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Abstract

This study uses 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 as compared to comparable homes without solar panels. While the residential solar home market continues to grow, there is surprisingly little direct evidence on the market capitalization effect. We find evidence using both hedonics and a repeat sales index approach that solar panels are capitalized at roughly a 3% premium. This premium is larger in communities with more registered Prius hybrid vehicles and in communities featuring a larger share of college graduates.

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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. Today, there are several state and federal programs actively subsidizing 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 solar PV is about 80 percent greater than the value of the electricity it will produce.

But, 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 the first theoretical analysis of this important 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 enjoys a consumption flow of "warm glow" for environmentalists who take pleasure in "doing their duty" in terms of producing minimal greenhouse gases associated with electricity consumption (Andreoni 1990). Since 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 highlights that in conservative communities that solar panels may offer less "warm glow" utility to its owners.

In this paper, we provide the first set of hedonic marginal valuation estimates for a large sample of solar homes based on recent real estate transactions in San Diego 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 hedonic study contributes to two literatures. The enormous real estate hedonics literature continues to explore 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 for 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.

A more 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. Delmas and Grant's (2010) study the demand for organic wine. Eichholtz, Kok, and Quigley (2010) estimate hedonic price regressions to uncover the capitalization of Energy Star and LEED status for commercial buildings. Brounen and Kok (2010) present a hedonic study documenting the capitalization of residential energy efficiency when Dutch homes are certified with regards to this criterion.

II. The Hedonic 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.

On the supply side, it is relevant to note that there are two sources of solar homes. One set represents existing homes whose owners have installed solar panels in the past and are now selling their home. Such owners would base their installation decision on a dynamic utility maximization decision that we will discuss below. 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. In a built up area such as San Diego, there are unlikely to be pockets of housing in which existing homes sit adjacent to vacant parcels that are being developed by developers. If existing homes were next to new housing developments, then the developer's profit motive would be more likely to place restrictions on the hedonic solar capitalization.

Recognizing that both households and developers choose whether to install a solar system or not, we now turn to discussing this "participation equation" for each of these two types of agents. We assume that there is a one sized system so the decision makers choose whether or not to install solar.

We will start with an incumbent home owner. His solar installation decision depends on the number years, j, until he sells his home, the price appreciation measured in dollars when he sells, Δ, the upfront cost of installing the panels, C, the flow utility from having solar panels, I (the warm glow), and the forgone electricity expenditure, $p * E$, where E is the electricity the panels generate and p is the price per unit of electricity.[2] Define the constant interest rate as r. Under perfect foresight, the home owner will install if

$$\frac{\Delta}{(1+r)^j} + \sum_j \frac{I + p * E}{(1+r)^j} > C * (1 - subsidy) \tag{1}$$

Consider the realistic case in which Δ is not a constant across homes and for the moment consider the unrealistic case in which heterogeneous households have perfect foresight about this capitalization effect. In this case, this essential heterogeneity creates an endogeneity issue for our hedonic pricing study (Heckman, Urzua, Vytlacil 2006). In our hedonic pricing regressions, the presence of solar panels will be our key explanatory variable. If equation (1) determines the solar installation decision, then it is clear that a "sorting on the gain" issue arises. Those households who expect that their home will appreciate the most due to solar installation are the most likely to install. This concern is even more likely for households who plan to sell soon (j is low) and for whom environmentalist ideology does not influence their decision (I=0). In a world with perfect foresight and heterogeneity, those households who expect the largest economic returns to selling the solar home and earning "delta" will have the greatest incentive to install solar. Such households with a j=0 and I=0 are effectively "developers" who are preparing to sell their home to maximize their profit.

While we acknowledge this potential concern, there are several factors that attenuate this endogeneity problem. First, we do not believe that households have perfect foresight about the returns to installing solar. Heckman et. al. (2006) point out that the essential heterogeneity problem does not arise in the case where agents are heterogeneous but do **not know** their own type. You cannot sort on what you do not know! Given that solar panels are a relatively new home attribute and that it is an open question among professionals in the industry concerning what is the capitalization, we believe that solar installers and future home buyers are making decisions over purchasing a solar home without knowing the marginal price premium they are paying for such a home. In addition, if the household who installs expects to stay in the home longer (a large j) then this attenuates endogeneity problem. In addition, those potential installers

[2] We acknowledge that an alternative interpretation for "*I*" is that there may be libertarian households who gain utility knowing that they are independent and self sufficient regardless of the environmental implications. Such individuals who "go off the grid" may embrace a very different ideology than those who purchase panels with public goods provision and warm glow in mind.

with a specific ideology (large I) will be more likely to install. When we estimate our hedonic regressions below, we discuss in detail potential omitted variables problems. For example, if ideological past owners install solar panels and install energy efficient windows, then a hedonic researcher who cannot control for the type of windows would miss this.[3]

It is interesting to contrast this home owner's installation decision with a new home developer's solar install decision. In this case, this profit maximize immediately sells the home and installs if:

$$\Delta > C * (1 - subsidy)$$

In terms of search activity, it remains an open question whether solar homes stay on the market less long than identical homes without solar panels.

In closing this section, it is relevant to note that equation (1) previews an identification strategy for bounding the role that ideology plays in determining the demand for solar panels. If we could estimate Δ, and had variation in electricity prices, solar cost installation and government solar subsidy policies, it would be possible to bound how much households must value solar panels due to ideological reasons. In this sense, we view our estimates of Δ as an input in a revealed preference analysis of the underlying causes of demand for green products.

III. Empirical Specification

To empirically assess the extent to which solar panels are capitalized into home prices, we employ both a hedonic and a repeat sales approach. 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. Average capitalization of solar panels is measured as the average additional appreciation across consecutive sales of homes with newly installed solar relative to other consecutive sales of homes within the same census tract. We also

[3] There is little evidence in the hedonic literature that more energy efficient homes, in the absence of Report Card style grades as in Brounen and Kok (2010), sell for a price premium. If this point generalizes and non-visible energy efficiency is not capitalized then a researcher who does not observe such information will consistently estimate the solar price premium.

augment each specification to allow the extent of solar capitalization to vary with the size of the system as well as ideological measures of "greenness" and demographic characteristics of the neighborhood.

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

$$\log(\text{Price}_{ijt}) = \alpha\text{Solar}_{it} + \beta\text{X}_i + \gamma_{jt} + \varepsilon_{ijt} \quad (2)$$

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 home and lot size to capitalize differentially over space by interacting the logs of these observable characteristics with zip code level indicator variables.[4] 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 (2), we are imposing that the solar capitalization rate does not vary across time or space.[5]

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[4] 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.

[5] Recently, there have major changes made in the federal tax incentives for solar and this 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 placed in service after December 31, 2008 http://www.clarysolar.com/residential-solar.html. In time, there will be enough sales of solar homes after this new law was enacted to test for whether the law has affected the size of the solar capitalization effect.

Hedonic research has taught us that marginal valuation parameters such as α reflect both supply and demand forces (Rosen 2002). The hedonic identification problem must be reckoned with if one seeks to make strong demand side statements based on estimates of α. For example, if a city such as San Diego experiences an increase in trained solar installers then the marginal cost of installation may fall and we could observe α declining over time even if aggregate demand for solar panels is increasing.

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 of the differences over space in the extent of price changes during our sample period which are correlated with the incidence of solar panel installation.

Any hedonic study is subject to the criticism that key explanatory variables are endogenous.[6] While we have access to a detailed residential data set providing numerous controls, we acknowledge that there are plausible reasons for 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 the assumption that the residual idiosyncratic variation in sales prices, ε_{ijt} in our framework, and solar panel installation and observable household and neighborhood attributes are uncorrelated. This would not be the case if there are unobserved differences between homes with solar and neighboring homes selling contemporaneously which are systematically correlated with solar panel installation. For example, homeowners who install solar panels may be more likely to make other

[6] We recognize that the standard OLS orthogonality condition is non-standard in our case. As discussed in Section II, if a perfect twin without solar panels exists for each home, then the no arbitrage argument implies that the capitalization of solar panels will equal the installation cost. To rule out the "twins case" requires that a home's attributes, X, and solar's presence not be independent (full spanning) but we require that E(ε|X Solar)=0. Intuitively, similar to any OLS study we require that unobserved home attributes be uncorrelated with observable attributes but we also require that the presence of solar panels be bundled with observable attributes of the home, X.

home improvements that increase sales prices of their homes than their neighbors. To investigate how this particular example influences our capitalization estimate, we estimate (1) with a control for whether a home improvement is observed in building permit data available for a large subset of San Diego County.

To allow the capitalization of panels to vary over system size and neighborhood characteristics, we interact our solar indicator variable in equation (1) with a linear term including the characteristic. Our estimating equation becomes;

$$\log\left(\mathrm{Price}_{ijt}\right) = \alpha_0 \mathrm{Solar}_{it} + \alpha_1 \mathrm{N} * \mathrm{Solar}_{it} + \beta \mathrm{X}_i + \gamma_{jt} + \varepsilon_{ijt}. \qquad (3)$$

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 factors. Households may have preferences for the production technology used to generate the electricity they use, motivated for example by a concern for individual environmental impact or a preference for individual energy independence. A desire to appear environmentally conscious may increase the value of solar, which allows a costly, permanent reminder of environmental activism to be installed on the roof. We use the percent of voters registered as Green party members in the census tract as a proxy for environmental idealism, and the Toyota Prius share of registered vehicles in the zip code to measure the neighborhood prevalence of demonstration of environmental concern.[7] 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 census tract log median income and percent of college graduates, as characteristics over which solar panel capitalization might vary.

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

[7] A high share of registered Green party members in a census tract may also capture an increased social return to demonstrating environmental awareness. A Prius purchase may, of course, also be motivated by a variety of additional factors, including environmental ideology.

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

$$\log\left(\frac{\text{Price}_{ij(t+\tau)}}{\text{Price}_{ijt}}\right) = \tilde{\alpha}\Delta\text{Solar}_{i(t+\tau)} + T_{j(t+\tau)} + \tilde{\varepsilon}_{ij(t+\tau)} \tag{4}$$

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.[8]

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[8] Note that our hedonic and repeat sales approaches are related. Differencing consecutive observations on the same property i in equation (2) results in equation (4) and so both methods estimate the same parameter for the average capitalization of solar panels, $\alpha = \tilde{\alpha}$. The log of the price ratio is the difference of the log prices of the two sales while $\Delta\text{Solar}_{i(t+\tau)} = \text{Solar}_{i(t+\tau)} - \text{Solar}_{it}$ is an indicator for the addition of solar. The contribution to the sales prices of house characteristics that do not change between t and $t+\tau$, including any unobservable characteristics not measured in X_i, is assumed to be equal in both periods. Census tract-quarter time effects, $T_{j(t+\tau)} = \gamma_{i(t+\tau)} - \gamma_{it}$, enter as a $1 \times (J * T)$ vector where J is the number of census tracts and T is the number of quarters. The element of $T_{j(t+\tau)}$ corresponding to census tract j and quarter $(t+\tau)$ is equal to 1; the element for census tract j in quarter t is equal to -1; and all other elements are equal to 0. In this specification we are jointly estimating quarterly repeat sales price indexes for each census tract. Since τ, the quarters between sales of a particular property i, varies over repeat sales observations, the distribution of the idiosyncratic error $\tilde{\varepsilon}_{ij(t+\tau)} = \varepsilon_{ij(t+\tau)} - \varepsilon_{ijt}$ is thought to depend on this parameter. To address this artifact of the repeat sales method, we adopt the standard repeat sales three stage GLS procedure by first estimating (4) by OLS, then regressing the magnitude of the first stage residual on a quadratic function of τ, and finally weighting observations by the inversed of the square of the predicted residual obtained in stage two in the third stage GLS estimation of (3).

IV. Data

We estimate the capitalization of solar panels in San Diego County home prices using administrative data tracking solar panel installations and county property transactions records. We control for home characteristics described by county tax assessor data and location defined by census tract boundaries. We use property addresses to match the subsidy program administrative records for all solar panels installed on single family residences in San Diego County to property transactions and characteristics records for all single family homes in the county. Properties are matched to census tract and zip code data using GIS processes to determine each property's location on the respective neighborhood maps. We examine how our capitalization estimates vary with neighborhood characteristics reported in California voter and vehicle registration summary datasets and the 2000 Census. Our analysis is limited to single family homes, since solar panel installations in multifamily buildings and condos often involve nonstandard ownership and electricity rate structures. A comparison of the characteristics of homes associated with each sales record where solar panels are installed to the full sample of records confirms that, on average, homes with panels are larger in terms of square footage and number of bedrooms and bathrooms, occupy larger lots, have more recent building years and are more likely to have a pools and views. They also sell less frequently at higher prices. We also find differences in the averages of neighborhood characteristics across neighborhoods where solar panels have been installed and those where no installations occur in our data.

Solar panel installations

Administrative records from four incentive programs that have subsidized residential solar panel systems in San Diego County are the source of or data on which homes have solar panels. 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.[9] 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%

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

of installations in our data. These programs are administered in areas of California serviced by 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.

The 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. Conversations with industry experts confirm that installations receiving subsidies for these four programs represent virtually all such systems in San Diego County. 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.[10]

The administrative dataset for the subsidy programs includes, 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 4,471 (89%) of the installation records for single family homes by address to public San Diego County Assessor property records for installations through 2009.[11] This allows us to identify 279 sales of homes with existing solar panel systems.

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 restrict our analysis to the county's 543,730 single family homes, for which the county characteristics records report the home square footage, the number of bedrooms and bathrooms, the year the home was built or most recently underwent a major remodeling,[12] whether the property has a pool, whether the property has a view, and if the property is subject to a lower tax rate because it is owner occupied

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[10] 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.

[11] Our 89% match rate is a lower bound, as some of the unmatched properties are likely 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 panels for a subset of the records.

[12] The building year is not recorded for 1,732 properties, 35 of which are matched to solar panel installations.

along with a unique "parcel number" identifier. 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. These are the observable home characteristics included in our hedonic models as controls, along with the number of times the property has transacted in our dataset and the number of public mortgage default notices associated with the properties, which are included as proxies for idiosyncratic home quality. [13] 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.[14] 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. For our hedonic analysis, we utilize 348,182 sales records occurring between January 1997 and September 2009.[15] To increase our sample of repeat sales with intermittent solar installation we use first sales beginning as early as January of 1990.

If homeowners who install solar panels also make other improvements to their homes more often than their neighborhoods, our estimate of the home price premium for solar panels will be biased. To address this concern, we utilize building permit reports of all permitted home improvements beginning in 2003 for San Diego City, the largest permit issuing jurisdiction in San Diego County, as well as the administrative dataset of all residential building permits in Escondido, a smaller municipality in our sample area. In San Diego City, building permits are required for "all new construction" including for "repair or replacement of existing fixtures, such

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

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

[15] Transactions are not included in our dataset if the sale date of the transaction is before the building year in county records (42,832 sales including two with previously installed solar panels; unfortunately, the assessor does not archive the original building year and property characteristics of properties which are rebuilt or remodeled), a mortgage on the property was in default during the year prior to the sale (23,178 sales including 27 with previously installed solar), or the listed sales price is not consistent with a correctly reported arms-length transaction or the property cannot be matched to a census tract (2,988 records with no installed solar). An additional 23 observations are omitted from the analysis because the recorded date of the solar panel installation occurs within the 90 days prior to the recorded date of the sale, casting doubt on whether the record is a treatment or a control observation.

as replacing windows." Permits are also required for changes to a home's "existing systems; for example, moving or adding and electrical outlet requires a permit."[16] A permit is not required "wallpapering, painting or similar finish work" and for small fences, decks, and walks.[17]

Neighborhood characteristics

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 broken out by political party affiliation for each census tract in California. From these reports we calculate the percent of voters in each tract that are Green Party registrants as a measure of the level of environmentalism in the neighborhood. See Kahn (2007) for a discussion on the Green Party and party membership as an identifier of environmentalists. 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) as a measure of the neighborhood prevalence of displayed environmentalism. We likewise calculate the percent registered Democrats and vehicles classified as trucks from the respective summary datasets as comparison measures. We directly apply reported census tract median income from the 2000 Census as a measure of average neighborhood financial capacity and calculate average census tract education levels as percent of the over age 25 population who are college graduates calculated from the Census education statistics.

Summary statistics for San Diego

Table 1 presents the mean characteristics of the dataset we use to estimate our hedonic framework and a comparison of observations with solar panels to those without. These

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[16] Anecdotally, many improvements are completed without a permit, which adds a variety of costs to a project, but we are able to identify a large number of "major renovations", which we define as a permit with a description referencing a kitchen, bath, HVAC, or roof with an associated value greater than $1,000, as well as a large number of "high value" renovations, which we define as permits with an associated value greater than $10,000. 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.

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

differences demonstrate the importance of controlling 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 also different from those where none were installed during period covered by our data. Table 2 presents the means across census tracts or zip codes for our neighborhood descriptors and additional neighborhood summary statistics. While this simple solar or no solar classification allows only a coarse comparison, the 103 of 478 census tracts where no solar has been installed have smaller homes on smaller lots, lower median incomes, more Democrats among registered voters, are less white and have fewer college graduates. 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. Estimation results

Given the results in Table 1 and 2 clearly indicate that solar is installed in a subset of the market both in terms of structure type and neighborhood type, it is important to remind the reader about our core identification strategy. We are not comparing large nice homes in rich white neighborhoods to small homes in poor minority neighborhoods. Instead, in our hedonic specification the 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. This is because the hedonic regressions based on equation (2) contain census tract by quarter fixed effects, so 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 observed household characteristics, including zip code specific square footage and land size values, and average prices in each census tract in each quarter.

We find that solar panels add 3.3% to the sales price of home after controlling for observable characteristics and flexible neighborhood price trends (see Table 3). This corresponds to a predicted $16,235 increase in price for the average sale with solar panels installed. 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.

Our capitalization estimate for our baseline specification described in equation (1) is 0.033 and is presented in the baseline column of Table 3. This implies that, on average, solar panels increase the sales prices of homes in our data where they are installed by 3.3%. We convert this percent to a dollar amount of $16,235 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.

Table 4 compares this value to four different measures of costs of solar panels. The first potential comparison is the average total cost of the systems, which is $26,700. However, this amount does not include subsidies that lowered the effective price to homeowners, which was on average $15,712. 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 $32,599 before and $22,266 after subsidies. It appears that, on average, homebuyers are paying less for already installed systems by paying more for a home with existing solar than they would spend putting a new system on a different home. Note however, that adding a 30% tax credit lowers this replacement cost measure net measure to $15,586, again approximately our estimated capitalization value. Table 4 also reports the predicted value of an additional kilowatt in size of $2,405. This figure is obtained by evaluating the System Size specification (equation (2)) estimates reported in table 3. The solar panel linear terms are jointly significant in this specification and suggest that, as expected, an additional kilowatt of solar is valued at well below the average value per watt.

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, we do not expect capitalization to increase proportionally with system size due to the institutional structure of electricity rates and the "net metering" system in CA that is used during our sample period to value electricity produced by residential solar panels. 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). The rate structure is relevant to the value of system size because households pay for electricity use in excess of what is produced by the panels at any given point in time. For excess generation, households may opt in to the net 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. 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.[18]

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

[18] 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.

listed in Table 5. 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 a Prius concentration, Green party and Democrat registrant share, and median income capitalize solar panels at a higher value, while in neighborhoods with relatively many trucks, panels provide less of a premium to home sales.

Results of our final hedonic specification, shown in table 6, suggests that our estimates are not driven by unobserved home upgrades besides solar panel installation. 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

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 the time between sales, and control for jointly estimated census tract level repeat sales indexes.[19] As presented in table 7, our average capitalization estimate of 3.6% applied to the average price at the first sale in the repeat pair of $558,100 implies an average additional $20,194 in the subsequent sales price due to the installation of solar panels. This value suggests that households that install panels recuperate more than their costs in subsequent sales, although this 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.

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

VI. Conclusion

This study has 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 as compared to comparable homes without solar panels. While the residential solar home market continues to grow, there is surprisingly little direct evidence on the market capitalization effect. We find evidence using both hedonics and a repeat sales index approach that solar panels are capitalized at roughly a 3% 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 that Borenstein (2008) has led concerning 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. Put simply, some households may take pride in knowing that they are producers of “green” electricity. For households who sufficiently derive such a “warm glow”, utility maximization may triumph over present discounted value calculations in determining a household’s install choice.

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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	Sales with solar	No solar - solar
	Mean *Std Dev*	Mean *Std Dev*	Difference in means *Pr(|T|>|t|)*
Sale price (real $s)	426,361 *374,520*	696,391 *425,167*	-270,031 *0.000*
Square feet	1,987 *961*	2,529 *1,134*	-542 *0.000*
Bedrooms	3.39 *0.89*	3.79 *0.86*	-0.40 *0.000*
Baths	2.38 *0.88*	2.91 *1.04*	-0.53 *0.000*
View	0.30 *0.46*	0.37 *0.48*	-0.07 *0.020*
Pool	0.18 *0.38*	0.34 *0.47*	-0.16 *0.000*
Acres	0.40 *1.53*	0.99 *2.78*	-0.59 *0.001*
Owner occupied	0.71 *0.46*	0.67 *0.47*	0.03 *0.219*
Building year*	1978 *19.5*	1984 *21.3*	-6.4 *0.000*
Sales since 1983	2.72 *1.36*	2.54 *1.15*	0.18 *0.009*
Defaults since 1999	0.26 *0.64*	0.24 *0.61*	0.02 *0.526*
System cost (Real $s)$^+$		26,700 *17,245*	
System size (kW)		3.18 *2.15*	
Incentive amount$^+$		10,988 *7,816*	
Observations	347,903 (*346,772)	279 ($^+$259)	

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	1,297	1,837	-540
	314	*536*	*0.000*
Average acreage	0.21	0.45	-0.24
	0.40	*0.89*	*0.000*
Percent with pools	3.49	15.33	-11.83
	4.03	*11.11*	*0.000*
Percent Green Party	0.50	0.52	-0.02
	0.50	*0.45*	*0.825*
Percent Democrat	47.15	35.26	11.89
	9.62	*8.66*	*0.000*
Median income ($1000s)	31.31	56.56	-25.25
	11.78	*22.87*	*0.000*
Percent White	27.54	61.89	-34.35
	22.61	*23.06*	*0.000*
Percent Owner Occupied	55.57	73.17	-17.59
	17.47	*8.88*	*0.000*
Percent College Grads	28.58	31.75	-17.90
	0.76	*0.82*	*0.000*
Percent Prius*	0.39	0.39	0.002
	0.03	*0.03*	*0.993*
Percent Truck*	46.01	45.61	6.21
	0.73	*0.73*	*0.126*
Observations	103	478	
	(*95)	(*89)	

*Auto data variables reported at the zip code level

Table 3: San Diego Hedonic OLS regression estimates of log sales price on solar panels

Variable	Baseline Coefficient *(Std Error)*	System Size Coefficient *(Std Error)*
Solar$_{ijt}$	0.033** *(0.011)*	-0.051 *(0.151)*
Log Size (watts) * Solar$_{ijt}$		0.011 *(0.019)*
Joint significance of solar terms		F Stat = 5.06, Prob > F = 0.006
Home characteristics	Yes	Yes
Census tract quarter fixed effects (578 tracts, 51 quarters)	27,854	27,854
Observations	348,182	348,182
Sales with solar	279	279
R^2 within; overall	0.64; 0.34	0.64; 0.34

**Significant at the 5% level

Table 4: Predicted value of solar from hedonic estimates and comparison sample values

Predicted added value of solar at mean characteristics of sales with solar	$16,235; ($5.09/watt)
Average total (before subsidy) system cost of solar for solar sales	$26,700; ($8.45/watt)
Average net (after subsidy) system cost of solar for solar sales	$15,712; ($4.94/watt)
Average mean total (before subsidy) system cost of all systems installed during quarter of home sale (replacement cost)	$32,599; ($7.60/watt)
Average mean net (after subsidy) system cost of all systems installed during quarter of home sale	$22,266; ($5.24/watt)
Predicted added value of an additional 1kW of system size	$2,405; ($2.41/watt)

Table 5: Hedonic OLS regression estimates of log price on solar panels with neighborhood characteristic interaction

Variable	Prius Share Coeff. *(S.E.)*	Truck Share Coeff. *(S.E.)*	Green Share Coeff. *(S.E.)*	Dems Share Coeff. *(S.E.)*	Log Med Income Coeff. *(S.E.)*	College Grads Coeff. *(S.E.)*
$Solar_{ijt}$	0.000 *(0.024)*	0.234*** *(0.084)*	0.023 *(0.015)*	-0.043 *(0.052)*	-0.081 *(0.292)*	-0.014 *(0.026)*
$NbhdVar_j$ * $Solar_{ijt}$	0.067* *(0.041)*	-0.004** *(0.002)*	0.020 *(0.022)*	0.003 *(0.002)*	0.010 *(0.026)*	0.001** *(0.0005)*
Joint significance of solar terms - F Stat; (Prob > F)	6.42; (0.002)	7.91; (0.0004)	5.32; (0.005)	6.03; (0.002)	4.95; (0.007)	6.85; (0.001)
Home characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Census tract quarter fixed effects (578 tracts, 51 quarters)	27,189	27,189	27,848	27,848	27,848	27,848
Observations	332,921	332,921	348,176	348,176	348,176	348,176
Sales with solar	271	271	279	279	279	279
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 6: 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 7: Repeat sales GLS regression estimates of log of sales price ratio on added solar

Variable	Baseline Coefficient *(Std Error)*	System Size Coefficient *(Std Error)*
ΔSolar$_{ijt}$	0.036** *(0.018)*	0.611** *(0.277)*
Log Size (watts) * ΔSolar$_{ijt}$		-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