non-linear hedonic pricing gradient is such that different homes are close substitutes at the margin (Rosen 2002). Since at any point in time the same home is not available with and without solar panels, there is no reason why the hedonic solar capitalization must equal the installation cost.

We recognize that the investment decision in solar has an option value component. Households may be uncertain about how much electricity the solar panels will generate, the future price of electricity and future price declines in quality adjusted solar systems. In a standard investment under uncertainty problem, it can be rational to delay and not exercise the option. Households may also be uncertain about what the resale value of their house would be if they install solar. All of these factors, as well as the household's power needs and its ideology, will influence demand for solar panels.

On the supply side, there are two sources of solar homes. There are existing homes whose owners have installed solar panels in the past and are now selling their home. In contrast, the second set of solar homes is produced by developers of new homes who will compare their profit for building a home with and without solar panels. Such developers are likely to have invested more effort in the basic marketing research of determining the market for this custom feature.

III. Empirical Specification

We employ both a hedonic and a repeat sales approach to assess the extent to which solar panels are capitalized into home prices. The hedonic specification decomposes home prices by observable characteristics for all transactions while flexibly controlling for spatial and temporal trends. Solar panels are included as a home characteristic and average capitalization is measured as the coefficient on the solar panel variable. The repeat sales model controls for average appreciation of properties from one sale to the next within each census tract, with an indicator for installation of panels between sales.

Hedonic approach

Our first approach to measuring the capitalization of solar panels in home sales is to decompose home prices by home characteristics and neighborhood level time trends. We interpret the average difference between the log price of homes with solar panels and those without after controlling for observable home characteristics and average neighborhood prices in each quarter as the average percent contribution to home sales price of solar panels. The baseline equation we estimate in our hedonic specification is

$$\log(\text{Price}_{ijt}) = \alpha\text{Solar}_{it} + \beta\text{X}_i + \gamma_{jt} + \varepsilon_{ijt} \qquad (1)$$

where Price_{ijt} is the observed sales price of home i in census tract j in quarter t. The variable Solar_{it} is an indicator for the existence of a solar panel on the property and α is the implicit price of the panels as a percentage of the sales price -- our measure of the extent of capitalization. Home, lot, and sale characteristics are included as X_i.

We allow for the differential capitalization across geographic areas of home and lot size by interacting the logs of these observable characteristics with zip code level indicator variables.[2] Additional characteristics contained in X_i are the number of bathrooms, the number of times the property has sold in our sales data, the number of mortgage defaults associated with the property since 1999, indicators for the building year, if the property has a pool, a view, and is owner occupied, and month of the year indicators to control for seasonality in home prices. In equation (1), we are imposing a constant solar capitalization rate across time and space.[3]

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[2] There is substantial variation in climate and other local amenities across the three counties in our data sets. Our specification allows a home or lot of a given size on the temperate coast near the beach to be valued by the market differently than the same size home or lot in the inland desert region.

[3] Recent changes in the federal tax incentives for solar may affect the solar price capitalization. On October 3, 2008 the President signed the Emergency Economic Stabilization Act of 2008 into law. The bill extends the 30% ITC for residential solar property for eight years through December 31, 2016. It also removes the cap on qualified solar electric property expenditures (formerly $2,000), effective for property

We control for housing market price trends and unobserved neighborhood and location amenities with census tract-quarter fixed effects, γ_{jt}. Allowing different appreciation patterns for different geographies is critical because these different geographical appreciation patterns are correlated with the incidence of solar panel installation.

Any hedonic study is subject to the criticism that key explanatory variables are endogenous. While we have access to a detailed residential data set providing numerous controls, we acknowledge that there are plausible reasons why the solar panel dummy could be correlated with unobserved attributes of the home.

Our OLS capitalization estimate of α measures the average differential in sales price of homes with solar panels and homes without panels in the same census tract selling in the same quarter after controlling for differences in observable home characteristics. Interpreting the hedonic coefficient estimate as the effect on home price of solar panels requires assuming that the residual idiosyncratic variation in sales prices (ε_{ijt} in our framework), solar panel installation and unobservable house attributes are uncorrelated. This assumption is invalid if homeowners who install solar panels are more likely to make other home improvements that increase sales prices of their homes than their neighbors who do not install. We investigate how this might influence our capitalization estimate by estimating (1) with a control for whether a home improvement is observed in building permit data available for a large subset of San Diego County. Alternatively, homes with solar panels may be homes of higher unobserved quality. We explore whether these homes command a time-invariant premium by including an indicator for whether a home will have panels installed at some point in the future relative to a particular sale.

We allow the capitalization of panels to vary over system size and neighborhood characteristics by interacting our solar indicator variable in equation (1) with a linear term including the characteristic. Our estimating equation becomes:

$$\log\left(\text{Price}_{ijt}\right) = \alpha_0 \text{Solar}_{it} + \alpha_1 \text{N} * \text{Solar}_{it} + \beta \text{X}_i + \gamma_{jt} + \varepsilon_{ijt}. \qquad (2)$$

The value of installed solar panels may be influenced by factors beside the financial implications of installation, and we estimate equation (2) using a number of proxies for other

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placed in service after December 31, 2008 http://www.clarysolar.com/residential-solar.html. We do not have enough observations to determine whether the law has affected the size of the solar capitalization effect.

factors. Households may have preferences for the production technology used to generate the electricity they use if they are concerned about their individual environmental impact or value their own energy independence. A desire to appear environmentally conscious may increase the value of solar, because it is a visible signal of environmental virtue. Our proxies for environmental idealism and the social return to demonstrating environmental awareness are the percent of voters registered as Green party members in the census tract and the Toyota Prius share of registered vehicles in the zip code. For comparison, we estimate capitalization variation by Democratic party registered voter share and the pickup truck share of registered vehicles in the zip code. We also examine solar panel capitalization by census tract log median income and percent of college graduates.

Repeat sales approach

A second approach to measuring the average additional value to a home sale of solar panels is to average the additional appreciation of a single home from one sale to the next (repeat sales) when solar panels are installed between sales. We interpret the average differential in the appreciation in consecutive sales of properties where solar was installed between sales and other properties in the same census tract with no installation between consecutive sales as the average capitalization of solar panels in home sales. The baseline equation we estimate for our repeat sales specification is

$$\log\left(\frac{\text{Price}_{ij(t+\tau)}}{\text{Price}_{ijt}}\right) = \tilde{\alpha}\Delta\text{Solar}_{i(t+\tau)} + T_{j(t+\tau)} + \tilde{\varepsilon}_{ij(t+\tau)} \tag{3}$$

where $\text{Price}_{ij(t+\tau)}$ and Price_{ijt} are consecutive sales of the same property i in neighborhood j occurring τ quarters apart where the first sale is in period t. The variable $\Delta\text{Solar}_{i(t+\tau)}$ is an indicator for the installation of solar panels at a property between sales (after t but before $t+\tau$). Census tract specific time effects are included as the vector $T_{j(t+\tau)}$, with remaining idiosyncratic property appreciation measured as $\tilde{\varepsilon}_{ij(t+\tau)}$.

Our repeat sales GLS capitalization estimate, $\tilde{\alpha}$, of the capitalization of solar panels in housing prices measures the average additional appreciation of homes with solar installed between sales beyond that measured by the housing price indexes of their respective census tracts. Interpreting $\tilde{\alpha}$ as the effect of panel installation on subsequent sales price requires the assumption that idiosyncratic price appreciation of homes is not correlated with solar panel installation. Again, this will not be the case if unobserved changes in properties are correlated with solar panel installation.[4]

IV. San Diego County Data

Our hedonic analysis utilizes single family home sales records occurring between January 1997 and early December 2010 in San Diego County. For our sample of repeat sales of single family homes in which solar was installed between sales we use first sales beginning as early as January of 1990. When we restrict our analysis to homes for which we know the home square footage, the number of bedrooms and bathrooms, the year the house was built or most recently underwent a major remodeling, whether the property has a pool, whether the property has a view, and if the property is subject to a lower tax because it is owner occupied, we obtain 364,992 sales records for the hedonic analysis and 80,182 records for the repeat sales analysis.[5] The Data Appendix provides details on the variables.

We control for the home observable characteristics mentioned above as well as lot size, the number of times the property has transacted in our dataset and the number of public mortgage default notices associated with the property. We view the latter as proxies for idiosyncratic home quality. We also control for neighborhood characteristics. We use the percent of voters in each census tract who are Green Party registrants as a measure of the level of environmentalism in the neighborhood. We use the Toyota Prius share of registered automobiles from zip code totals of year 2007 automobile registration data as a proxy of the neighborhood prevalence of both the level of environmentalism and of displayed environmentalism.[6] We use the percent

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[4] Our hedonic and repeat sales approaches are related. Since differencing consecutive observations on the same property i in equation (1) results in equation (3), both methods estimate the same parameter for the average capitalization of solar panels, $\alpha = \tilde{\alpha}$. An advantage of the repeat sales approach is that this differencing controls for unobservable time-invariant housing characteristics, in addition to the observable X_i, that may be correlated with solar installations. The census tract-quarter time effects, $T_{j(t+\tau)} = \gamma_{i(t+\tau)} - \gamma_{it}$, are jointly estimated as quarterly repeat sales price indexes for each census tract using standard GLS procedures to account for the dependence of the idiosyncratic error $\tilde{\varepsilon}_{ij(t+\tau)}$ on τ, the number of quarters between sales.

[5] The building year is not recorded for 1,681 properties, 46 of which are matched to solar panel installations.

[6] See Kahn (2007) for a discussion on the Green Party and party membership as an identifier of environmentalists.

registered Democrats and vehicles classified as trucks from the respective summary datasets as comparison measures. We control for year 2000 census tract median income and average census tract education levels as percent of the over age 25 population who are college graduates. We also control for census tract specific time effects.

We know which homes have solar panels from administrative records from four incentive programs which have subsidized residential solar panel systems in San Diego County (details about these programs are given in the Data Appendix). These programs cover virtually all solar installations in San Diego County, as we have confirmed with conversations from industry experts.

The solar systems consist of solar panels installed on the property, typically on the roof, which are connected to the electricity grid, meaning the home draws electricity both from the panels and from standard utility lines and the panels supply electricity to the local infrastructure when production exceeds consumption at a given home. We use a dataset of the administrative records from these programs to determine the presence of solar panels on a property being sold as well as the installation of panels between sales.[7]

We know, for each installation, the address of the property, size of the system in terms of kilowatt production potential, and date completed. Most installations also include information on the cost of the system and the amount subsidized by the respective program. We successfully match installation records to 6,249 single family homes by address to public San Diego County Assessor property records for installations through early December 2010.[8]

We assign each home in our sample to one of four mutually exclusive and exhaustive categories. At the time the home was sold, the home can 1) already have solar panels installed (329 observations); 2) concurrently have installed solar panels (73 observations); 3) have solar panels installed in the future but be sold without solar panels at the time of the specific sale (3,433 observations); and, 4) not have solar panels as of Winter 2010. In the regressions, this

[7] Federal tax credits allow homeowners to recover 30% of the costs of a system, but we do not have access to tax return data as an additional source of installation detail.

[8] We match nearly 90% of installation records, and have verified that many unmatched records are business or multifamily addresses. Match quality was verified by inspecting publicly available aerial photographs (www.bing.com/maps) of the installation addresses for the existence of solar panels for a subset of the records.

fourth category will be the omitted category.[9] We use the date of installation of each system to determine how many homes in the same census block had solar panels installed for each month of our sample.

We use building permit data to examine whether homeowners who install solar panels also make other improvements to their homes more often than their neighborhoods, thus potentially biasing our estimate of the home price premium for solar panels. Our building permit reports begin in 2003 for San Diego City, the largest permit issuing jurisdiction in San Diego County, and for Escondido, a smaller municipality in our sample area. We define a "major renovation" as one referencing a kitchen, bath, HVAC, or roof with an associated value greater than $1,000 and a "high value" renovations as one with an associated value greater than $10,000.

Summary statistics for San Diego

Table 1 shows that compared to homes sold without solar, those sold with solar are bigger, have more bedrooms and bathrooms, and are more likely to have a view and a pool, among various other characteristics. We thus need to control for observable home characteristics as well as census tract location in our empirical specification so that our regressions are comparing sales prices of homes with solar panels to sales of similar homes in the same census tract.

Neighborhoods where solar panels have been installed are richer, whiter, more educated, have more registered Democrats, and have larger homes than the 103 of 478 census tracts where no solar was installed during period covered by our data (see Table 2). Our empirical analysis exploits the gradation in these differences across neighborhoods to examine how capitalization in home price varies with ideological and demographic characteristics.

V. Who Lives in Solar Homes?

Most hedonic real estate studies have detailed information about the home, its sales price, location and physical attributes but they know little about the marginal buyer who chose to pay the sales price to live there. For the city of San Diego in 2009, we have information for

[9] An additional 50 transactions with an existing solar systems occurred within the year following a public mortgage default notice or sometimes attendant notice of trustee's sale. These are excluded from the analysis here. Including them, along with an indicator for a sale following default for all observations does substantively alter our results.

registered voters on their age, education, political party of registration, and contributions to environmental, political, and religious organizations.[10] These data enable us to investigate what types of people self select into solar homes.

We estimate linear probability models using the full stock of City of San Diego homes in the year 2009. We regress a dummy variable indicating whether the home has solar panels on various household characteristics, including the number of voters in conservative (Republican, American, and Libertarian) and liberal parties (Democrat, Peace and Freedom, and Green), whether the two oldest registered voters in the household contribute to environmental, political, and religious organizations, the highest education level of the two oldest registered voters, the age of the oldest registered voter in the household, whether a child is present, the highest imputed income (based on census block data and the age of the household) of the two oldest registered voters in the household, and census tract fixed effects.

We find that households in which everyone is a registered liberal and in which the household contributes to environmental organizations are much more likely to be in solar homes controlling for education, imputed income, the age of the oldest registered household member, and whether any children are present in the household (see Table 3). When everyone in the household is a registered liberal (and also controlling for contributions to organizations) the probability of being in a solar home increases by 0.002, an 18 percent increase from the base of 0.011. When the household contributes to environmental organizations (and controlling for party registration) the probability of being in a solar home increases by 0.006, a 55 percent increase.

Education, age, and income were also predictors of living in a solar home. Those with a college education have a 0.003 greater probability of living in a solar home than those with less than a high school education and those with a graduate degree have a 0.006 greater probability of living in a solar home. This represents roughly a 27-55% increase in the probability of living in a solar home. Households living in a solar home are also most likely to be those where the oldest voter was born after 1950 (relative to being born before 1950) and households with imputed income above the 70th percentile compared to households with imputed income between the 50th and 60th percentile (results not shown).

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[10] Our data are from www.aristotle.com. We merged by street address to each home. We were able to match 90% of the sample.

We have shown that environmentalists, the college-educated, baby-boomers and later generations, and richer households paid the hedonic premium to live in solar homes. We next estimate the size of these hedonic premia.

VI. Estimation results

Tables 1 and 2 showed that large nice homes in rich white neighborhoods are more likely to have solar than small homes in poor minority neighborhoods. Our estimated solar coefficient is the average premium for a large nice home with solar (in a rich white neighborhood) relative to the other homes *in the same neighborhood* after flexibly controlling for observable differences between the two homes. Because the hedonic regressions based on equation (2) contain census tract by quarter fixed effects, the coefficient picks up the price premium for a home with solar relative to homes in the same tract. Similarly, our repeat sales approach measures the average additional increase in price between sales for homes with solar installed between sales relative to other homes in the neighborhood because we are fitting census tract specific repeat sales indexes.

Hedonic estimates

All of our hedonic specifications estimate the capitalization of solar panels in observed property sales while controlling for housing characteristics, and census tract/quarter fixed effects. We find that solar panels add 3.6% to the sales price of a home after controlling for observable characteristics and flexible neighborhood price trends (see Table 4). This corresponds to a predicted $22,554 increase in price for the average sale with solar panels installed.[11] Homes which do not yet have solar installed but will at some subsequent time in our sample have no associated premium, indicating that our measured solar effect is not attributable to unobserved, time-invariant differences in these homes. Homes in which the solar installation was done "concurrently" receive a statistically insignificant capitalization rate of 2.8 percent, probably because they are a combination of two types of installations. If the installation was done before the sale (for example, for new developments or contract remodels) then the price will be capitalized in the sales price. If the installation was done after the sale, the home owner probably added the panels. Unfortunately, we cannot distinguish between these two cases because we do not have the precise date of installation.

[11] We convert the coefficient estimate to a dollar amount by differencing the predicted sales price from our estimated model with our solar indicator equal to one and zero and all other characteristics equal to the mean values of all other homes with solar.

We estimate the solar premium to be 1% higher if other homes in the same census block have previously installed panels, but the coefficient is not statistically different from zero. We observe a decreasing return to additional system size, a positive relationship between the capitalization rate and Prius penetration, Green party registration share, Democrat registration share, median income, and education, as well as a negative relationship between capitalization and truck ownership. Controlling for building permit activity in a subsample of our data suggests that the solar panel addition rather than unobserved home improvements are responsible for the measured price premium.

The Returns to Solar Investment Based on the San Diego Estimates

Table 5 compares this predicted increase in price of $22,554 to four different measures of costs of solar panels. The first potential comparison is the average total cost of the systems, which is $35,967.[12] However, this amount does not include subsidies which lowered the effective price to homeowners to about $20,892. Although we do not know the value to the homeowners of federal tax credits for each installation, this comparison suggests that, on average, homeowners fully recover their costs of installing solar panels upon sale of the property. Another measure of the value of panels is the average cost of adding panels during the quarter in which the home was sold. We calculate this value for each quarter in our data, and for our sales the average of this replacement cost measure is $30,858 before and $21,047 after subsidies. Buyers purchasing homes with pre-installed solar panels are paying less than the cost of a new system. However, the 30% tax credit lowers this replacement cost measure net measure to $14,733, below our estimated capitalization value.

We use our hedonic estimates of equation (3) to test for heterogeneous impacts of solar installation across communities and structure attributes. First we include the log of the size in watts (maximum production capacity) of the solar system, $\mathrm{N} = \log(Watts_{it})$ as a measure of the expected energy production from the system. Although a larger system by definition produces more electricity, because of the structure of electricity rates and the valuation of electricity produced under California's "net metering" system, we do not expect capitalization to increase proportionately with system size. For excess generation, households may opt in to the net

[12] All dollar amounts are adjusted to 2010 dollars using the "All items less shelter" consumer price index from the Bureau of Labor Statistics.

metering system that compensates them for electricity returned to the grid at (currently) between $0.171 and $0.275/kWh depending on the time of day, but the compensation is capped at the total of their annual electric bill and households face typically higher time of use prices for any electricity purchased from the utility.[13] The combined effect of the rate structure and net metering is that electricity produced by residential solar panels in excess of their annual electricity consumption is essentially donated to the utility. While households may value larger systems for other reasons, additional financial incentives to installing capacity decrease with system size.[14]

Allowing capitalization to vary by neighborhood characteristics demonstrates that the addition to a home's market value from solar panels varies across neighborhoods by environmental ideology, income, and education levels. The estimated coefficients on the linear solar term are jointly statistically significant in each neighborhood variable specification, as listed in Table 6. In each case, the capitalization of solar panels follows a pattern that would be predicted by the measure of environmental ideology, income, or education. Neighborhoods with relatively high Prius concentrations, Green party and Democrat registrant share, and median income capitalize solar panels at a higher value, while in neighborhoods with a large share of trucks, panels provide less of a premium to home sales.

Our final hedonic specification suggests that our estimates are not driven by unobserved home upgrades besides solar panel installation (see Table 8). Our capitalization estimate of 6.2% in the smaller subsample of San Diego City and Escondido is robust to the inclusion of our building permit measures. Our estimates suggest that remodeling a kitchen or bath or replacing a roof or HVAC system has a small impact on price, while high value renovations with costs similar to solar panels are estimated to have a similar value on home prices.

Repeat sales estimates

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[13] Consumer electricity prices in San Diego County are tiered by monthly consumption, with each household allocated a geography specific baseline amount of electricity (from 9.6 kWh along the coast to 16.4 kWh per month in the inland desert during the summer) at a relatively low price (currently $0.039/kWh during the summer months) with an up to five fold increases for above baseline consumption (the top of four tiers is $0.197/kWh during the summer for all consumption over 200% of the baseline). Households pay for electricity use in excess of what is produced by the panels at any given point in time.

[14] Because of these institutional factors, estimated or actual household specific expected electricity demand is necessary for a complete accounting of the financial benefit of installing a system as a function of system size, and is beyond the scope of this paper.

The results of our hedonic specification are largely replicated in our repeat sales approach. All of the presented results are based on three stage GLS estimates, with observations in the final stage weighted based on time between sales, and controlling for jointly estimated census tract level repeat sales indexes.[15] Our average capitalization estimate of 3.6% (see Table 8) implies that installing solar panels leads to an increase of $20,194 from the first to the second sale when the average price of the first sale is $558,100. Households who install panels thus recuperate more than their costs in subsequent sales even though our estimated value remains below our "replacement cost" measure of solar value. Our estimate of the contribution of system size to the capitalization rate suggests an anomalous large negative relationship. Neighborhood characteristics estimates in the repeat sales framework also indicate that the capitalization of solar panels depends on local preferences and incomes (results not shown).

VII. Capitalization of Solar Homes: Evidence from Sacramento County

We examine the robustness of our capitalization estimates using data on 90,686 single family home transactions in Sacramento County between January 2003 and November 2010. We believe that this is a 100% sample of all homes transacted in this period in the county. For each of these homes, we observe its sales date and sales price and its physical attributes. We are also able to identify every single family home in Sacramento County that has solar panels as of November 2010 and that was sold at least once between January 2003 and November 2010. For each of these 620 homes, we know the solar system's installation date. Using the information on the installation date and the sales date, we are able to partition these homes into four mutually exclusive and exhaustive categories. A home can either not have solar panels, or it can have solar panels already installed at the time of the sale (true for 256 observations), concurrently have installed solar panels (52 observations), or in the future this same home will have solar panels installed but it does not have solar panels at the time of the specific sale (312 observations).[16] We also define a "solar" street as a street where at least two homes adjacent to each other have solar panels. These streets are more likely to be new developments and solar installation is cheaper when done on all homes in a new development.

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[15] OLS estimates of solar capitalization that do not correct for time between sales do not vary greatly from our GLS estimates.

[16] For the "concurrent" set of homes, we do not know if the home had solar panels when it was sold. Either the new home buyer installed solar panels after purchase or the developer installed solar panels.

We find that the premium for solar homes in Sacramento is 4 percent (see Table 9), similar to the premium for solar homes in San Diego (see Table 4). We find an even larger capitalization of 7 percent for a solar home in Sacramento that is not on a solar street and a smaller one of 3 percent when it is on a solar street.

VIII. Conclusion

This study used a large sample of homes in the San Diego area to provide some of the first capitalization estimates of the resale value of homes with solar panels relative to comparable homes without solar panels. Although the residential solar home market continues to grow, there is little direct evidence on the market capitalization effect. Using both hedonics and a repeat sales index approach we find that solar panels are capitalized at roughly a 3% to 4% premium. This premium is larger in communities with more registered Prius hybrid vehicles and in communities featuring a larger share of college graduates.

Our new marginal valuation estimates inform the debate led by Borenstein (2008) on whether expenditure on residential solar is a "good investment." His analysis, consistent with those taken by others in the literature, treats residential solar installations as a 'pure' investment good judged in terms of upfront cost and power generation. Our evidence suggests that similar to other home investments such as a new kitchen, solar installation bundles both investment value and consumption value. Some households may take pride in knowing that they are producers of "green" electricity and "warm glow" may triumph over present discounted value calculations in determining a household's install choice.

Data Appendix

Solar panel installations

California's Emerging Renewables Program subsidized solar panel installations as early as 1999 and supported almost all installations through 2007, when it was replaced as the primary State subsidy regime by the California Solar Initiative, which continues today.[17] Over 95% of the systems in our data are installed under these two programs. The New Solar Homes Partnership aims to encourage developers to include solar on new properties, and accounts for less than 1% of installations in our data. These programs are administered in areas of California serviced by

[17] http://www.gosolarcalifornia.org/about/gosolar/california.php

public utilities, including San Diego County. A final program supported solar panel installations on rebuilding projects during 2005 to 2007 following wildfires in San Diego County.

Property records

The San Diego County Assessor maintains public records of characteristics and transactions of all property in the county for tax assessment purposes. We use a corresponding publicly available map file (GIS shapefile) of the boundaries of all county properties to determine the acreage of the lot on which each home is built. We also obtain information on the number of times the property has transacted in our dataset and the number of public mortgage default notices associated with the property.[18] Homes are grouped spatially using the county property map and census tract and zip code boundary maps to assign each parcel number to the respective geography in which its property lies.[19] We use these groupings to construct spatial and temporal controls as well as for matching a home to the characteristics of its census tract and zip code. The assessor also maintains a record of each property transaction in the county. The date, sales price, and parcel number identifier of all single family home sales since 1983 is publicly available from these records, which form the dataset which is our source for sales prices and dates.

Our building permit data begin in 2003 for San Diego City and for Escondido. In San Diego City, building permits are required for "all new construction" including for "repair or replacement of existing fixtures, such as replacing windows." Permits are also required for changes to a home's "existing systems"; for example, moving or adding an electrical outlet requires a permit."[20] A permit is not required "wallpapering, painting or similar finish work" and for small fences, decks, and walks.[21]

Neighborhood characteristics

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[18] Default data is matched by parcel number from public records published online by the San Diego Daily Transcript.

[19] Maps were retrieved from www.sangis.org.

[20] Although not all improvements may be completed with a permit, as long as homeowners who install solar panels are not less likely than others to obtain permits for other improvements, including permitting activity in our capitalization regressions should provide evidence of the extent of bias due to unobserved home improvements and maintenance in our capitalization estimates.

[21] http://www.sandiego.gov/development-services/homeownr/hometips.shtml#whendo

We use voter registration summary statistics for each San Diego County Census tract in the year 2000 from the Berkeley IGS (see http://swdb.berkeley.edu/), zip code level automobile registration summary statistics from 2007, and 2000 Census tract level demographic as sources of descriptors of San Diego neighborhoods over which solar panel capitalization may vary. The voter registration summary files report the total number of registrants by political party affiliation for each census tract in California. From these reports we calculate the percent of voters in each tract who are Green Party registrants. Similarly, we calculate the Toyota Prius share of registered autos from zip code totals of year 2007 automobile registration data (purchased from R.L Polk). We likewise calculate the percent registered Democrats and vehicles classified as trucks from the respective summary datasets. We obtain reported census tract median income and the percent of the over age 25 population who are college graduates from the 2000 Census.

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Table 1: San Diego Summary statistics and mean comparisons for solar and no solar home sales

Variable	Sales with no solar Mean *Std Dev*	Sales with solar Mean *Std Dev*	No solar - solar Difference in means *Pr(|T|>|t|)*
Sale price (2000 $s)	427,047 *380,536*	667,645 *426,980*	-240,599 *0.000*
Square feet	1,984 *961*	2,512 *1,124*	-528 *0.000*
Bedrooms	3.39 *0.89*	3.76 *0.86*	-0.37 *0.000*
Baths	2.37 *0.88*	2.86 *1.00*	-0.48 *0.000*
View	0.30 *0.46*	0.36 *0.48*	-0.06 *0.020*
Pool	0.18 *0.38*	0.33 *0.47*	-0.15 *0.000*
Acres	0.40 *1.51*	0.88 *2.56*	-0.49 *0.001*
Owner occupied	0.70 *0.46*	0.69 *0.46*	0.02 *0.531*
Building year*	1978 *19.5*	1983 *20.9*	-5.56 *0.000*
Sales since 1983	2.76 *1.39*	2.60 *1.19*	0.17 *0.012*
Defaults since 1999	0.29 *0.62*	0.22 *0.51*	0.07 *0.018*
System cost (2000 $s)$^+$		27,790 *17,245*	
System size (kW)		3.37 *2.23*	
Incentive amount$^+$		11,930 *8,301*	
Observations	364,663 (*363,504)	329 ($^+$307)	

Table 2: San Diego neighborhood summary stats and comparison by solar penetration

Variable	Neighborhoods with no solar Mean *Std Dev*	Neighborhoods with at least one solar Mean *Std Dev*	No Solar - Solar Difference in Means *Pr(|T|>|t|)*
Average square footage	1,278 *326*	1,822 *535*	-544 *0.000*
Average acreage	0.22 *0.44*	0.44 *0.88*	-0.22 *0.000*
Percent with pools	3.01 *3.73*	15.01 *11081*	-12.00 *0.000*
Percent Green Party	0.50 *0.50*	0.52 *0.45*	-0.02 *0.709*
Percent Democrat	47.38 *9.42*	35.63 *8.95*	11.75 *0.000*
Median income ($1000s)	30.35 *11.97*	55.86 *22.85*	-25.51 *0.000*
Percent White	26.73 *22.70*	60.85 *23.67*	-34.13 *0.000*
Percent Owner Occupied	53.89 *18.21*	72.87 *8.95*	-18.99 *0.000*
Percent College Grads	13.54 *13.33*	31.19 *17.95*	-17.66 *0.000*
Percent Prius*	0.39 *0.03*	0.39 *0.03*	0.002 *0.993*
Percent Truck*	51.83 *8.23*	45.61 *6.92*	6.21 *0.126*
Observations	89 (*6)	496 (*89)	

*Auto data variables reported at the zip code level, all others are census tract averages

Table 3: Correlates of Living in a Solar Home in the City of San Diego in 2009

	Full Sample			Aristotle Sample	
Dependent Variable:		Coefficient	Coefficient		Coefficient
Dummy=1 if lives in a solar home	Mean	(Std Error)	(Std Error)	Mean	(Std Error)
Home has solar panels (count)	2,282			1,272	
Conservative (all HH voters)	0.703			0.405	
Liberal (all HH voters)	0.199	0.002***	0.002**	0.399	0.002**
		(0.001)	(0.001)		(0.001)
Mixed Conservative and Liberal	0.0111	0.005	0.005*	0.022	0.005
		(0.003)	(0.003)		(0.003)
Other Party	0.0866	0.000	0.000	0.174	0.000
		(0.001)	(0.001)		(0.001)
Less than high school	0.0337			0.067	
High school grad	0.103		0.001	0.205	0.001
			(0.001)		(0.001)
Some College	0.125		0.000	0.249	0.000
			(0.001)		(0.001)
College Grad	0.127		0.003**	0.253	0.003**
			(0.001)		(0.001)
Post graduate	0.0859		0.006***	0.171	0.006***
			(0.001)		(0.001)
Household has contributed to					
environmental organizations	0.0404		0.005***	0.080	0.005***
			(0.002)		(0.002)
political organizations	0.246		-0.001	0.490	-0.001
			(0.001)		(0.001)
religious organizations	0.0289		0.001	0.058	0.001
			(0.002)		(0.002)
Census Tract Fixed Effects		Y	Y		Y
Observations		202,864	202,864		100,943
R-squared		0.012	0.013		0.010

Estimated from a linear probability model. Additional controls include the age of the oldest registered voter in the household, whether a child is present in the household, the highest imputed income of the two oldest registered voters in the household, and an indicator for the being in the Aristotle data base. A conservative is registered as Republican, American, or Libertarian Party. A liberal is a registered as Democrat, Peace and Freedom, or Green Party. Robust standard errors in parentheses. The symbols *, **, and *** indicate significance at the 10, 5, and 1 percent level, respectively.

Table 4: San Diego Hedonic OLS regression estimates of log sales price on solar panels

Dependent variable: Log(SalePrice)	Baseline	Neighborhood	System Size
	Coefficient *(Std Error)*	Coefficient *(Std Error)*	Coefficient *(Std Error)*
Solar	0.036*** *(0.010)*	0.031** *(0.014)*	0.043 *(0.137)*
Solar will be installed	0.004 *(0.003)*	0.004 *(0.003)*	
Solar concurrently installed	0.028 *(0.021)*	0.028 *(0.021)*	
Solar home in solar block		0.010 *(0.020)*	
Log Size (watts) * Solar			-0.001 *(0.017)*
Joint significance of solar terms			F Stat = 6.60, Prob > F = 0.001
Log(Acres)†	0.074*** *(0.003)*	0.074*** *(0.003)*	0.074*** *(0.003)*
Swimming Pool	0.050*** *(0.001)*	0.050*** *(0.001)*	0.050*** *(0.001)*
View	0.049*** *(0.001)*	0.049*** *(0.001)*	0.049*** *(0.001)*
Log(SquareFoot)†	0.432*** *(0.003)*	0.432*** *(0.003)*	0.432*** *(0.003)*
Bathrooms	0.024*** *(0.001)*	0.024*** *(0.001)*	0.024*** *(0.001)*
Constant	9.385*** *(0.012)*	9.385*** *(0.012)*	9.385*** *(0.012)*
Census tract quarter fixed effects (578 tracts, 56 quarters)	30,426	30,426	30,426
Observations	364,992	364,992	364,992
Sales with solar	329	329	329
R^2 within; overall	0.64; 0.34	0.64; 0.34	0.64; 0.34

Significant at *** 1% and ** 5% levels; † Zip code specific variation in these coefficients is also estimated; Building vintage, mortgage default frequency, sales frequency, owner occupancy tax status, and month in year of sale are included in all regressions, with coefficient estimates available from the authors by request.

Table 5: Predicted value of solar from hedonic estimates and comparison sample values (Adjusted to 2010 dollars)

Predicted added value of solar at mean characteristics of sales with solar	$22,554; ($5.65/watt)
Average total (before subsidy) system cost of solar for solar sales	$35,967; ($9.02/watt)
Average net (after subsidy) system cost of solar for solar sales	$20,892; ($5.24/watt)
Average mean total (before subsidy) system cost of all systems installed during quarter of home sale (replacement cost)	$30,858; ($7.74/watt)
Average mean net (after subsidy) system cost of all systems installed during quarter of home sale	$21,047; ($5.28/watt)

Table 6: Hedonic OLS regression estimates of log price on solar panels with neighborhood characteristic interaction

	Prius Share	Truck Share	Green Share	Dems Share	Log Med Income	College Grads
Variable	Coeff. *(S.E.)*	Coeff. *(S.E.)*	Coeff. *(S.E.)*	Coeff. *(S.E.)*	Coeff. *(S.E.)*	Coeff. *(S.E.)*
$Solar_{ijt}$	-0.002	0.198***	0.031**	-0.027	-0.156	-0.022
	(0.022)	*(0.078)*	*(0.014)*	*(0.047)*	*(0.277)*	*(0.026)*
$NbhdVar_j$ * $Solar_{ijt}$	0.076**	-0.004**	0.009	0.002	0.017	0.001*
	(0.038)	*(0.002)*	*(0.022)*	*(0.002)*	*(0.025)*	*(0.0005)*
Joint significance of solar terms - F Stat; (Prob > F)	8.77; (0.000)	8.90; (0.000)	6.69; (0.001)	7.55; (0.001)	6.84; (0.001)	8.09; (0.000)
Home characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Census tract quarter fixed effects (578 tracts, 56 quarters)	29,697	29,697	30,420	30,420	30,420	30,420
Observations	349,108	349,108	364,985	364,985	364,985	364,985
Sales with solar	319	319	329	329	329	329
R^2 within; overall	0.64; 0.33	0.64; 0.33	0.64; 0.34	0.64; 0.34	0.64; 0.34	0.64; 0.34

***,**,* Significant at 1%, 5%, 10% levels, respectively

Table 7: Hedonic OLS regression estimates of solar on log price with building permits

Variable	Baseline Coefficient *(Std Error)*	Major renovation Coefficient *(Std Error)*	High value renovation Coefficient *(Std Error)*	Any Permit Coefficient *(Std Error)*
$Solar_{ijt}$	0.062*** *(0.016)*	0.062*** *(0.016)*	0.060*** *(0.016)*	0.062*** *(0.016)*
$Building\ Permit_{ijt}$		0.025*** *(0.007)*	0.056*** *(0.005)*	-0.036*** *(0.001)*
Home characteristics	Yes	Yes	Yes	Yes
Census tract quarter fixed effects (578 tracts, 51 quarters)	13,416	13,416	13,416	13,416
Observations	136,389	136,389	136,389	136,389
Sales with solar	122	122	122	122
Sales with permit		725	1,411	20,324
Sales with solar and permit		4	12	25
R^2 within; overall	0.57; 0.31	0.57; 0.31	0.57; 0.31	0.57; 0.32

***Significant at the 1% level

Table 8: Repeat sales GLS regression estimates of log of sales price ratio on added solar

	Baseline	System Size
Variable	Coefficient *(Std Error)*	Coefficient *(Std Error)*
$\Delta Solar_{ijt}$	0.036** *(0.018)*	0.611** *(0.277)*
Log Size (watts) * $\Delta Solar_{ijt}$		-0.073** *(0.035)*
Joint significance of solar terms		F Stat = 4.36, Prob > F = 0.013
Census tract specific HPIs	110	110
Observations	80,182	80,164
Sales with solar	160	160
R^2	0.76	0.76

**Significant at the 5% level

Table 9: Sacramento Hedonic OLS regression estimates of log sales price on solar panels

Dependent Variable: Log(Sale Price)		Baseline	Street
	Mean	Coefficient (Std Error)	Coefficient (Std Error)
Solar	0.003	0.04	0.073
		(0.014)***	(0.026)***
Solar will be installed	0.003	0.009	0.009
		(0.013)	(0.013)
Solar concurrently installed	0.001	0.024	0.065
		(0.030)	(0.041)
Solar home on solar street			-0.046
			(0.030)
Log(acres)	-1.803	0.156	0.156
		(0.002)***	(0.002)***
Swimming Pool	0.116	0.076	0.076
		(0.002)***	(0.002)***
Log(Square Foot)	7.365	0.559	0.559
		(0.004)***	(0.004)***
Bathrooms	2.201	0.018	0.018
		(0.002)***	(0.002)***
Constant		8.523	8.523
		(0.028)***	(0.028)***
Year Built Dummies		Y	Y
Zip Code/Year/Month Dummies		Y	Y
Observations		90686	90686
Sales with solar		265	265
R^2		0.852	0.852

*** indicates significantly different from 0 at ***1% level. Regressions include year built dummies. Average sales price is $305,178.