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Mr. Alfred Pollard, General Counsel September 9th 2012
Attn: Comments/RIN 2590-AA53
Federal Housing Finance Agency, Eighth Floor
400 Seventh Street, SW.
Washington, DC 20024
Subject: RIN 2590-AA53
RegComments@fhfa.gov

Dear Mr. Pollard,

Over the last two years, new peer reviewed econometric studies have provided credible evidence that investments in solar panels, and achieving energy efficiency standards are capitalized into the sales price of homes. These papers use standard micro econometric techniques to rigorously test the hypotheses, using a large number of home sales for dwellings that have made these investments, and compares the sales price to observationally similar homes in the same neighborhoods, sold at roughly the same point in time that do not have "green" features. This letter reviews the key findings of these papers based on data from California and Holland.

This letter's main results challenge Freddie Mac's assertion cited by FHFA on page 36091 of the Federal Register.[1] "Freddie Mac asserted that ''we are not aware of reliable evidence supporting a conclusion that energy efficiency improvements increase property values in an amount equal to the cost of the improvement. Rather, our experience with other home improvements suggests that any increase in property values is likely to be substantially less than such cost, meaning that homeowners who take on PACE loans are likely to increase the ratio of their indebtedness relative to the value of their properties.'' The new empirical work discussed in this letter strongly suggests that Freddie Mac's pessimism is misplaced. Energy efficiency is capitalized into resale values and the effects appear to be large enough to cover the initial investment.

New Empirical Findings from Sacramento and San Diego, California

Dastrup et. al. (2012) use a large sample of recent home sales in California's Sacramento and San Diego counties to study the price premium for solar homes.[2] The San Diego sample offers 329 solar

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1 **Federal Register** / Vol. 77, No. 116 / Friday, June 15, 2012 / Proposed Rules

2 Dastrup, Samuel & Joshua S. Graff Zivin & Dora L. Costa & Matthew E. Kahn, 2012. "Understanding the Solar Home Price Premium: Electricity Generation and "Green" Social Status," European Economic Review (download paper here: http://tinyurl.com/99vrbcm).

home sales and Sacramento County offers 265 solar home sales. The authors use multivariate regressions to study how the sales prices for these homes compare to the sales price for the thousands of comparable homes located in the same community that do not have solar panels, sold at the same point in time. As shown in Tables 4 and 9 of their paper, in San Diego the solar homes sell for a 3.5% price premium while in Sacramento the solar homes sell for a 4% price premium. Intuitively, this means that a home that would have sold for $400,000 had it not had solar panels is predicted to sell for $416,000 with solar panels.

Based on the data from San Diego County (as shown in Dastrup et. al.'s 2012 Table 5), the predicted average price increase in the sales price of the home is $22,554 while the after subsidy installation cost of solar averages $20,892. Dastrup et. al's (2012) calculations suggest that the market is fully capitalizing the value and this suggests that the FHFA's concerns, voiced on pages 36091, 36092, 36099 of the Federal Register, are not warranted. The Dastrup et. al. (2012) study documents the capitalization of solar panels into local home prices in two independent large real estate markets (Sacramento and San Diego).

In addition to using a large sample of solar homes and non-solar homes, Dastrup et. al. (2012) provide a convincing "placebo test". The authors know when homes had solar panels installed. They document that those homes that in the future will have solar panels installed but have not installed them yet *do not sell* for a price premium in earlier sales. This is strong evidence rejecting the hypothesis that solar homes are "different" from the other housing stock. Dastrup et. al. (2012) document that the capitalization of solar panels varies across residential communities. This premium is larger in communities with a greater share of college graduates and of registered Prius hybrid vehicles. Economic theory predicts that this premium will be larger in areas that are warmer (and thus more electricity is used for air conditioning) and in areas where electricity prices are high and expected to rise.

Evidence from Holland

In a 2011 research paper, Brounen and Kok investigate the capitalization of energy efficiency in the Dutch housing market.[3] In Europe, homes receive energy efficiency grades of "A", "B", "C", "D", "E", "F" and "G," which is part of the broader EU regulation on energy efficiency in the real estate sector. Those homes that meet the most energy efficient criteria receive a grade of "A" while those who achieve a lower total energy efficiency standard achieve a "B," etc.. These report cards are public information that a potential home buyer observes before bidding for the house. In this sense, these report cards inform the potential buyers of what their annual operating expenditure for heating, cooling and use of appliances will be. Brounen and Kok (2011) model the probability of adopting a "green label" and its effect on the home price premium using the Nobel Laureate James Heckman's well known two-step "selection correction" and find that homes with a ‘‘green'' label sell at a premium of 3.7 percent relative to otherwise comparable dwellings with non-green labels (see Table 3 in the paper).

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[3] Brounen, Dirk & Nils Kok, 2011. "On the Economics of Energy Labels in the Housing Market," Journal of Environmental Economics and Management (download paper here: http://tinyurl.com/9w22ydu).

The price premium varies with the label category of the energy performance certificate and is robust to variations in housing quality. Importantly, the variation in the premium for energy efficiency seems to be related to the present value of future energy savings resulting from higher energy efficiency (see footnote 17 in the paper). The findings of Brounen and Kok provide an indication that private consumers use the information disclosed by the energy label and take the relative energy efficiency of their prospective home into account when making investment decisions.

Evidence on Energy Star and LEED Home Price Capitalization in California

More recently, Kahn and Kok (2012) examined the sales price premium for Energy Star and LEED certified homes relative to observationally similar homes located close to the "green homes" and selling at roughly the same point in time.[4] Their econometric study focuses on California home sales between the years 2006 and 2011. They conduct a hedonic pricing analysis of all single-family home sales in California over the time period 2007 to 2012, documenting that homes labeled with Energy Star, LEED or Greenpoint Rated, transact for a premium of nine percent relative to otherwise comparable, non-labeled homes (see Table 4 on page 28 of Kahn and Kok (2012). A notable feature of their study is the large number of green home sales transactions (4,231). Their study includes over 1.6 million transactions and the subset of "green home" sales is 4,231. This is a large enough sample to directly address the FHFA's concerns about the absence of direct evidence supporting the claim of a significant "green capitalization effect" (see page 36092).

One Comment about Counter-Evidence

On pages 36099 and 36100 of the Federal Register, there is a discussion of a 2011 study that reports that window replacement tends to offer only a 70% capitalization rate of the initial cost. This study is cited in footnote #12. We have gone to the source and found the specifics reported about the methodology used. Here is a direct quote:

"Construction cost estimates are generated by HomeTech Publishing (www.hometechpublishing.com), which updates its database of construction costs quarterly, using construction commodity data, as well as labor cost information from a nationwide network of remodeling contractors. The company prepares a detailed construction estimate for each project, then adjusts this baseline cost for each city to account for regional pricing variations. Construction cost figures include labor, material, and subtrade expenses, plus industry-standard overhead and profit. However, project costs are based on estimates for hypothetical projects, with no reliable way to accommodate local and short-term fluctuations in supply and demand.

Resale value data for each project are aggregated from estimates provided by members of the National Association of REALTORS®. In cooperation with REALTOR® magazine, e-mail surveys containing project descriptions and three-dimensional illustrations, plus construction costs and median home price data for each city, are sent to some 150,000 appraisers, sales agents, and brokers. Respondents are instructed not to make judgments about the motivation of the homeowner in either the decision to undertake the remodeling project or to sell the house. The 2010-11 survey was in the field for

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[4] Kahn, Matthew and Nils Kok 2012. "The Value of Green Labels in the California Housing Market," Working Paper (download paper here: http://tinyurl.com/9kbv9tc).

approximately 8 weeks in June, July, and August of 2010. More than 3,000 survey respondents participated."

(source http://www.remodeling.hw.net/2011/costvsvalue/article/costvsvaluedatasource.aspx).

It is important to note that both the estimate of the cost of installing the windows and the price appreciation attributable to the window installation are pure guesswork. The methodology sketched above could not be published in any academic journal and merely represents an averaging of guesses posed in a hypothetical situation. This "study" appears to contain very little information of value.

Concluding Thoughts

Skeptics have questioned whether the market rewards "green homes" with a significant price premium relative to observationally similar conventional homes. This document has provided a non-technical review of three new applied econometric papers. Two of these have been published in academic peer reviewed journals. The Journal of Environmental Economics and Management and the European Economic Review are two of the world's leading economic journals. The third paper discussed in this memo, Kahn and Kok (2012) will be submitted to the academic journal Regional Science and Urban Economics. These three papers share a common theme; green home investments are capitalized and the effect is quantitatively large and robust across different settings. The FHFA's concerns are misplaced. Home buyers who purchase a "green home" are enjoying a full capitalization of these benefits in the resale value of the home.

Sincerely,

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Understanding the Solar Home price premium: Electricity generation and "Green" social status ☆

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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.

1. 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% 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

☆ An early draft of this paper was presented at the Conference on "Green Building: The Economy, and Public Policy", March 22–24, 2011, Maastricht University, The Netherlands. We thank our conference discussants, Thomas Dohmen, Henry Overman, and an anonymous reviewer for helpful comments on that draft. We also thank the University of California Center for Energy and Environmental Economics (UCE^3) for research support and Andrew McAllister, Melanie McCutchan and Timothy Treadwell at the California Center for Sustainable Energy for feedback and data assistance.

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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 et al., 2011) highlights that in conservative communities solar panels may offer less "warm glow" utility to its owners.

In this paper, we examine two aspects of solar purchases. We provide new hedonic marginal valuation estimates for a large sample of solar homes based on recent real estate transactions in San Diego County and 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 that use sales data (rather than Census data) know very little about the household who actually lives 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 et al., 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 et al.'s (forthcoming) 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.

2. 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, the hedonic price premium for a solar home should equal c dollars. 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. On the other hand, many of the tax incentive programs to foster the adoption of solar panels have been designed with a declining rebate structure and even the duration of these programs are uncertain, making delay costly.[1] 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. For a formal model of hedonic pricing with a redevelopment option see Clapp and Salavei (2010).

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

[1] For example, the California Solar Initiative began with a rebate of $2.50 per watt on residential installations that is scheduled to drop to $0.15 per watt.

new homes who will compare their profit for building a home with and without solar panels.[2] Such developers are likely to have invested more effort in the basic marketing research of determining the market for this custom feature.

3. 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.

3.1. 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

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

where $\mathbf{Price}_{ijt}$ is the observed sales price of home i in census tract j in quarter t. The variable $\mathbf{Solar}_{it}$ 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 $\mathbf{X}_i$.

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.[3] Additional characteristics contained in $\mathbf{X}_i$ 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 Eq. (1), we are imposing a constant solar capitalization rate across time and space.[4]

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.

Our OLS capitalization estimate, 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.[5] 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 Eq. (1) with a linear term including the characteristic. Our estimating equation becomes:

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

[2] While the costs of new installations are quite similar to the cost of a retrofit for new custom home construction, large developments will create economies of scale that may reduce the costs of residential solar systems. The magnitude of this cost advantage is presumably limited, as a large share of system costs are devoted to system hardware.

[3] 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.

[4] 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 $2000), effective for property 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.

[5] In Bajari and Benkard's (2005) study of hedonic pricing, they demonstrate that because the solar option is discrete (i.e., a home either has or does not have panels), groups of diverse buyers with different tastes will be forced to choose among the discrete number of alternative hedonic packages. For those who choose to buy a home with solar panels, we can infer that the hedonic price provides a lower bound on such a household's willingness to pay for this attribute.

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

3.2. 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.[6]

4. 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.[7] 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. As measures of local community member preferences for "green products", 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.[8] We use the percent 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.[9] 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

[6] Our hedonic and repeat sales approaches are related. Since differencing consecutive observations on the same property i in Eq. (1) results in Eq. (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 $\mathbf{X}_i$, 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.

[7] The building year is not recorded for 1681 properties. Sales of these properties are included with a building year unknown indicator variable.

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

[9] See Wheaton (1977) for a discussion of how parameters in the utility function enter the hedonic pricing function. We thank a reviewer for pointing us to this reference.

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.[10]

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 6249 single family homes by address to public San Diego County Assessor property records for installations through early December 2010.[11]

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 (3433 observations); and, (4) not have solar panels as of Winter 2010. In the regressions, this fourth category will be the omitted category.[12] 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 $1000 and a "high value" renovations as one with an associated value greater than $10,000.

4.1. 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.

5. 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 registered voters on their age, education, political party of registration, and contributions to environmental, political, and religious organizations.[13] These data enable us to investigate what types of people self select into solar homes.

We estimate linear probability models using the City of San Diego homes in the year 2009 that are represented in the voter registration data. 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.

[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] 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.

[12] 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.

[13] Our data are from www.aristotle.com. We merged by street address to each home. We were able to match 83% of the voter records in the sample, which accounts for 50% of single family properties in the City of San Diego.

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	667,645	−240,599
	380,536	*426,980*	*0.000*
Square feet	1,984	2,512	−528
	961	*1,124*	*0.000*
Bedrooms	3.39	3.76	−0.37
	0.89	*0.86*	*0.000*
Baths	2.37	2.86	−0.48
	0.88	*1.00*	*0.000*
View	0.30	0.36	−0.06
	0.46	*0.48*	*0.020*
Pool	0.18	0.33	−0.15
	0.38	*0.47*	*0.000*
Acres	0.40	0.88	−0.49
	1.51	*2.56*	*0.001*
Owner occupied	0.70	0.69	0.02
	0.46	*0.46*	*0.531*
Building year*	1978	1983	−5.56
	19.5	*20.9*	*0.000*
System cost (2000 $s)+		27,790	
		17,245	
System size (kW)		3.37	
		2.23	
Incentive amount+		11,930	
		8,301	
Observations	364,663	329	
	(*363,504)	(+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	1,822	−544
	326	*535*	*0.000*
Average acreage	0.22	0.44	−0.22
	0.44	*0.88*	*0.000*
Percent with pools	3.01	15.01	−12.00
	3.73	*11,081*	*0.000*
Percent green party	0.50	0.52	−0.02
	0.50	*0.45*	*0.709*
Percent democrat	47.38	35.63	11.75
	9.42	*8.95*	*0.000*
Median income ($1000s)	30.35	55.86	−25.51
	11.97	*22.85*	*0.000*
Percent white	26.73	60.85	−34.13
	22.70	*23.67*	*0.000*
Percent owner occupied	53.89	72.87	−18.99
	18.21	*8.95*	*0.000*
Percent college grads	13.54	31.19	−17.66
	13.33	*17.95*	*0.000*
Percent prius*	0.39	0.39	0.002
	0.03	*0.03*	*0.993*
Percent truck*	51.83	45.61	6.21
	8.23	*6.92*	*0.126*
Observations	89	496	
	(*6)	(*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.

	Aristotle sample	
Dependent variable: Dummy = 1 if lives in a solar home	Mean	Coefficient (Std Error)
Home has solar panels (count)	1272[a]	
Conservative (all HH voters)	0.405	
Liberal (all HH voters)	0.399	0.002**
		(0.001)
Mixed conservative and liberal	0.022	0.005
		(0.003)
Other party	0.174	0.000
		(0.001)
Less than high school	0.067	
High school grad	0.205	0.001
		(0.001)
Some college	0.249	0.000
		(0.001)
College grad	0.253	0.003**
		(0.001)
Post graduate	0.171	0.006***
		(0.001)
Household has contributed to environmental organizations	0.080	0.005***
		(0.002)
Political organizations	0.490	−0.001
		(0.001)
Religious organizations	0.058	0.001
		(0.002)
Census tract fixed effects		*Y*
Observations		100,943
R-squared		0.010

Estimated from a linear probability model. Sample includes all single family homes in San Diego City that were successfully matched to Aristotle data. 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% level, respectively.

[a] Our solar indicator in this specification equals one if any home has solar panels, in contrast to results below, where the solar indicator denotes whether a home that is sold has solar panels.

We find that households in which all voters are 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 all voters in the household are registered liberal (and also controlling for contributions to organizations) the probability of being in a solar home increases by 0.002, an 18% 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% 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).

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.

6. 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 Eq. (2) contain census tract by

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***	0.031**	0.043[a]
	(0.010)	*(0.014)*	*(0.137)*
Solar will be installed	0.004	0.004	
	(0.003)	*(0.003)*	
Solar concurrently installed	0.028	0.028	
	(0.021)	*(0.021)*	
Solar home in solar block		0.010	
		(0.020)	
Log size (watts) * Solar			−0.001[b]
			(0.017)
Log(Acres)[b]	0.074***	0.074***	0.074***
	(0.003)	*(0.003)*	*(0.003)*
Swimming pool	0.050***	0.050***	0.050***
	(0.001)	*(0.001)*	*(0.001)*
View	0.049***	0.049***	0.049***
	(0.001)	*(0.001)*	*(0.001)*
Log(SquareFoot)[b]	0.432***	0.432***	0.432***
	(0.003)	*(0.003)*	*(0.003)*
Bathrooms	0.024***	0.024***	0.024***
	(0.001)	*(0.001)*	*(0.001)*
Constant	9.385***	9.385***	9.385***
	(0.012)	*(0.012)*	*(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.

[a] A joint test rejects that both $\alpha_0 = 0$ and $\alpha_1 = 0$, indicating that the total solar effect, $\alpha_0 \text{Solar}_{it} + \alpha_1 \text{LogSize}_{it} * \text{Solar}_{it}$, is significantly different from zero.

[b] 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.

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.

6.1. 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.[14] 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%, 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.

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

[14] 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.

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)

ownership. Our results on the larger capitalization effect of solar panels in liberal/environmentalist communities are consistent with the theoretical work of Kotchen (2006) who argues that environmentalists are more likely to be willing to purchase private goods that help to supply public goods. In this case, a private household buys a home with solar panels but this contributes to the public good of reducing greenhouse gas production. 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.

6.2. *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.[15] 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 Eq. (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, $N = \log(\text{Watts}_{it})$ 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 metering system that compensates them for electricity returned to the grid at (currently) between $0.171 and $0.275/kW h 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.[16] 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.[17] Indeed, the statistical insignificance of the estimated coefficient for Log Size indicates that the premium for solar installation does not vary with system size.

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. Tables 6 and 7 report estimates of Eq. (2) that indicate that the sales price premium for solar panel installations does vary with neighborhood characteristics. 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 and College graduate share capitalize solar panels at a higher value with statistically significant coefficients. While the coefficients for heterogeneous capitalization by Green party and Democrat registrant share and median income have the expected positive signs, they are not statistically significantly different from zero. In contrast, solar panels provide statistically significantly less of a premium to home sales in neighborhoods with a larger share of trucks.

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

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

[16] 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 kW h along the coast to 16.4 kW h per month in the inland desert during the summer) at a relatively low price (currently $0.039/kW h during the summer months) with an up to five fold increases for above baseline consumption (the top of four tiers is $0.197/kW h 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.

[17] 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.

Table 6
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.)*
$Solar_{ijt}$	−0.002	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)*
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; A joint test rejects that both $\alpha_0 = 0$ and $\alpha_1 = 0$, indicating that the solar effect, $\alpha_0 Solar_{it} + \alpha_1 N_j * Solar_{it}$, is statistically significant in all models.

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***	0.062***	0.060***	0.062***
	(0.016)	*(0.016)*	*(0.016)*	*(0.016)*
Building $Permit_{ijt}$		0.025***	0.056***	−0.036***
		(0.007)	*(0.005)*	*(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.

Variable	Baseline Coefficient *(Std error)*	System Size Coefficient *(Std error)*
$Solar_{ijt}$	0.036**	0.611**
	(0.018)	*(0.277)*
Log Size (watts) * $Solar_{ijt}$		−0.073**
		(0.035)
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.

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.

6.3. 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 time between sales, and

Table 9
Sacramento hedonic OLS regression estimates of log sales price on solar panels.

Dependent variable: Log(sale price)	Mean	Baseline Coefficient (Std error)	Street 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 (ft^2)	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		90,686	90,686
Sales with solar		265	265
R^2		0.852	0.852

***,**,* indicate statistical significance at the 1%, 5%, 10% levels, respectively. Regressions include year built dummies. Average sales price is $305,178.

controlling for jointly estimated census tract level repeat sales indexes.[18] 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.[19] 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).

7. 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).[20] 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.

We find that the premium for solar homes in Sacramento is 4% (see Table 9), similar to the premium for solar homes in San Diego (see Table 4). We find an even larger capitalization of 7% for a solar home in Sacramento that is not on a solar

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

[19] Given the larger number of sales available for our hedonic estimate, we prefer the Log Size estimate in Table 4. We anticipate the reliability of this coefficient will improve with additional observations that will accumulate over time, and would be informed by an analysis of rate tiers and panel installation discussed in note 16 above.

[20] 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.

street and a smaller one of 3% when it is on a solar street. Similar to our San Diego results, we fail to reject the hypothesis that there is no price premium for homes that will install solar panels in the future.

8. Conclusion

This study used a large sample of homes in the San Diego and Sacramento areas 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 evaluates residential solar installations solely as a 'pure' investment good judged in terms of upfront cost and subsequent 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.[21] 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 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.[22] 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.[23] 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.[24] A permit is not required "wallpapering, painting or similar finish work" and for small fences, decks, and walks.[25]

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

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

[22] Default data are matched by parcel number from public records published online by the San Diego daily transcript.

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

[24] 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.

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

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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On the economics of energy labels in the housing market ☆

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ABSTRACT

Energy efficiency in the residential housing market can play an important role in the reduction of global carbon emissions. This paper reports the first evidence on the market adoption and economic implications of energy performance certificates implemented by the European Union. The results show that adoption rates are low and declining over time, coinciding with a negative sentiment regarding the label in the popular media. Labels are clustered among smaller, post-war homes in neighborhoods with more difficult selling conditions. We also document that geographic variation in the adoption rate of energy labels is positively related to the fraction of "green" voters during the 2006 national elections. Within the sample of labeled homes, the energy label creates transparency in the energy efficiency of dwellings. Our analysis shows that consumers capitalize this information into the price of their prospective homes.

1. Introduction

The current focus on carbon abatement has lead to increased attention on energy efficiency in the built environment, which offers substantial opportunities for the reduction of greenhouse gasses [12,28]. Although building codes have generally been mildly effective in reducing energy consumption [3,18], globally policy makers target the real estate sector with stricter energy-efficiency standards and mandates. For instance, the European Union implemented the Energy Performance of Buildings Directive (EPBD) in January 2003 with the explicit goal of promoting energy performance improvements in buildings. The Directive, which was recently recast, includes an explicit element on the disclosure of energy performance in buildings: "…Member states shall ensure that, when buildings are constructed, sold or rented out, an energy performance certificate is made available to the owner or by the owner to the prospective buyer or tenant."[1] The Directive has lead to the implementation of national Energy Performance Certificates (EPCs) for residential dwellings as well as utility buildings (e.g., office, retail, schools, and healthcare facilities) across the European Union.

The introduction of energy labels can be viewed as an additional step to enhance the transparency of energy consumption in the real estate sector. Greater transparency may enable private and corporate occupiers to take energy

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[1] Article 7, Energy Performance of Buildings Directive, EU, 2009.

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efficiency into account when making housing decisions. Recent evidence shows that providing feedback to private consumers with respect to their energy consumption is an effective "nudge" to improve energy efficiency [4,8]. From an economic perspective, the energy label could have financial utility for both real estate investors and tenants, as the energy savings resulting from more efficient building may result in lower operating costs and higher property values.

However, evidence regarding the implementation and valuation of energy labels is limited, the diffusion and uptake of energy labels across Europe has been slow, and private consumers are uncertain about the value represented by labels that indicate some level of modeled energy efficiency.

This paper is the first to empirically address the implementation of energy labels under a large-scale certification program in the European Union. Using a standardized measure to reflect the thermal efficiency of a structure, we study the determinants of the adoption of energy performance certificates and the consequent economic implications in the residential housing market. We use the Netherlands as a laboratory, as energy performance certification for homes was introduced in the Netherlands in January 2008, one year before the official introduction date prescribed by the European Union. Energy conservation is presumably quite important for Dutch residents, as the average energy bill of a Dutch household was €152 per month in 2009 (€53 for electricity and €99 for gas), ranging from €105 for the most energy efficient homes to €231 for the least energy efficient homes. For some households, energy costs represent almost half of the total monthly housing expense.

Energy performance certification is not fully mandatory in the Netherlands: homebuyers are allowed to sign a waiver that obviates the seller's obligation to certify the dwelling. Based on some 177,000 housing transactions from January 2008 through August 2009, we find that during the first three months of 2008, more than 25 percent of all housing transactions had an energy label. Soon after, the adoption rate of energy labels started to decline, eventually reaching an adoption rate of less than seven percent of the 150,000 homes that were for sale as of September 2009. This sharp decrease in the adoption rate coincides with a negative sentiment created by the main bodies in the real estate industry, such as the Association of Realtors and the Association of Homeowners. Our "News Index," based on counts of negative or positive reporting on the energy label in the popular press, leads the energy label adoption curve by some three months.

Our empirical results show that the choice of certification is also determined by the quality of a dwelling. We find that more heterogeneous homes, constructed post-war and during the seventies and eighties, located in high-density and low-income areas are significantly more likely to obtain an energy label. The thermal characteristics of a dwelling, like insulation and the heating system, do not influence the certification decision. Our results also provide some indication of ideology as an explanation for the adoption of energy labels: adoption rates are higher among homeowners that voted for "green" political parties during the 2006 national elections.

We then turn to the market implications of the energy label. The label seems to fulfill its informational role and has a moderately powerful market signal. We track the transaction process of some 32,000 labeled homes and document a positive relation between the energy efficiency of a dwelling and its transaction price. Using the Heckman [17] two-step method, we find that homes with a "green" label sell at a premium of 3.6 percent relative to otherwise comparable dwellings with non-green labels. This transaction premium varies with the outcome of the label, and calculations indicate that this variation can be partially explained by the underlying energy consumption of the dwelling.

This paper contributes to the early literature on the capitalization of thermal efficiency in residential dwellings [9,14,22]. It also contributes to a more recent, growing literature on the economic implications of energy efficiency and sustainability labels in the real estate sector, which has thus far predominantly addressed the commercial property market [10,11,13]. The paper also relates to the fast-growing literature on environmentalism and consumer choice [16,19] that increasingly focuses on residential energy consumption [7,8]. For policy makers, the results of this paper may shed light on the main assumption underlying the widespread implementation of energy rating systems: the ability of the market to capitalize energy efficiency in investment decisions. It may also help to further refine energy performance certification programs and stimulate increased market demand for energy labels.

The next section of this paper is a brief review of the literature on energy efficiency in the built environment. Section 3 discusses the various programs of energy performance certification in the real estate sector and provides more details on the European energy performance certification program. Section 4 describes the data and provides descriptive statistics. Section 5 discusses the empirical results and Section 6 concludes.

2. Related literature

Models attempting to predict future residential energy consumption not only take the housing stock and its projected growth into account, but also demographic, social, and behavioral characteristics of the occupants [5,20]. To ultimately reduce the carbon footprint of the real estate sector, demand from occupiers and investors for more energy-efficient real estate is necessary. Glaeser and Kahn [15] argue that if the carbon externality were appropriately priced, costs per household would range from $830 to $1410 per year, depending on the climatic conditions and, more importantly, on a city's population and density. However, the early literature as well as more recent studies both show that households do not directly take carbon emissions into account in relocation decisions, but rather focus on environmental externalities, like pollution, traffic, and the availability of nature [1,6,16,25].

There are a handful of papers that explicitly address the willingness to pay for energy efficiency in residential dwellings. Lacquatra [22] studies a small sample of newly constructed homes and documents that the Thermal Integrity Factor (TIF), a proxy for energy efficiency, has a positive relation to the transaction price. Dinan and Miranowski [9] find a similar relation between standardized energy consumption and prices of homes transacted in Des Moines, Iowa. In fact the documented relation is quite precise: one dollar of energy savings leads to a $11.63 increase in the transaction price. Gilmer [14] applies energy labels to a model of economic search and documents that benefits of labels are positive but modest, i.e., energy labels shorten the search process.

More recently, evidence on the willingness to pay for energy efficiency in the real estate sector has mostly focused on the commercial real estate sector. In a series of papers that study investor and tenant demand for "green" office space in the U.S. office market, Eichholtz et al. [10,11] show that buildings with an Energy Star label – indicating that a building belongs to the top 25 percent of the most energy-efficient buildings – have rents that are two to three percent higher as compared to regular office buildings. Transaction prices for energy-efficient office buildings are higher by 13–16 percent. Further analyses show that the cross-sectional variation in these premiums has a strong relation to real energy consumption, indicating that tenants and investors in the commercial property sector capitalize energy savings in their investment decisions.

To improve the energy performance of the built environment, building codes have become more stringent over the past decades and construction standards have improved. These mostly supply-side measures have lead to substantial energy savings [3,27]. However, other studies have documented a stagnating trend in the energy efficiency of buildings in Western economies. Nässén et al., [24] find that energy price elasticity has decreased over time, mainly due to a lack of understanding of the life cycle cost – or, the economic payoff – following investments in energy efficiency. This is in line with Kempton and Layne [21], who show that inefficient allocation of data on energy consumption restricts the energy savings behavior of consumers. Also, there is documentation that deficiencies in public policies regarding energy efficiency, limited regulation, and the conservatism in the building industry are to blame for the slow implementation of energy efficiency measures [26].

Increased information transparency in energy consumption can be instrumental as a "nudge" to encourage energy conservation among private consumers. Some recent experiments show that providing feedback to consumers on energy consumption can substantially reduce energy bills [4], although political ideology seems to be an important moderating factor [8]. Standardized energy performance certification programs can provide a cheap alternative to these small-scale experiments, but these programs for energy ratings rest on the assumption that the residential housing market can effectively incorporate information on thermal efficiency.

3. Energy performance certification and the EPBD

Various national governments have initiated rating systems that measure the extent to which both residential dwellings and commercial buildings adhere to energy efficiency standards. The Energy Star program, a joint initiative by the U.S. Department of Energy and the U.S. Environmental Protection Agency, is a long-running and notable example. Residential buildings can receive an Energy Star certification if they are at least 15 percent more energy efficient than homes built to the 2004 International Residential Code (IRC) and include additional energy-saving features that typically make them 20–30 percent more efficient than standard homes. For consumers, there should be a clear relation between investments in energy efficiency and the consequent savings, as stated by the EPA: "…energy efficiency improvements save homeowners money—about $200–$400 per year on utility bills. More importantly, monthly energy savings can easily exceed any additional mortgage cost for the energy efficiency improvements, resulting in a positive cash-flow from the first day of home ownership."[2] To date, close to a million dwellings have earned an Energy Star label.

Although numerous countries have introduced comparable initiatives to raise consumer awareness of energy consumption and carbon emissions resulting from their homes, until recently, none have had the scope of the Energy Star program. This changed in December 2002, when the European Parliament ratified Directive 2002/91/EC on the energy performance of buildings, which makes energy performance disclosure mandatory for all member states. The Directive argues that "a common approach […] will contribute to a level playing field as regards efforts made in member states to save energy in the buildings sector and will introduce transparency for prospective owners or users with regard to the energy performance in the Community property market."[3] This Directive mandates the introduction of comparable Energy Performance Certificates (EPCs) across the European Union. The Directive should have been formally implemented in January 2006 but member states were given an additional period of three years to fully adhere to the certification procedures, due to the lack of qualified and/or accredited experts. The recast of the Directive in 2009 expanded the existing legislation: the certificate now has to be included in all advertisements for selling or renting properties. Moreover, the certificate and its energy saving recommendations have to be part of the documentation accompanying a rental or sales transaction.

The European energy label has a common base across all member states and is derived from the thermal quality of the dwelling. It takes elements such as insulation quality, heating installation, (natural) ventilation and indoor air climate, solar systems, and built-in lighting into account. The certificate contains a simple universal indicator of the energy

[2] See http://www.energystar.gov/index.cfm?c=home_improvement.hm_improvement_index for more information.

[3] Press release MEMO/08/693, Brussels, 13 November 2008.

consumption – the energy index – based on *modeled* primary energy consumption under average conditions.[4] Based on the energy index, the energy performance certificate ranges from ‘‘A++,’’ for exceptionally energy-efficient dwellings, to ‘‘G’’ for highly inefficient dwellings. Besides an energy-efficiency score, the certificate also contains specific advice on how to improve the thermal performance of a building. Appendix A provides an example.

Professionally trained surveyors issue the certificates, with model inputs based on a physical inspection of the dwelling. The certificate is valid for 10 years and requires an investment of some €200, which is incurred by the seller of the building. Dwellings that have been constructed after 1999, or that have been officially registered as monuments, are exempt from mandatory disclosure of an energy performance certificate. Importantly, if the buyer of a dwelling signs a waiver, the seller is also exempt from providing the certificate at the time of the transaction.

The energy performance certificate offers a variety of benefits to private consumers. The certificate increases the transparency in the energy consumption of a specific dwelling and results in EU-wide recognition of investments in energy conservation. This recognition not only assures homeowners that energy-efficiency investments are recognized at the time of sale, but it may also lead to a lower cost of funding through more favorable mortgage terms for energy-efficient homes. An energy label may also shorten the economic search process by disclosing information to prospective homeowners [14]. This may be important in the opaque market for housing transactions.[5]

However, poorly defined label requirements and insufficient training of official certification agencies have characterized the recent introduction of energy performance certificates across the European Union. Also, the possibility of signing a waiver has allowed private consumers to circumvent the mandatory disclosure of energy performance certificates in housing transactions. In addition, industry bodies have openly questioned the reliability of the information provided by energy labels and the need for providing such information to consumers. The combination of these factors has lead to a slow implementation of energy labels across European residential housing markets and may affect the economic value of energy performance certificates in the market place.

In the remainder of this paper, we empirically address the patterns and determinants of label adoption, and the effectiveness of the energy label as a market signal. We use a large sample of housing transactions in the Netherlands, which in January 2008 was one of the first EU member states to introduce energy performance certificates.

4. Data

4.1. Data sources

Agentschap NL, an agency of the Dutch Ministry of Economic Affairs, exerts quality control and maintains registration of the energy performance certificates in the Netherlands. We have access to the database of this organization, which provides information on the energy performance rating, the address, and some physical building characteristics of all buildings with an energy performance certificate. As of September 2009, more than 100,000 residential homes (rental and owner-occupied) had been certified.[6]

To obtain information on housing transactions, we use the database of the Dutch Association of Realtors (NVM), which includes information on the dwelling address, the characteristics of the transaction, and a wide array of quality characteristics for each transacted dwelling.[7] As of September 2009, the NVM database contained 194,379 housing transactions since the introduction of energy performance certificates in January 2008.[8]

For a slightly smaller subset of our sample, we are able to collect economic data on the neighborhood characteristics of the home from the Central Bureau of Statistics (CBS). We collect information on housing density, as measured by the number of addresses within a one-kilometer radius, and on the average monthly household income, both for 2007. This information is available at the zip code level.[9] As a proxy for local housing market conditions, we calculate the average time on the market for homes transacted in 2006 and 2007, also at the zip code level.

To account for ideological heterogeneity of homeowners, we obtain voting data on the 2006 national elections and calculate the percentage of votes for ‘‘green’’ parties.[10] The Netherlands has two political parties that distinctly focus on animal rights and environmental conservation: the ‘‘Green Party’’ and the ‘‘Party for the Animals.’’

[4] The primary energy consumption of a dwelling is modeled based on occupancy by an average household under normal climatic conditions. The energy label thus provides an indication of energy consumption under standardized behavior and is not based on the *actual* energy consumption as measured by energy bills.

[5] There is a large body of literature that addresses the lack of information transparency in the residential housing market. See Levitt and Syverson [23] for one example.

[6] The sample of certified rental homes mostly consists of public housing owned by social housing corporations. As such, this sample is less suitable for a study on energy labels and private market rents.

[7] The members of the NVM collectively cover approximately 70 percent of all housing transactions in the Netherlands.

[8] We only include transactions for which all data are available and for which the transaction price ranges between €10,000 and €10,000,000.

[9] The zip code covers an area of less than a square mile around a home. Zip codes are of comparable size across our sample, and therefore a useful proxy for the quality of the immediate neighborhood.

[10] Data are obtained from http://www.verkiezingsuitslagen.nl.

The 2006 national elections had a turnout of more than 80 percent and are a proxy for the political balance at the city level.

4.2. Descriptive statistics

We match the various data sets based on address information. Approximately, 18 percent of the transaction sample – 31,993 residential dwellings – has an energy performance certificate. However, these certified transactions are not evenly distributed over the sample period. Fig. 1A presents the total number of transaction per month and the fraction of homes transacted with an energy label. The number of housing transactions provides an indication for the dry-up of liquidity in the housing market, with year-on-year transactions decreasing by some 35 percent. The graph also shows that the fraction of rated homes strongly decreased during the sample period, starting at a label adoption rate of 25 percent in January 2008 and decreasing to a label adoption rate of approximately 10 percent in the Summer of 2009. Anecdotally, we can explain this remarkable drop in the adoption rate by the initial problems surrounding the implementation of the energy label.

To more systematically address these initial problems, we assess the evolution of the public opinion regarding the energy label by constructing a quantitative measure: the "News Index." We use LexisNexis to collect all articles published in the four major Dutch newspapers between January 2007 and August 2009, using a Boolean search on "energy label" and related terms. In line with Antweiler and Frank [2] and Tetlock [29], we convert these newspaper articles into a numeric score by manually screening the articles on their sentiment regarding the energy label. Positive news receives a

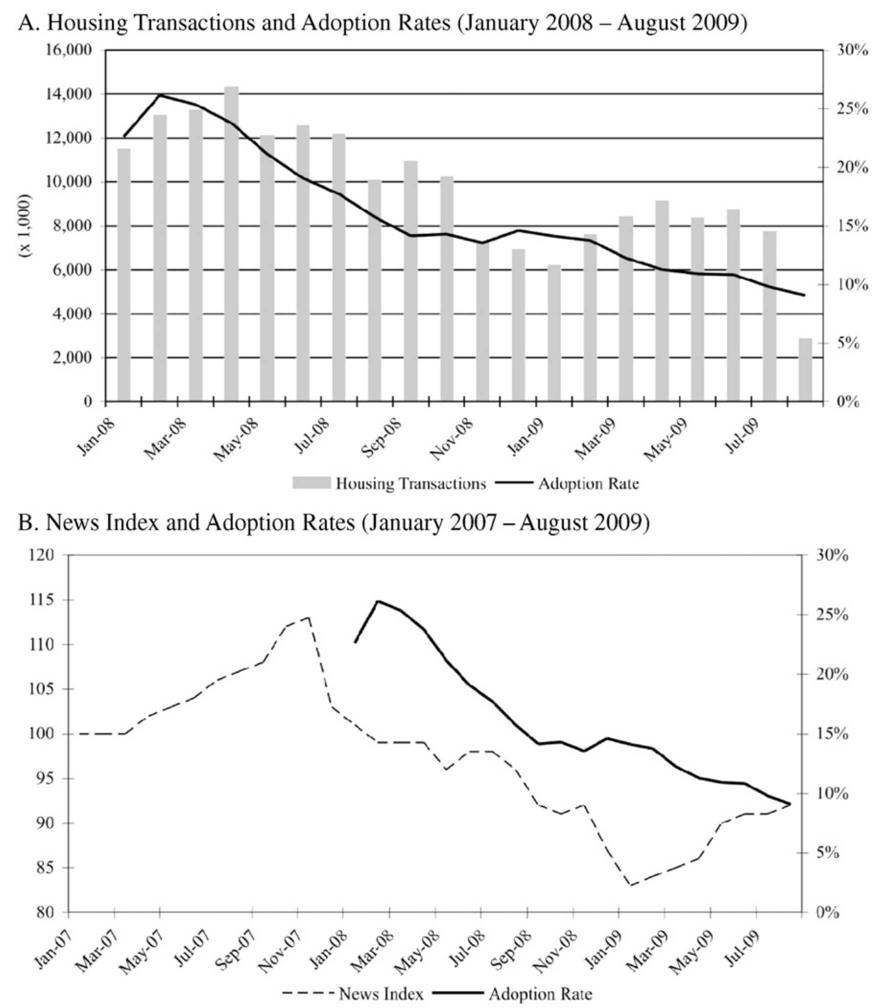

Fig. 1. Energy label dynamics housing transactions, adoption rates and the News Index.
Source: LexisNexis, Dutch Association of Realtors (NVM), and Agentschap NL.

score of 1, whereas negative news receives a score of −1. Front page news presumably has more impact and receives a score of 2 or −2, respectively.

Fig. 1B shows the News Index for the period January 2007–August 2009. The popular media was generally positive on the energy label in the run-up to the launch, but just before the official start of the labeling program, the Dutch Association of Homeowners launched a media campaign asserting the lack of consistency and reliability of the energy performance certification process. These critiques made headlines in the national press starting December 2007. During the Spring of 2008, several other important real estate bodies, including the Association of Realtors and the Association of Public Housing Corporations, fueled the skepticism regarding the quality of the signal conveyed by the energy label and questioned the need for an energy label in the housing market. This public dismay forced the Minister of Housing to admit that the implementation of the certificate left something to be desired. Subsequent program improvements included better training of certifying surveyors and enhancing the transparency of the labeling process. These advances were implemented during the Fall of 2008, which favorably changed the public opinion on the energy label after January 2009.

The dynamics of the News Index are leading the adoption rate of the energy label in housing transactions. Simple calculations show that the correlation is highest when the News Index is lagged by one quarter. Thus, public opinion and media sentiment seem to be important determinants of the adoption rate of the energy performance certification program.

There is also substantial regional variation in the market penetration of energy labels. Fig. 2 shows labeled housing transactions as a fraction of the total transaction volume for the 12 provinces in the Netherlands. The two main provinces that form the economic core of the Netherlands (the so-called "Randstad"), North-Holland, which includes Amsterdam, and Utrecht, both have relatively low adoption rates of energy performance certificates. These rates are in contrast to the high adoption rates in more distant provinces like Zeeland and Limburg.

Table 1 provides descriptive statistics on the physical characteristics of the labeled and non-labeled sample. Simple comparisons show that labeled dwellings sell for slightly lower prices and are on the market six days longer, on average. The dwelling type composition of the labeled sample is comparable to the composition of the sample of non-labeled dwellings. There are some quality differences between labeled homes and non-labeled homes: the former are smaller by about six square meters and are predominantly constructed between 1960 and 1990. Maintenance of the interior and

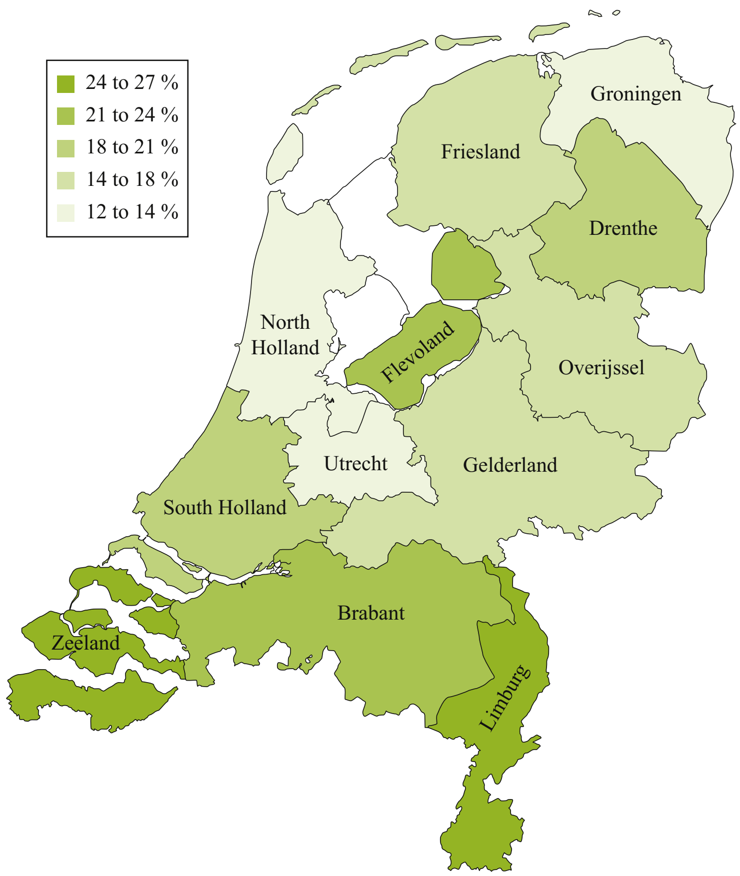

Fig. 2. The geography of energy label adoption rates (The Netherlands, January 2008–August 2009).
Source: Dutch Association of Realtors (NVM) and Agentschap NL.

Table 1
Comparison of labeled and non-labeled dwellings (January 2008–August 2009).

Sample size	Labeled dwellings 31,993		Non-labeled dwellings 145,325	
	Mean	St.Dev.	Mean	St.Dev.
Transaction price (€/square meter)	2,003.04	691.24	2,202.06	836.96
Time on market (days)	137.79	154.73	131.63	153.12
Dwelling type (percent)				
Apartment	30.82	46.17	32.34	46.78
Duplex	45.89	49.83	42.07	49.37
Semi-detached	13.26	33.92	13.44	34.11
Detached	10.03	30.05	12.15	32.67
Period of construction (percent)				
Pre-1930	12.76	33.37	18.60	38.91
1930–1944	6.32	24.34	8.35	27.66
1945–1960	9.80	29.73	7.55	26.42
1960–1970	18.57	38.88	15.48	36.18
1970–1980	22.19	41.55	15.64	36.32
1980–1990	17.79	38.24	12.85	33.47
1990–2000	11.84	32.31	14.29	34.99
> 2000	0.70	8.36	7.11	25.69
Thermal and quality characteristics				
Dwelling size (square meters)	114.01	46.15	119.82	55.69
Central heating (1 = yes)	91.00	28.62	91.08	28.51
Insulation quality (1–5)	2.13	1.76	2.21	1.82
Interior maintenance (1 = "Good")	86.95	33.68	88.44	31.97
Exterior maintenance (1 = "Good")	91.45	27.96	91.73	27.54
Neighborhood characteristics[a]				
Housing density (dwellings in 1 km radius)	1,962.40	1,731.65	2,105.82	1,990.42
Average time on market (days)[b]	129.20	46.69	126.44	49.28
Average monthly household income (€)	2,087.21	616.37	2,201.67	660.23
Political ideology (percent)				
Green vote[c]	6.96	3.18	7.37	3.49
Period of transaction (percent)				
Q1 2008	28.06	44.93	17.60	38.08
Q2 2008	25.03	43.32	19.20	39.39
Q3 2008	15.91	36.58	17.42	37.93
Q4 2008	10.25	30.33	13.06	33.70
Q1 2009	8.89	28.46	12.04	32.54
Q2 2009	8.66	28.13	14.61	35.32
Q3 2009	3.19	17.58	6.07	23.89
Energy label (percent)				
A	0.60	7.73		
B	8.19	27.43		
C	24.15	42.80		
D	26.95	44.37		
E	19.25	39.43		
F	13.27	33.92		
G	7.45	26.26		

[a] neighborhood characteristics are all at the zip code level.
[b] calculation based on dwellings transacted in 2006 and 2007 at the zip code level.
[c] the calculation of *Green Vote* is based on the total votes for the Green Party and the Party for the Animals as a fraction of the total votes during the 2006 national election.

exterior and the insulation are of slightly lower quality as compared to the non-labeled transaction sample. The neighborhood characteristics show that labeled dwellings are located in less dense areas with lower average household incomes, and where homes are on the market longer.

Within the sample of labeled dwellings, about one third of the transactions has been awarded a "green" label—corresponding to a rating of A, B, or C. About a quarter of the certified homes have a D rating, where D indicates that there is room for improvement in energy efficiency. Thirty-nine percent of the certified dwellings have a red label (E or lower), which indicates that there are considerable opportunities to increase the energy performance of these particular dwellings. Last, the economic downturn is clearly reflected in the distribution of the transactions over the sample period: more than half of the transactions took place in the first two quarters of 2008, with transactions in the housing market virtually grinding to a halt in the third quarter of 2009.

5. Method and results

5.1. The adoption process of energy performance certificates

To better understand the adoption process of energy performance certificates in the Dutch housing market, and to more formally explore the determinants of label adoption, we estimate the following logit model:

$$\Pr(EPC)_i = \alpha + \beta_i X_i + \delta_n L_n + \rho g_c + \sum_{p}^{p=1} \lambda_p p_p + \varepsilon_i \quad (1)$$

where EPC_i is the binary variable with a value of one if transacted dwelling i has an energy performance certificate, and zero otherwise. X_i represents a vector of quality characteristics of a dwelling, such as size, age, and building quality. L_n is a vector of variables that reflect the neighborhood characteristics of each individual dwelling in cluster n; such as density, average monthly household income, and the average time on the market. These variables are all at the zip code level and vary per neighborhood n. g_c is the fraction of votes for "green" parties during the 2006 national elections that varies per city c. To further control for geographical effects, p_i is the dummy variable with a value of one if a dwelling is located in province p, and zero otherwise.

Table 2 presents the results of the logit estimation of Model (1). Results are provided for four different specifications. All specifications include the News Index to control for time-variation in the adoption of energy labels, and province-fixed effects to control for regional variation in the adoption rate. In the first Column, we include housing type, dwelling size and the period of construction. Relative to detached dwellings (the default category), semi-detached dwellings, and especially duplex dwellings are significantly more likely to have an energy performance certificate. In contrast, apartments are

Table 2
Logit regression results. The determinants of label adoption.

	(1)	(2)	(3)	(4)
Dwelling type[a]				
Apartment	−0.120*** [0.029]	−0.119*** [0.029]	−0.184*** [0.033]	−0.195*** [0.034]
Duplex	0.082*** [0.023]	0.082*** [0.023]	−0.019 [0.026]	−0.018 [0.026]
Semi-detached	0.059** [0.027]	0.059** [0.027]	0.032 [0.028]	0.037 [0.028]
Dwelling size (log)	−0.431*** [0.023]	−0.430*** [0.024]	−0.264*** [0.025]	−0.259*** [0.025]
Period of construction[b]				
1931–1944	0.068** [0.030]	0.068** [0.030]	0.074** [0.030]	0.079*** [0.030]
1945–1960	0.557*** [0.027]	0.558*** [0.027]	0.557*** [0.027]	0.565*** [0.027]
1960–1970	0.494*** [0.023]	0.495*** [0.023]	0.503*** [0.023]	0.515*** [0.024]
1971–1980	0.685*** [0.022]	0.686*** [0.022]	0.738*** [0.023]	0.754*** [0.023]
1981–1990	0.646*** [0.023]	0.647*** [0.023]	0.688*** [0.024]	0.702*** [0.024]
1991–2000	0.161*** [0.025]	0.162*** [0.025]	0.272*** [0.026]	0.281*** [0.026]
> 2000	−1.953*** [0.070]	−1.952*** [0.070]	−1.911*** [0.070]	−1.904*** [0.070]
Monument	−0.103 [0.078]	−0.103 [0.078]	−0.078 [0.078]	−0.080 [0.078]
Thermal and quality characteristics				
Central heating		−0.019 [0.023]	−0.016 [0.023]	−0.016 [0.023]
Insulation quality		0.000 [0.004]	0.001 [0.004]	0.001 [0.004]
Exterior maintenance		−0.001 [0.023]	0.006 [0.023]	0.006 [0.023]
Neighborhood characteristics				
Housing density (in thousands, logs)			0.046*** [0.009]	0.037*** [0.009]
Average time on market (in hundreds of days, logs)			0.011 [0.021]	0.046** [0.023]
Average monthly household income (in €thousand, logs)			−0.718*** [0.030]	−0.727*** [0.030]
Green vote[c]				1.263*** [0.309]
News index	0.041*** [0.001]	0.041*** [0.001]	0.042*** [0.001]	0.042*** [0.001]
Constant	−3.681*** [0.145]	−3.669*** [0.146]	−4.226*** [0.202]	−4.440*** [0.209]
Sample size	177,318	177,318	177,318	177,318
Pseudo R^2	0.055	0.055	0.059	0.059

Notes:
models also include province-fixed effects.
* significance at the 0.10 level.
[a] default for dwelling type is "Detached."
[b] default for period of construction is "Pre-1930."
[c] the calculation of *Green Vote* is based on the total votes for the Green Party and the Party for the Green Party and the Party for the Animals as a fraction of the total votes during the 2006 national election.
** significance at the 0.05 level.
*** significance at the 0.01 level.

significantly less likely to be labeled. The relative homogeneity of apartments as compared to other housing types may decrease the need to disclose information about the thermal performance of the dwelling to the seller. The square footage of a dwelling significantly decreases the likelihood of energy performance certification—larger dwellings are less likely to be labeled.

The period of construction has a distinct influence on the likelihood of energy performance certification. Relative to the reference period, which consists of all dwellings constructed before 1930, only dwellings constructed after 2000 are significantly less likely to be labeled. This is in line with the legislation regarding the certification process: dwellings that have been constructed after 1999 are exempted from energy performance certification in the transaction process. The coefficients further indicate that post-war homes and dwellings constructed between 1970 and 1990 are especially more likely to be certified. Monuments are less likely to be certified (albeit insignificantly): current legislation does not require an energy performance certificate for dwellings that have been awarded the official "monument" status.

Importantly, the coefficient on the lagged News Index has a significant and positive relation to the label adoption rate. Thus, sentiment in the public media has a distinct influence on the likelihood of label adoption during the sample period.

In Column (2), we add thermal and quality characteristics of the dwelling to the model. It seems that the odds of label adoption are not simply a reflection of the thermal characteristics of the dwelling. The presence of central heating and the quality of insulation – two factors that are directly reflected in the modeled energy efficiency that determines the outcome of the certification process – do not significantly increase the likelihood of energy performance certification. The label does not seem to be systematically used by private consumers to disclose information on the thermal quality of a dwelling to the market. Other quality attributes of certified dwellings, measured by the maintenance of the exterior, also lack a consistent effect on label adoption.[11]

Column (3) of Table 2 includes neighborhood characteristics in the analysis. The results show that adoption rates are highest among homes that are located in neighborhoods with higher densities and populated by households with lower average incomes. Difficult selling conditions, as measured by average time on the market, are also associated with higher adoption rates.

In the last Column, we address the environmental ideology of homeowners as a determinant of label adoption. The literature on ideology and consumer choice provides evidence that "green" consumers are more likely to adopt environmental innovations [19] and are more responsive to energy conservation "nudges" [8]. As a proxy for environmental ideology, we include the fraction of votes for "green" parties in the 2006 national elections. This variable is available for 479 cities. The results on voting preferences and label adoption show a significantly positive coefficient on our measure of voting "green", which provides some indication that the choice for adopting the energy label may also be driven by ideological beliefs.[12]

Summarizing, recently introduced energy labels are adopted at a steadily decreasing rate in the Dutch housing market, which is partially driven by media sentiment. However, we also find evidence that dwelling and neighborhood-specific characteristics significantly influence the likelihood of label adoption. Households living in more heterogeneous dwellings (as opposed to apartments) of moderate size are more likely to have their home certified. The propensity to take out a label also increases in neighborhoods where density is high, average monthly income is low, and voting for "green" political parties is more common. Difficult housing market conditions have an association with higher adoption rates, which could be an indication that sellers use label adoption as a "strategic" tool – regardless of the outcome – to resolve part of the asymmetric information problem to facilitate the transaction process. However, sellers do not seem to adopt an energy label to signal superior building quality to prospective buyers.

5.2. *The market pricing of energy performance certificates*

The premise of residential energy performance disclosure is that increased transparency through reliable information on energy efficiency leads to the capitalization of energy efficiency in housing transactions. This capitalization should translate into a price discount for less energy efficient homes or a premium for more energy efficient homes, where the price effect partially depends on the discount rates used by private consumers.[13]

In estimating the effects of energy performance certification on the transaction process, we face a sample selection issue because we observe the thermal efficiency just for a subset of the total sample of transacted dwellings. We have reason to believe that this subset of labeled dwellings is nonrandom due to self-selection or sorting of particular homes, in particular locations, into the sample. This sorting might bias the regression results, and we, therefore, use the Heckman [17] two-step method that includes our self-constructed News Index as an exogenous determinant of label adoption. Presumably, this variable is unrelated to the transaction price.[14] We first estimate a probit model on the probability of receiving certification, similar to the model estimated in Column (4) of Table 2. We then construct consistent estimates of

[11] A robustness check (results not reported) indicates that the maintenance of the interior is not related to the likelihood of label adoption either.

[12] We note that we cannot control for the individual demographic characteristics of voters. Also, the voting data provides just a reflection of political preferences at the city level, rather than political preferences of individual voters.

[13] There is a large body of literature on the capitalization of energy savings in prices of appliances and homes and the discount rate used therein. See Train [30] for an early discussion.

[14] The correlation between average monthly transaction prices and the News Index is very low—0.17.

Table 3
Heckman two-step estimation results. Energy labels and transaction prices (dependent variable: natural logarithm of transaction price per square meter).

	(1)	(2)	(3)	(4)
"Green" energy label (A, B, or C)	0.037*** [0.003]		0.036*** [0.003]	
Energy label score				
A		0.102*** [0.021]		0.102*** [0.021]
B		0.056*** [0.006]		0.055*** [0.006]
C		0.022*** [0.004]		0.021*** [0.004]
E		−0.005 [0.004]		−0.005 [0.004]
F		−0.025*** [0.004]		−0.023*** [0.004]
G		−0.051*** [0.006]		−0.048*** [0.006]
Thermal and quality characteristics				
Central heating			0.014*** [0.005]	0.012** [0.005]
Exterior maintenance			0.027*** [0.005]	0.024*** [0.005]
Insulation quality			0.003*** [0.001]	0.002*** [0.001]
Dwelling type[a]				
Apartment	−0.386*** [0.011]	−0.388*** [0.011]	−0.387*** [0.011]	−0.388*** [0.011]
Duplex	−0.358*** [0.007]	−0.358*** [0.007]	−0.358*** [0.007]	−0.358*** [0.007]
Semi-detached	−0.223*** [0.007]	−0.221*** [0.007]	−0.223*** [0.007]	−0.221*** [0.007]
Dwelling size (log)	−0.266*** [0.012]	−0.268*** [0.012]	−0.268*** [0.012]	−0.269*** [0.012]
Number of rooms	0.003*** [0.001]	0.003*** [0.001]	0.003*** [0.001]	0.003*** [0.001]
Monument	0.051*** [0.016]	0.051*** [0.016]	0.055*** [0.016]	0.055*** [0.016]
Neighborhood characteristics				
Housing density (in thousands, logs)	−0.016*** [0.003]	−0.016*** [0.003]	−0.016*** [0.003]	−0.016*** [0.003]
Average time on market (in hundreds of days, logs)	−0.177*** [0.004]	−0.176*** [0.004]	−0.177*** [0.004]	−0.176*** [0.004]
Average monthly household income (in €thousand, logs)	0.538*** [0.023]	0.537*** [0.023]	0.536*** [0.023]	0.535*** [0.023]
Selection variable ($\hat{\lambda}$)	−0.329*** [0.071]	−0.322*** [0.071]	−0.326*** [0.071]	−0.319*** [0.071]
Constant	9.941*** [0.069]	9.938*** [0.069]	9.903*** [0.069]	9.904*** [0.069]
Sample size	31,993	31,993	31,993	31,993
R^2	0.525	0.527	0.526	0.528
R^2-adj	0.524	0.526	0.525	0.527

Notes: models also include time-fixed effects, province-fixed effects, and period of construction controls. News index is included as the selection variable in a first stage probit regression. Estimation results of the first stage are not reported.
Standard errors are corrected for heteroskedasticity and stated in brackets.
* significance at the 0.10 level.
[a] Default for dwelling type is "Detached."
** Significance at the 0.05 level.
*** Significance at the 0.01 level.

the inverse Mills ratio, and include this selection variable as an instrument in the following model:

$$\log P_i = \alpha + \beta_i X_i + \delta_n L_n + \rho G_i + \sum_{p}^{p=1} \gamma_p p_p + \theta \hat{\lambda}_i + \varepsilon_i \qquad (2)$$

In the formulation represented by Eq. (2), the dependent variable is the logarithm of the transaction price per square foot of dwelling *i*. X_i is the vector of the hedonic characteristics of building *i*.[15] To control for local economic conditions, L_n is the vector of variables capturing the attributes of neighborhood n in which a dwelling is located. G_i is the dummy variable with a value of one if building i is rated A, B, or C, indicating that the home obtained a "green" energy label, and a value of zero otherwise. Alternatively, G_i represents the vector of the scores in the energy label, ranging from A to G (where the D-label serves as the reference group). $\hat{\lambda}_i$ is the inverse Mills ratio constructed based on the first step of the estimation. To further control for locational variation in transaction prices, p_p is the dummy variable with a value of one if building i is located in province p, and zero otherwise.

Table 3 presents the results of the second stage of the Heckman model in which the logarithm of transaction price per square foot has is related to a set of hedonic characteristics, including the inverse Mills ratio. Results are corrected for heteroskedasticity [31] and all specifications include province-fixed effects, monthly time-fixed effects and controls for the period of construction.

[15] In line with a suggestion of one referee, we estimate Eq. (2) without transactions of dwellings constructed post-2000, because the number of labeled observations in this cohort is very small.

The model in Column (1) explains some 52 percent of the natural logarithm of the transaction price based on 31,993 labeled observations. Duplex dwellings and apartments transact at discounts of 36–39 percent, relative to detached dwellings. Selling prices are higher for smaller dwellings, although the number of bedrooms has a significantly positive effect on price. An additional bedroom adds some 0.3 percent to the transaction price, *ceteris paribus*.

Age becomes valuable once it is officially recognized: dwellings that are registered as monuments sell at a premium of about five percent.

The variables that reflect local economic conditions mostly show the expected signs: the average monthly household income in the neighborhood has a positive relation to the transaction price, and the average time on the market in the neighborhood has a negative relation to the transaction price. House prices seem to be lower in high-density areas.

Most importantly, within the sample of certified dwellings, we document that homes with a label A, B, or C, which are generally referred to as "green" labels, transact at an average price premium of 3.7 percent, *ceteris paribus*. Considering that the average transaction price of a dwelling in the certified sample equals €231,000, the euro value of the "green" price premium amounts to €8449, at the point of means.

The coefficient on the selection variable, the inverse Mills ratio, is negative and significant. This result indicates that the error terms in the selection equation and the primary equation are negatively correlated. So, (unobserved) factors that make energy labeling more likely tend to be associated with lower transaction prices of dwellings.[16]

The second Column of Table 3 presents the results when the specific score of the energy label is included in the model. We document that the premium for energy efficiency constitutes a series of positive price effects that correspond to the outcomes of the different label categories. We find that A-labeled homes transact at a price premium of 10.2 percent as compared to similar homes with the intermediate D-label, and dwellings with a G-label transact at a discount of some 5 percent.

The variation in the premium for energy efficiency seems to be related to the present value of future energy savings resulting from higher energy efficiency. In 2009, a standardized Dutch dwelling had an average monthly energy bill of €152, ranging between €105 for energy label A, to €231 for energy label G. Capitalizing the difference in the energy bill of an F-labeled dwelling, compared to a G-labeled dwelling, results in a present value of €4000.[17] This is about 1.8 percent of the average transaction price and slightly lower as compared to the average price difference between F- and G-labeled dwellings documented in Table 3. Comparing the capitalized energy savings of A-labeled dwellings with G-labeled dwellings yields a present value of about €16,000, or 7.2 percent of the average transaction price. Hence, the 15 percent price premium for A-labeled dwellings (compared to G-labeled dwellings, based on coefficients reported in Table 3) seems to reflect more than just future energy savings alone.

Part of the "green" increment might be explained by the better building quality of homes with an A, B, or C label. Therefore, Columns (3) and (4) more explicitly control for differences in thermal characteristics and dwelling quality.

The results in Column (3) show that the quality of thermal characteristics has a positive effect on home prices: the presence of central heating – now prevalent in most homes in the Netherlands – and better insulation both have significant and positive relations with the transaction price. Central heating leads to an average increase in transaction prices of 1.4 percent. In line with expectations, high-quality exterior maintenance positively affects property prices. This effect is substantial: well-maintained homes transact at a price premium of 2.7 percent.

When controlling for the quality of the dwelling, the "green" increment decreases slightly to 3.6 percent, but it remains statistically and economically significant. The coefficients on the energy ratings in Column (4) are slightly smaller as well, but remain equally significant both economically and statistically.

Further, we test for the robustness of the "green" transaction premium over the sample period by including interaction terms of "green" and quarterly time dummies in Model (2). We hypothesize that, with decreasing consumer confidence in the energy performance certificate, the signaling value of the label might be negatively affected. Fig. 3 reports point estimates for the average "green" premium per quarter, including the 95 percent confidence interval for each coefficient. Controlling for differences in location and quality, the average price premium for homes with an A, B, or C certificate remains relatively constant during the first year of the sample period, but drops to about zero in the first quarter of 2009. However, the "green" premium increases again to 1.5 and 2 percent in the second and third quarter of 2009, respectively. This rebound might have a relation with increased consumer confidence in the energy label following some months of positive media coverage.

Summarizing, our results provide an indication that private consumers use the information disclosed by the energy label and take the relative energy efficiency of their prospective home into account when making investment decisions. This evidence adds to the small number of studies that have addressed the empirical relation between characteristics of thermal efficiency and transaction prices of residential dwellings [9,14,22] and to studies on energy efficiency, labels, rents, and prices in commercial buildings [10,11].

[16] The regression results change slightly when the analysis is repeated without including the inverse Mills ratio. Results of this robustness check are available from the authors upon request.

[17] To calculate the present value of future energy savings, we capitalize the monthly difference between the average energy bills of dwellings with different energy labels (A through G), assuming a duration of twelve years (the average holding period of Dutch homeowners), and a four percent discount rate (assuming homeowners treat proceeds from future energy savings as risk-free). The Dutch Ministry of Housing provided the data on the average energy bills of dwellings in different labels classes based on a sample of 4750 homes.

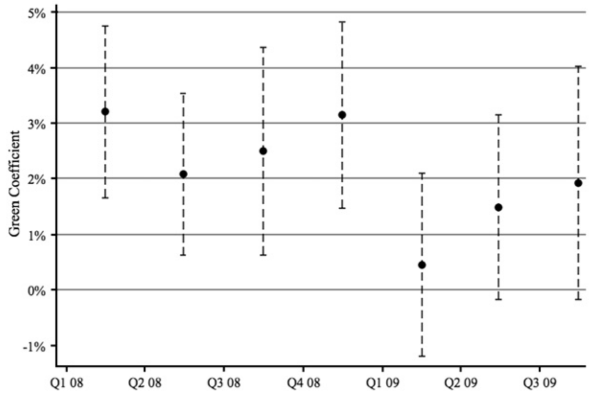

Fig. 3. Dynamics of the "green" premium (Q1 2008–Q3 2009).
Notes: coefficients on quarterly premiums based on interaction terms included in Eq. (2). 95 percent confidence intervals indicated by dotted lines.

6. Conclusions

Energy efficiency improvements in the residential housing market can play an important role in the reduction of global carbon emissions. Besides more traditional policies, such as stricter buildings codes, energy labels can be instrumental in resolving information asymmetries regarding the energy performance of private dwellings and commercial buildings. The information provided by energy labels may thus encourage energy conservation in the housing sector. This paper reports the first evidence on the market adoption and economic implications of energy performance certificates using a large-scale mandatory labeling program in the European Union. We exploit the residential sector in the Netherlands as a laboratory, as the Dutch housing market was one of the first to experience the formal introduction of energy labels for residential dwellings in January 2008.

Using a data set of some 177,000 transactions, we first address the implementation of energy labels in the housing market. We find that energy labels are adopted at a declining rate, lead by negative sentiment in the public media. More heterogeneous dwellings of moderate size, constructed post-war, and between 1970 and 1990, are most likely to be labeled, but thermal and other quality characteristics of the home have no relation to the label adoption rate. The label is not systematically used to signal superior dwelling quality. Neighborhood characteristics have a distinct influence on the propensity to adopt a label: labeled dwellings are mostly located in neighborhoods where density is higher, monthly household incomes are lower, and voting for "green" parties is more common. Some of the neighborhood characteristics and the regional variation in label adoption have a relation to less competition in local housing markets (i.e., where the average time on the market is longer). Our results imply that the initial lack of transparency in labeling practices, in combination with the current legislation regarding energy performance certification that provides a simple escape clause, hinders a complete uptake of energy labels in the market. As a result, the energy label is adopted in a nonrandom way.

We also study the effects of energy performance certification on the outcome of the transaction process. Controlling for thermal and other hedonic characteristics of residential dwellings, we document that homebuyers are willing to pay a premium for homes that have been labeled as more energy efficient, or "green". Our results show that this price premium varies with the label category of the energy performance certificate and is robust to variations in housing quality. The energy performance certificate is instrumental in creating transparency in the energy performance of a dwelling and seems to be an effective signaling device that is capitalized into home prices.

These findings contain some important lessons for homeowners – private as well as institutional. When improving the energy efficiency of a dwelling, there is not only an immediate financial benefit from lower energy expenses, but the increased energy efficiency is also recognized at the time of sale, which leads to a higher transaction price. Although we provide some intuition on relation between the size of the energy-efficiency increment and real energy savings, we are ultimately not able to distinguish between the intangible effects of labeling itself and the economic effects of energy savings per se. Detailed information on energy consumption of the individual households would allow us to further disentangle these effects.

For policy makers, the results of this paper may help in refining energy performance certification programs and in stimulating more extensive dissemination of the energy labels. This paper shows that current legislation regarding the adoption of the label is not strong enough. The numerous opt-outs allow homeowners to avoid certification of dwellings. For the energy performance of the complete residential stock to improve, all homes should have an energy performance certificate.[18]

[18] In fact, at the time of writing, the European Parliament had just approved new legislation to make the energy performance certificate fully mandatory across the European Union, including elimination of the waiver-option.

The case of the Netherlands demonstrates that start-up problems surrounding the implementation of the energy label were neither adequately tackled, nor clearly communicated by policy makers. The negative publicity that surrounded the energy performance certification process hindered the market uptake. The resulting lack of confidence in the energy label is costly to repair. Other governments should learn from these mistakes, because the information conveyed by a well-regarded energy labeling system seems to represent an effective market signal. This effectiveness might trigger investments in more energy-efficient buildings, thereby reducing energy consumption and carbon emissions.

Appendix A

See appendix Fig. A1 below.

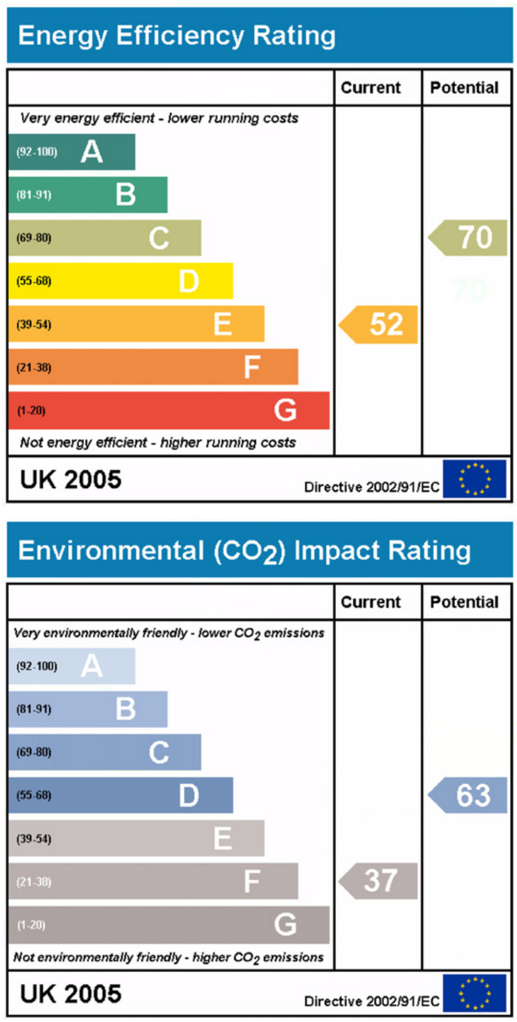

Fig. A1. Energy labels in the European Union (example from the United Kingdom).

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THE VALUE *of* GREEN LABELS *in the* California Housing Market

An Economic Analysis of the Impact of Green Labeling on the Sales Price of a Home

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THE VALUE *of* GREEN LABELS *in the* California Housing Market

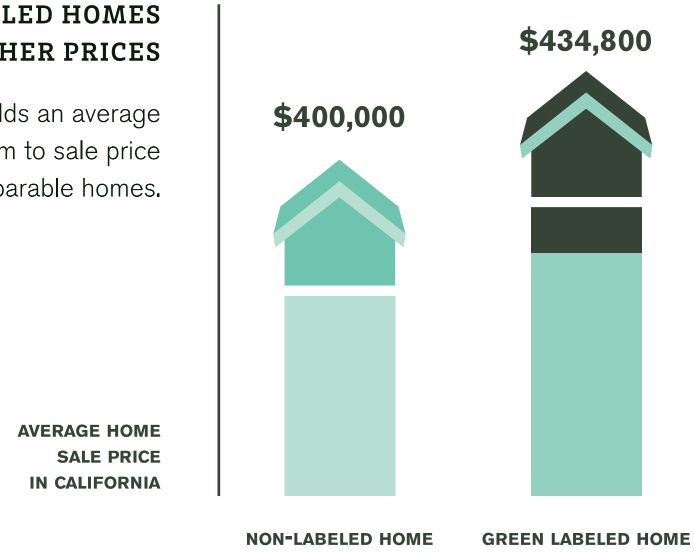
"The Value of Green Labels in the California Housing Market" is the first study to provide statistical evidence that, holding other factors constant, a green label on a single-family home in California provides a market premium compared to a comparable home without the label. The research also indicates that the price premium is influenced by local climate and environmental ideology. To reach these conclusions, researchers conducted an economic analysis of 1.6 million homes sold in California between 2007 and 2012, controlling for other variables known to influence home prices in order to isolate the added value of green home labels.

KEY FINDING: *Green Home Labels Add 9 Percent Price Premium*

This study, conducted by economists at the University of California, Berkeley and University of California, Los Angeles, finds that California homes labeled by Energy Star, LEED for Homes and GreenPoint Rated sell for 9 percent more (±4%) than comparable, non-labeled homes. Because real estate prices depend on a variety of factors, the study controlled for key variables that influence home prices including location, size, vintage, and the presence of major amenities such as swimming pools, views and air conditioning. Considering that the average sales price of a non-labeled home in California is $400,000, the price premium for a certified green home translates into some $34,800 more than the value of a comparable home nearby.

GREEN LABELED HOMES SELL AT HIGHER PRICES

A green label adds an average **9%** price premium to sale price versus other comparable homes.



GREEN LABELS FOR HOMES

Green home labels such as Energy Star, LEED for Homes, and GreenPoint Rated have been established to verify and communicate to consumers that a home is designed and built to use energy efficiently. Green homes also provide benefits beyond energy savings, such as more comfortable and stable indoor temperatures and more healthful indoor air quality. LEED and GreenPoint Rated homes also feature efficient water use; sustainable, non-toxic building materials; and other features that reduce their impact on the environment, such as proximity to parks, shops and transit.

EXPLAINING THE GREEN PREMIUM

This study yields two key insights into the effect of green labels on property values, and why these effects can be so significant. This is especially important in light of the fact that the added value of a green-labeled home far exceeds both the estimated cost of adding energy efficiency features to a home and the utility-bill savings generated by those improvements. Clearly, other factors are in play in producing this premium:

- The results show that the resale premium associated with a green label varies considerably from region to region in California, and is highest in the areas with hotter climates. It is plausible that residents in these areas value green labels more due to the increased cost of keeping a home cool.
- The premium is also positively correlated to the environmental ideology of the area, as measured by the rate of registration of hybrid vehicles. In line with previous evidence on the private value of green product attributes, this correlation suggests that some homeowners may attribute value to intangible qualities associated with owning a green home, such as pride or perceived status.

RESEARCH METHODOLOGY

The study, conducted by Matthew E. Kahn of UCLA and Nils Kok, visiting scholar at UC Berkeley and affiliated with Maastricht University in the Netherlands, examined all of the 1.6 million single-family homes sold between 2007 and 2012 in California. Of those homes, 4,321 were certified under Energy Star Version 2, GreenPoint Rated, or LEED for Homes. Seventy percent of the homes with a green label that were sold during this time period were new construction. The economic approach used, called "hedonic pricing analysis," controlled for a large number of variables that affect real estate pricing, such as vintage, size, location (by zip code) and the presence of major amenities (e.g., pools, views, and air conditioning). The findings of this study echo the results of previous research in the commercial real estate sector, which has found that green labels positively affect rents, vacancy rates and transaction prices for commercial space in office buildings.

RESEARCH QUESTIONS:

- *Commercial real estate investors and tenants value "green" building features. Do homeowners?*
- *How much more value do green homes have?*
- *What factors influence the value homeowners place on green or energy efficient homes? Hotter climate? Higher electricity prices? Environmental ideology?*

1 INTRODUCTION

Increased awareness of energy efficiency and its importance in the built environment have turned public attention to more efficient, green building. Indeed, previous research has documented that the inventory of certified green commercial space in the U.S. has increased dramatically since the introduction of rating schemes that attest to the energy efficiency or sustainability of commercial buildings (based on criteria published by the public and private institutions administering the rating schemes). Importantly, tenants and investors value the green features in such buildings. There is empirical evidence that green labels affect the financial performance of commercial office space: Piet Eichholtz et al. (2010) study commercial office buildings certified under the LEED program of the US Green Building Council (USGBC) and the Energy Star program of the EPA, documenting that these labels positively affect rents, vacancy rates and transaction prices.

Of course, private homeowners may be different from tenants and investors in commercial buildings, especially in the absence of standardized, publicly available information on the energy efficiency of homes. But in recent years, there has been an increase in the number of homes certified as energy efficient or sustainable based on national standards such as Energy Star and LEED and local standards such as GreenPoint Rated in

California. By obtaining verification from a third party that these homes are designed and built to use energy and other resources more efficiently than prescribed by building codes, homes with green labels are claimed to offer lower operational costs than conventional homes. In addition, it is claimed that owners of such homes enjoy ancillary benefits beyond energy savings, such as greater comfort levels and better indoor environmental quality. If consumers observe and capitalize these amenities, hedonic methods can be used to measure the price premium for such attributes, representing the valuation of the marginal buyer (Patrick L. Bajari and Lanier C. Benkard, 2005, Sherwin Rosen, 1974).

In the European Union, the introduction of energy labels, following the 2003 European Performance of Buildings Directive (EPBD), has provided single-family homebuyers with information about how observationally identical homes differ with respect to thermal efficiency. Presumably, heterogeneity in thermal efficiency affects electricity and gas consumption. The EU energy label seems to be quite effective in resolving the information asymmetry in understanding the energy efficiency of dwellings: Dirk Brounen and Nils Kok (2011) estimate hedonic pricing gradients for recently sold homes in the Netherlands and document that homes receiving an "A" grade in terms of energy efficiency sell for a 10 percent price premium. Conversely, dwellings that are labeled as inefficient transact for substantial discounts relative to otherwise comparable, standard homes.

We are not aware of any large sample studies the United States that have investigated the financial performance of green homes. There is some information on the capitalization of solar panels in home prices; one study based in California documents that homes with solar panels sell for roughly 3.5 percent more than comparable homes without solar panels (Samuel R. Dastrup et al., 2012). But unlike findings in previous research on the commercial real estate sector, there is a dearth of systematic evidence on the capitalization of energy efficiency and other sustainability-related amenities in asset prices of the residential building stock, leading to uncertainty among private investors and developers about whether and how much to invest in the construction and redevelopment of more efficient homes.[1]

This paper is the first to systematically address the impact of labels attesting to energy efficiency and other green features of single-family dwellings on the value of these homes as observed in the marketplace, providing evidence on the private returns to the investments in energy-efficient single-family dwellings, an increasingly important topic for the residential market in the U.S.

Using a sample of transactions in California, consisting of some 4,231 buildings certified by the USGBC, EPA, and a statewide rating agency, Build It Green, and a control sample of some 1.6 million non-certified homes, we relate transaction prices of these dwellings to their hedonic characteristics, controlling for geographic location and the time of the sale.

[1] There are some industry-initiated case studies on the financial performance of green homes. An example is a study by the Earth Advantage Institute, which documents for a sample of existing homes in Oregon that those with a sustainable certification sell for 30 percent more than homes without such a designation, based on sales data provided by the Portland Regional Multiple Listing Service. However, the sources of the economic premiums are diverse, not quantified, and not based on rigorous econometric estimations.

The results indicate the importance of a label attesting to the sustainability of a property in affecting the transaction price of recently constructed homes as observed in the marketplace, suggesting that an otherwise comparable dwelling with a green certification will transact for about 9 percent more.

The results are robust to the inclusion of a large set of control variables, such as dwelling vintage, size and the presence of amenities, although we cannot control for "unobservables," such as the prestige of the developer and the relative quality of durables installed in the home.

In addition to estimating the average effect, we test whether the price premium is higher for homes located in hotter climates and in electric utility districts featuring higher average residential electricity prices. Presumably, more efficient homes are more valuable in regions where climatic conditions demand more cooling, and where energy prices are higher. In line with evidence on the capitalization of energy efficiency in commercial buildings (Piet Eichholtz et al., in press), our results suggest that a label appears to add more value in hotter climates, where cooling expenses are likely to be a larger part of total housing expenses. This provides some evidence on the rationality of consumers in appropriately capitalizing the benefits of more efficient homes.

We also test whether the price of certified homes is affected by consumer ideology, as measured by the percentage of hybrid registrations in the neighborhood. A desire to be environmentally conscious may increase the value of green homes because it is a tangible signal of environmental virtue (Steven E. Sexton and Alison L. Sexton, 2011), and an action a person can take in support of their environmental commitment. The results show that the green premium is positively related to the environmental ideology of the neighborhood; green homes located in areas with a higher fraction of hybrid registrations sell for higher prices. Some homeowners seem to attribute non-financial utility to a green label (and its underlying features), which is in line with previous evidence on the private value of green product attributes (Matthew E. Kahn, 2007).

The remainder of this paper is organized as follows: Section 2 describes the empirical framework and the econometric models. Section 3 discusses the data, which represent a unique combination of dwelling-level transaction data with detailed information on green labels that have been assigned to a subsample of the data. In Section 4, we provide the main results of the analysis. Section 5 provides a discussion and policy implications of the findings.

1.6 MILLION HOMES SOLD IN CALIFORNIA DURING THE STUDY PERIOD *(control group)*

4,231 CALIFORNIA HOMES SOLD
with a green label from Energy Star, GreenPoint Rated or LEED for Homes

*An otherwise comparable home with a green certification transacts for **8.7% more** (+/-4%).*

The green homes in our sample are mostly "production homes" and not high-end custom homes. Many large residential developers, such as KB Homes, are now constructing Energy Star and GreenPoint Rated homes.

2 METHOD AND EMPIRICAL FRAMEWORK

Consider the determinants of the value of a single-family dwelling at a point in time as a bundle of residential services consumed by the household (John F. Kain and John M. Quigley, 1970). It is well-documented in the urban economics literature that the services available in the neighborhood, such as schools, public transport and other amenities, will explain a large fraction of the variation in price (see, for example, Joseph Gyourko et al., 1999). But of course, the dwelling's square footage, architecture and other structural attributes will also influence its value.

In addition to attributes included in standard asset pricing models explaining home prices, the thermal characteristics and other "sustainability" features of the dwelling may have an impact on the transaction price. These characteristics provide input, which combined with energy inputs, provide comfort (John M. Quigley and Daniel L. Rubinfield, 1989). However, the energy efficiency of homes (and their equipment) is often hard to observe, leading to information asymmetry between the seller and the buyer. In fact, homeowners typically have limited information on the efficiency of their own home; it has been documented that the "energy literacy" of resident households is quite low (Dirk Brounen et al., 2011). Indeed, recent evidence shows that providing feedback to private consumers with respect to their energy consumption is a simple, but effective "nudge" to improve their energy efficiency (Hunt Allcott, 2011).

To resolve the information asymmetry in energy efficiency, and also in related green attributes, energy labels and green certificates have been introduced in commercial and residential real estate markets. The labels can be viewed as an additional step to enhance the transparency of resource consumption in the real estate sector. Such information provision may enable private investors to take sustainability into account when making housing decisions, reducing costly economic research (Robert W. Gilmer, 1989). From an economic perspective, the labels should have financial utility for prospective homeowners, as the savings resulting from purchasing a more efficient home may result in lower operating costs during the economic life, or less exposure to utility cost escalation over time.[2] In addition, similar to a high quality "view," various attributes of homes, such as durability or thermal comfort, may not provide a direct cash flow benefit, but may still be monetized in sales transactions.

To empirically test this hypothesis, we relate the logarithm of the transaction price to the hedonic characteristics of single-family homes, controlling precisely for the variations in the measured and unmeasured characteristics of rated buildings and the nearby control dwellings, by estimating:

$$(1)\ \log(R_{ijt}) = \alpha green_{it} + \beta X_i + \gamma_{jt} + \varepsilon_{ijt}$$

In this formulation, R_{ijt} is the home's sales price commanded by dwelling i in cluster j in quarter t; X_i is the set of hedonic characteristics of building i, and ε_{ijt} is an error term. To control more precisely for locational effects, we include a set of dummy variables, one for each of the j zip codes. These zip-code-fixed effects account for cross-area differences in local public goods such as weather, crime, neighborhood demographics and school quality. To capture the time-variance in local price dynamics, we interact zip-code-fixed effects with year/month indicators; the transaction prices of homes are thus allowed to vary by each month during the time period, in each specific location. This rich set of fixed effects allows for local housing market trends and captures the value of time-varying local public goods, such as crime dynamics or the growth or decline of a nearby employment district. $green_i$ is a dummy variable with a value of one if dwelling i is rated by the EPA, USGBC or Build It Green, and zero otherwise. $\alpha, \beta, \gamma_{jt}$ are estimated coefficients. α is thus the average premium, in percent, estimated for a labeled building relative to those observationally similar buildings in its geographic cluster–the zip code. Standard errors are clustered at the zip code level to control for spatial autocorrelation in prices within zip codes.

[2] For the commercial real estate market, a series of papers that study investor and tenant demand for green office space in the U.S. show that buildings with an Energy Star label–indicating that a building belongs to the top 25 percent of the most energy-efficient buildings–or a LEED label have rents that are two to three percent higher as compared to regular office buildings. Transaction prices for energy-efficient office buildings are higher by 13 to 16 percent. Further analyses show that the cross-sectional variation in these premiums has a strong relation to real energy consumption, indicating that tenants and investors in the commercial property sector capitalize energy savings in their investment decisions (Piet Eichholtz *et al.*, 2010; in press).

In a second set of estimates, we include in equation (1) additional interaction terms where we interact "green" with a vector of locational attributes:

$$(2)\ \log(R_{ijt}) = \alpha_0 green_{it} + \alpha_1 N green_{it} + \beta X_i + \gamma_{jt} + \varepsilon_{ijt}$$

We estimate equation (2) to study whether the "green label" premium varies with key observables such as climatic conditions and local electricity prices.[3] We posit that green homes will be more valuable in areas that experience more hot days and areas where electricity prices are high. Presumably, the present value of future energy savings is highest in those regions, which should be reflected in the valve attributed to the "green" indicator.

A second interaction effect addressed in this study is whether the capitalization effect of green labels is larger in communities that reveal a preference for "green products." A desire to appear environmentally conscious or to act on one's environmental values may increase the financial value of "green" homes because it is a signal of environmental virtue.[4] Our proxy for environmental idealism is the Toyota Prius share of registered vehicles in the zip code (these data are from the year 2007).[5] Last, we test for whether the green home premium differs over the business cycle. The recent sharp recession offers significant variation in demand for real assets, which may affect the willingness to pay for energy efficiency and other green attributes.

Anecdotally, we know that the green homes in our sample are mostly "production homes" and not high-end custom homes–many large residential developers, such as KB Homes, are now constructing Energy Star and GreenPoint Rated homes. But, it is important to note that we do not have further information on the characteristics of the developers of "green" homes and conventional homes. Therefore, we cannot control for the possibility that some developers choose to systematically bundle green attributes with other amenities, such more valuable appliances in green homes or a higher-quality finishing. We assume that such unobservables are not systematically correlated with green labels. Otherwise, we would overestimate the effects of "green" on housing prices.

[3] In model (2), we replace the zip-code-fixed effects for county fixed effects, as data on Prius registrations, electricity prices and the clustering of green homes is measured at the zip code level. To further control for the quality of the neighborhood and the availability of local public goods, we include a set of demographic variables from the Census bureau, plus distance to the central business district (CBD) and distance to the closest public transportation hub.

[4] This is comparable to private investors' preference for socially responsible investments (Jeroen Derwall *et al.*, 2011).

[5] See Matthew E. Kahn (2007) for a discussion of Prius registrations as proxy for environmentalism.

3 DATA

A. Green Homes: *Measurements and Data Sources*

In the U.S., there are multiple programs that encourage the development of energy efficient and sustainable dwellings through systems of ratings to designate and publicize exemplary buildings. These labels are asset ratings: snapshots in time that quantify the thermal and other sustainability characteristics of the building and predict its energy performance through energy modeling. They neither measure actual performance, nor take occupant behavior into account. The Energy Star program, jointly sponsored by the U.S. Environmental Protection Agency and the U.S. Department of Energy, is intended to identify and promote energy-efficient products, appliances, and buildings. The Energy Star label was first offered for residential buildings in 1995.[6]

The Energy Star label is an asset rating touted as a vehicle for reducing operational costs in heating, cooling, and water-delivering in homes, with conservation claims in the range of 20 to 30 percent, or $200 to $400 in annual savings. In addition, it is claimed that the label improves comfort by sealing leaks, reducing indoor humidity and creating a quieter environment. But the Energy Star label is also marketed as a commitment to conservation and environmental stewardship, reducing air pollution.

In a parallel effort, the US Green Building

[6] Under the initial rating system, which lasted until 2006, buildings could receive an Energy Star certification if improvements were made in several key areas of the home, including high-performance windows, tight constructions and ducts, and efficient heating and cooling equipment. An independent third-party verification by a certified Home Energy Rater was required. Homes qualified under Energy Star Version 1 had to meet a predefined energy efficiency score ("HERS") of 86, equating more than 30 percent energy savings as compared to a home built to the 1992 building code. From January 2006 until the end of 2011, homes were qualified under Energy Star Version 2. This version was developed in response to increased mandatory requirements in the national building codes and local regulations, as well as technological progress in construction practices. The updated guidelines included a visual inspection of the insulation installation, a requirement for appropriately sized HVAC systems, and a stronger promotion of incorporating efficient lighting and appliances into qualified homes. An additional "thermal bypass checklist" (TBC) became mandatory in 2007. As of 2012, Energy Star Version 3 has been in place, including further requirements for energy efficiency measures and strict enforcement of checklist completion.

Council, a private non-profit organization, has developed the LEED (Leadership in Energy and Environmental Design) green building rating system to encourage the "adoption of sustainable green building and development practices." Since adoption in 1999, separate standards have been applied to new buildings and to existing structures.

The LEED label requires sustainability performance in areas beyond energy use, and the requirements for certification of LEED buildings are substantially more complex than those for the award of an Energy Star rating. The certification process for homes measures six distinct components of sustainability: sustainable sites, water efficiency, materials and resources, indoor environmental quality, innovation, as well as energy performance. Additional points can be obtained for location and linkages, and awareness and education.[7]

Whereas LEED ratings for commercial (office) space have diffused quite rapidly over the past 10 years (see Nils Kok et al., 2011, for a discussion), the LEED for Homes rating began in pilot form only in 2005, and it was fully balloted as a rating system in January 2008.

It is claimed that LEED-certified dwellings reduce expenses on energy and water, have increased asset values, and that they provide healthier and safer environments for occupants. It is also noted that the award of a LEED designation "demonstrate[s] an owner's commitment to environmental stewardship and social responsibility."

In addition to these national programs intended for designating exemplary performance in the energy efficiency and sustainability of (single-family) homes, some labeling initiatives have emerged at the city or state level. In California, the most widely adopted of these is GreenPoint Rated, developed by Build It Green, a non-profit organization whose mission is to promote healthy, energy- and resource-efficient homes in California.

The GreenPoint Rated scheme is comparable to LEED for Homes, including multiple components of "sustainability" in the rating process, with minimum rating requirements for energy, water, indoor air quality, and resource conservation. Importantly, the GreenPoint Rated scheme is available not just for newly constructed homes, but it is applicable to homes of all vintages. The label is marketed as "a recognizable, independent seal of approval that verifies a home has been built or remodeled according to proven green standards." Comparable to other green rating schemes, proponents claim that a GreenPoint rating can improve property values at the time of sale.

[7] For more information on the rating procedures and measurements for LEED for Homes, see: http://www.usgbc.org/DisplayPage.aspx?CMSPageID=147.

B. Data on Homes Prices and Their Determinants

We obtain information on LEED-rated homes and GreenPoint Rated homes using internal documentation provided by the USGBC and Build It Green, respectively. Energy-Star-rated homes are identified by street address in files available from local Energy Star rating agencies. We focus our analysis on the economically most important state of California, covering the 2007—2012 time period.

The number of homes rated by the green schemes is still rather limited — 4,921 single-family homes rated with GreenPoint Rated and 489 homes rated with LEED for Homes (as of January 2012). The number of homes that obtained an Energy Star label is claimed to be substantially larger, but we note that data on Energy Star Version 1 has not been documented, and information on homes certified under Energy Star Version 2 is not stored in a central database at the federal level. Therefore, we have to rely on information provided by consultants who conduct Energy Star inspections. We obtained details on 4,938 single-family dwellings that have been labeled under the Energy Star Version 2 program.

We matched the addresses of the buildings rated in these three programs as of January 2012 to the single-family residential dwellings identified in the archives maintained by DataQuick. The DataQuick service and the data files maintained by DataQuick are advertised as a "robust national property database and analytic expertise to deliver innovative solutions for any company participating in the real estate market."[8] Our initial match yielded 8,243 certified single-family dwellings for which an assessed value or transaction price, and dwelling characteristics could be identified in the DataQuick files; of those homes, 4,231 transacted during the sample period.[9]

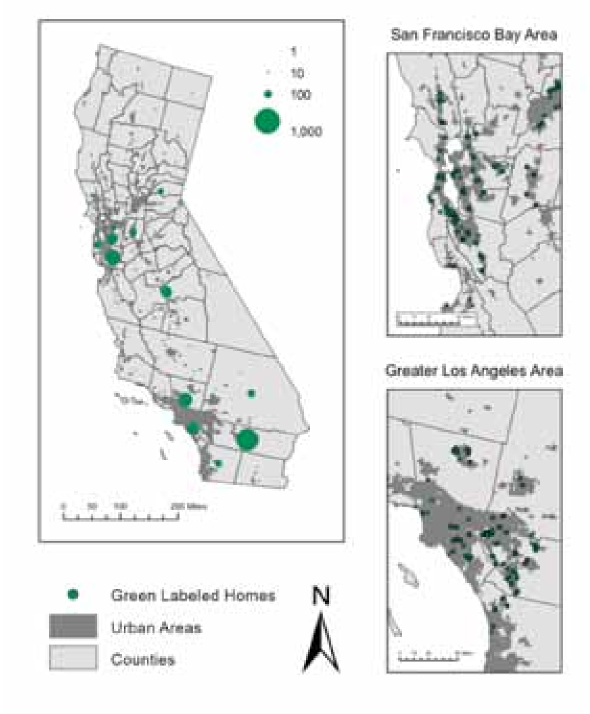
[8] DataQuick maintains an extensive micro database of approximately 120 million properties and 250 million property transactions. The data has been extensively used in previous academic studies. See, for example, Raphael W. Bostic and Kwan Ok Lee (2008) and Fernando Ferreira *et al.* (2010).

[9] We were not able to match the remaining 2,105 certified properties to the DataQuick files. Reasons for the missing observations include, for example, properties that were still under construction, and incomplete information on certified properties.

Figure 1 shows the geographic distribution of the certified homes in our sample. There is a clustering of green rated homes in certain areas, such as the Los Angeles region and the San Francisco region. The geographic distribution is correlated with higher incomes (e.g., in the San Francisco Bay Area), but also with higher levels of construction activity in recent years (e.g., in the Central Valley). As shown by the maps, in the case of Los Angeles, many of the "green label" homes are built in the hotter eastern part of the metropolitan area. It is important to note that there is little new construction in older, richer cities such as Berkeley and Santa Monica (Matthew E. Kahn, 2011). This means that it is likely to be the case that there will be few single-family "green homes" built in such areas.

FIGURE 1.

Certified Homes in California *(2007–2012)*



Sources: Build It Green, EPA, and USGBC

GEOGRAPHIC DISTRIBUTION *of* **GREEN-LABELED HOMES** *is correlated with*

- *Higher incomes (e.g., San Francisco Bay Area)*
- *Higher levels of construction activity (e.g., Central Valley)*
- *Hotter local climate (e.g., inland areas around Los Angeles and Central Valley)*

HEDONIC VARIABLES CONSIDERED:

- *size*
- *quality*
- *number of bedrooms*
- *renovations*
- *garage*
- *swimming pool*
- *air conditioning*
- *view*

To investigate the effect of energy efficiency and sustainability on values of dwellings as observed in the market, we also collect information on all non-certified single-family dwellings that transacted during the same time period, in the same geography. In total, there are nearly 1.6 million dwellings in our sample of green buildings and control buildings with hedonic and financial data.

Besides basic hedonic characteristics, such as vintage, size and presence of amenities, we also have information on the time of sale. Clearly, during the time period that we study, many homes in our geography were sold due to financial distress (i.e., foreclosure or mortgage delinquency). This, of course, has implications for the transaction value of homes (John Y. Campbell et al., 2011). We therefore create an indicator for a "distressed" sale, based on information provided by DataQuick.

We also collect data on environmental ideology, proxied by the registration share of Prius vehicles in each zip code.[10] Local climatic conditions are assessed by the total annual cooling degree days at the nearest weather station (measured by the longitude and latitude of each dwelling and each weather station) during the year of sale.[11] Information on electricity prices is collected at the zip code level.[12]

C. Descriptive Statistics

Table 1 summarizes the information available on the samples of certified and non-certified dwellings. The table reports the means and standard deviations for a number of hedonic characteristics of green buildings and control buildings, including their size, quality, and number of bedrooms, as well as indexes for building renovation, the presence of on-site amenities (such as a garage or carport, swimming pool, or presence of cooling equipment), and the presence of a "good" view.[13]

Simple, non-parametric comparisons between the samples of certified and non-certified homes show that transaction prices of green homes are higher by about $45,000, but of course, this ignores any observable differences between the two samples. Indeed, green homes are much younger–70 percent of the dwellings in the green sample have been constructed during the last five years.

More than two-thirds of the stock of green homes are those certified by Energy Star, but there is substantial overlap among the green certifications–about 20 percent of the green homes have multiple labels.

[10] We calculate the Toyota Prius share of registered vehicles from zip code totals of year 2007 automobile registration data (purchased from R.L. Polk).

[11] Data retrieved from http://www.ncdc.noaa.gov/cdo-web/.

[12] Data retrieved from http://www.energy.ca.gov/maps/serviceareas/electric_service_areas.html. We thank the California Energy Commission for providing a list containing each zip code in California and the corresponding local electric utility provider.

[13] DataQuick classifies the presence and type of view from the property. A "good" view includes the presence of a canyon, water, park, bluff, river, lake or creek

4 RESULTS

Table 2 presents the results of a basic regression model relating transaction prices of single-family dwellings to their observable characteristics and a green rating. Zip-code-fixed effects account for cross-area differences in local public goods, such as weather, crime, neighborhood demographics and school quality. The analysis is based upon more than 1.6 million observations on rated and unrated dwellings. Results are presented for ordinary least squares regression models, with errors clustered at the zip code level. Coefficients for the individual location clusters and the time-fixed effects are not presented.

Column 1 reports a basic model, including some hedonic features: dwelling size in thousands of square feet, the number of bed and bathrooms, and the presence of a garage or carport. We also include zip-year/month fixed effects. The model explains about 85 percent of the variation in the natural logarithm of home prices.

Larger homes command higher prices; 1,000 square feet increase in total dwelling size (corresponding to an increase of about 50 percent in the size of typical home) leads to a 31 percent higher transaction price. Controlling for dwelling size, an additional bathroom adds about 10 percent to the value of a home, and a garage yields about 6 percent, on average.

In column 2, we add a vector of vintage indicators to the model. Relative to homes constructed more than 50 years ago (the omitted variable), recently developed homes fetch significantly higher prices. The relation between vintage and price is negative, but homes constructed during the 1960-1980 period seem to transact at prices similar to very old ("historic") homes. Renovation of dwellings is capitalized in the selling prices, although the effect is small; prices of renovated homes are just one percent higher.[14]

[14] We replace the original "birth year" of a home with the renovation date in the analysis, so that vintage better reflects the "true" state of the home. This may explain the low economic significance of the renovation indicator.

Column 3 includes a selection of dwelling amenities in the model. The results show that homes that were sold as "distressed," for example following mortgage default, transact at a discount of 16 percent, on average. The presence of a swimming pool, cooling system or a "view" contributes significantly to home prices.

Importantly, holding all hedonic characteristics of the dwellings constant, column 4 shows that a single-family dwelling with a LEED, GreenPoint Rated or Energy Star certificate transacts at a premium of 12 percent, on average. This result holds while controlling specifically for all the observable characteristics of dwellings in our sample. The green premium is quite close to what has been documented for properties certified as efficient under the European energy labeling scheme. A sample of 32,000 homes classified with an energy label "A" transacted for about 10 percent more as compared to standard homes (Dirk Brounen and Nils Kok, 2011). In the commercial property market, green premiums have been documented to be slightly higher – about 16 percent (Piet Eichholtz, et al., 2010).

A. Robustness Checks

In Table 3, the green rating is disaggregated into three components: an Energy Star label, a LEED certification, and a GreenPoint Rated label. The (unreported) coefficients of the other variables are unaffected when the green rating is disaggregated into these component categories. The estimated coefficient for the Energy Star rating indicates a premium of 14.5 percent. The GreenPoint Rated and LEED rating are associated with insignificantly higher transaction prices. Energy efficiency is an important underlying determinant of the increased values for green certified dwellings.[15] But of course, sample sizes for homes certified under the alternative rating schemes are quite limited, and just a small fraction of those homes transacted over the past years. An alternative explanation for the lack of significant results for the GreenPoint Rated and LEED schemes is the still limited recognition of those "brands" in the marketplace[16]

The downturn in housing markets and the subsequent decrease in transaction prices may also have an impact on the willingness to pay for more efficient, green homes. It has been documented that prices are more procyclical for durables and luxuries as compared to prices of necessities and nondurables (see Mark Bils and Peter J. Klenow, 1998). To control for the time-variation in the value attributed to green, we include interaction terms of year-fixed effects and the green indicator in column 4. When interaction terms of year-fixed effects are included in the model (the years 2007 and 2012 are omitted due to the lack of a sufficient number of observations in those years), we document substantial variation in the premium for green dwellings over the sample period.

[15] The fundamental energy efficiency requirement is identical across the three different labeling schemes, and the mechanisms for verification are almost entirely similar. The three labels require design for 15 percent energy savings beyond building code requirements and all schemes require various on-site verifications to confirm the delivered home was built to that standard. GreenPoint Rated and LEED offer the highest number of credits for exceeding that minimum requirement. Energy Star rated homes are thus not necessarily better energy performers as compared to the other rating schemes.

[16] The Energy Star label is recognized by more than 80 percent of U.S. households, and 44 percent of households report they knowingly purchased an Energy Star labeled product in the past 12 months (see http://www.cee1.org/eval/00-new-eval-es.php3). Energy Star is one of the most widely recognized brands in the U.S. While similar data is not available for GreenPoint Rated or LEED, both were introduced as building labels much more recently, and do not benefit from near ubiquitous cobranding in consumer products.

In the first years of the sample, labeled homes sold for a discount, albeit insignificantly (which may be related to the lack of demand for newly constructed homes during that time period), whereas the premium is large and significant in later years. The parallel with the business cycle suggests that, among private homeowners, demand for green is lower in recessions, but increases as the economy accelerates. This is contrasting evidence for the commercial market: It has been documented that green-certified office buildings experienced rental decreases similar to conventional office buildings during the most recent downturn in the economy (Eichholtz et al., in press).

As noted in Table 1, most homes certified by one of three rating schemes have been construced quite recently — some 70 percent of the green homes were constructed less than six years ago. Recognizing this point, we seek a similar control sample of non-certified single-family transactions, restricting the analysis to dwellings that are five years old or younger.[17]

Table 4 presents the results of this simple robustness check. Control variables, location-fixed effects and time-fixed effects are again omitted. The results presented in Table 4 are not consistently different from the results in Table 3, but the green premium is slightly lower: On average, green-rated homes that were constructed during the last five years transact at a premium of some 9 percent. The Energy Star label is significantly different from zero. We note that the estimated coefficient for the LEED rating indicates a premium of some 10 percent in transaction prices, but this is not statistically significant at conventional levels.

[17] Quite clearly, this paper mostly deals with labeled developer homes rather than existing homes that went through the labeling process. As noted in Section 2, this raises the possibility of a "developer effect" in explaining the price variation between green and conventional homes. More information on the identity of developers of labeled and non-labeled homes would allow us to further disentangle this effect, but we have information on the developers of green homes only. About one third of the homes in the labeled sample have been constructed by KB Homes. Regressions that exclude homes constructed by KB Homes lead to similar results, with the green premium decreasing to about 6 percent.

B. Testing for Heterogeneity in "Green Label" Capitalization

As demonstrated in the statistical models reported in Tables 2–4, there is a statistically significant and rather large premium in the market value for green-certified homes. The statistical analysis does not identify the source of this premium, or the extent to which the signal about energy efficiency is important relative to the other potential signals provided by a building of sufficient quality to earn a label. Of course, the estimates provide a common percentage premium in value for all rated dwellings. But the value of green certification may be influenced by factors related to the location of homes: Figure 1 suggests that the distribution of green-rated dwellings is not random within urban areas in California, and this may affect the geographic variation in the value increment estimated for green-certified homes. For example, non-financial utility attributed to green certification may be higher for environmentally conscious households (comparable to the choice for solar panels, see Samuel R. Dastrup et al., 2012, for a discussion) or in areas where such homes are clustered (This peer effect is referred to as "conspicuous conservation" in a recent paper by Steven E. Sexton and Alison L. Sexton, 2011).

But, the financial utility of more efficient homes may also be affected by other factors related to the location of a dwelling. The financial benefits of a more efficient home should increase with the temperature of a given location, keeping all other things constant. (Presumably, more energy is needed for the heating of dwellings in areas with more heating degree days, and more energy is needed for the cooling of buildings in areas with more cooling degree days.) To test this hypothesis, we interact the green indicator with information on cooling degree days for each dwelling in the transaction year, based on the nearest weather station in the database of the National Oceanic and Atmospheric Administration (NOAA). Similarly, in areas with higher electricity costs, the return on energy efficiency should be higher. We therefore interact the climate variable with information on the retail price of electricity in the electric utility service area.

KEY FINDING

Homeowners in areas with a hotter climates are willing to pay more for a green, energy-efficient home.

Table 5 presents a set of models that include a proxy for ideology, green home density, climatic conditions and local electricity prices. In this part of the analysis, we seek to (at least partially) distinguish the effects of the energy-saving aspect of the rating from other, intangible effects of the label itself. The results in column 1 show that more efficient homes located in hotter climates (e.g., the Central Valley) are more valuable as compared to labeled homes constructed in more moderate climates (e.g., the coastal region). At the mean temperature level (6,680 cooling degree days), the green premium equals about 10 percent. But for every 1000 cooling degree day increase, the premium for certified homes increases by 1.3 percent, keeping all other things constant. **This result suggests that private homeowners living in areas where cooling loads are higher are willing to pay more for the energy efficiency of their dwellings.**[18]

There is a statistically significant premium in the market value for of green-certified homes.

In column 2, we add an interaction of climatic conditions with local electricity prices. (In models 2-4, we control for location using county-fixed effects.) Presumably, energy savings are more valuable if the price of electricity per kWh is higher. **However, our results do not show a difference in the capitalization of energy savings between consumers paying high rates** (the maximum rate in our sample equals 0.27 cent/kWh) **and those paying lower rates** (the minimum rate in our sample equals 0.07 cent/kWh). This may be because the true driver of consumer behavior is their overall energy outlay rather than the unit cost per kWh.

[18] While we do not have household level data on electricity consumption, the "rebound effect" would predict that such homeowners might respond to the relatively lower price of achieving "cooling" by lowering their thermostat. In such a case, the actual energy performance of the buildings would not necessarily be lower, because of this behavioral response.

Homeowners in environmentally-conscious communities place a higher value on homes with a green label.

In Column 3, we include the share of Prius registrations for each zip code in the sample, interacted with the indicator for green certification. Quite clearly, the capitalization of green varies substantially by heterogeneity in environmental idealism: **In areas with higher concentrations of hybrid vehicle registrations, the value attributed to the green certification is higher.** These results on the larger capitalization effect of green homes in more environmentally conscious communities are consistent with empirical work on solar panels (Samuel R. Dastrup, et al., 2012) and theoretical work on the higher likelihood for the private provision of public goods by environmentalists (Matthew J. Kotchen, 2006).

In column 4, we include a variable for the "density" of green homes in a given street and zip code, and built by the same developer. One could argue that in areas with a larger fraction of green homes, there is a higher value attributed to such amenity by the local residents. Households who purchase a home on this street know that their neighbors also will be living in a green home and this will create a type of Tiebout sorting as those who want to live near other environmentalists will be willing to pay more to live there. In this sense, the "green label" density acts as a co-ordination device. However, competition in the share of green homes in a given neighborhood may also negatively affect the willingness to pay for green, as such feature is becoming a commodity (see Andrea Chegut et al., 2011, for a discussion).

When including the density indicator, the point estimate for green certification does not change significantly, but the coefficient on green home density is pointing to a negative relation between the intensity of local green development and the transaction increment paid for green homes. This finding is not significant, but the sign of the coefficient is in line with evidence on green building competition in the UK. As more labeled homes are constructed, the marginal effect relative to other green homes becomes smaller, even though the average effect, relative to non-green homes, remains positive.

KEY FINDING

No evidence that homeowners in areas with higher electricity prices are willing to pay more for a green, energy-efficient home.

5 DISCUSSION & CONCLUSIONS

The economic significance of the green premium documented for labeled homes is quite substantial. **Considering that the average transaction price of a non-labeled home equals $400,000 (see Table 1), the incremental value of 9 percent for a certified dwelling translates into some $34,800 more than the value of a comparable dwelling nearby.**

Of course, this raises the issue of relative input costs. The increment in construction costs of more efficient, green homes is open to popular debate, and there is a lack of consistent and systematic evidence. Anecdotally, a recent industry report shows that estimated cost to reach a modeled energy efficiency level of 15 percent above California's 2008 energy code is between $1,600 and $2,400 for a typical 2,000 sq. ft. dwelling, depending on the climate zone. To reach a modeled energy efficiency level of some 35 percent above the 2008 code, estimated costs range from $4,100 to $10,000 for a typical 2,000 sq. ft. dwelling, again depending on the climate zone.[19] (Some of these costs are offset by incentives, and it is estimated that about one-third of the costs could be compensated for by rebates.) These admittedly rough estimates suggest that the capitalization of energy efficiency features in the transaction price (about $35,000) far exceeds the input cost for the developer (about $10,000, at most).

[19] Source: Gabel Associates, LLC. (2008). "Codes and Standards: Title 24 Energy-Efficient Local Ordinances."

From the perspective of a homeowner, the benefits of purchasing a labeled home, or of "greening" an existing dwelling, include direct cost savings during tenure in the home. Indeed, we document some consumer rationality in pricing the benefits of more efficient homes, as reflected in the positive relation between cooling degree days in a given geography and the premium rewarded to a certified home. Presumably, the capitalization of the label should at least reflect the present value of future energy savings. Considering that the typical utility bill for single-family homes in California equals approximately $200 per month, and savings in a more efficient home are expected to yield a 30 percent reduction in energy costs, the annual dollar value of savings for a typical consumer is some $720. Compared to the increment for green-labeled homes documented in this paper, that implies a simple payback period of some 48 years.

Quite clearly, there are other (unobservable) features of green homes that add value for consumers. This may include savings on resources other than energy, such as water, but the financial materiality of these savings is relatively small. **However, there are also other, intangible benefits of more efficient homes, such as better insulation, reducing draft, and more advanced ventilation systems, which enhance indoor air quality. These ancillary benefits may be appealing to consumers through the comfort and health benefits they provide.**

The results documented in this paper also show that the premium in transaction price associated with a green label varies considerably across geographies. **The premium is positively related to the environmental ideology of the neighborhood.** In line with previous evidence on the private value of green product attributes, some homeowners seem to attribute non-financial utility to a green label (and its underlying features), explaining part of the premium paid for green homes.

B. Conclusion

Buildings are among the largest consumers of natural resources, and increasing their energy efficiency can thus play a significant role towards achieving cost savings for private consumers and corporate organizations, and can be an important step in realizing global carbon reduction goals. With these objectives in mind, an ongoing effort has sought to certify buildings that have been constructed more efficiently. Considering the lack of "energy literacy" among private consumers, if homebuyers are unaware of a building's steady state (modeled) energy consumption, then they will most likely not appropriately capitalize energy savings in more efficient dwellings.

Comparable to evidence documented for the commercial sector in the U.S., and for the residential sector in Europe, the results in this paper provide the first evidence on the importance of publicly providing information about the energy efficiency and "sustainability" of structures in affecting consumer choice.

Green homes transact for significantly higher prices as compared to other recently constructed homes that lack sustainability attributes. This is important information for residential developers and for private homeowners: Energy efficiency and other green features are capitalized in the selling price of homes.

We note that the green homes in our sample are not high-end, custom homes, but rather "production homes" built by large developers. From the developer's perspective, there are likely to be economies of scale from producing green homes in the same geographic area. If green communities command a price premium and developers enjoy cost savings from producing multiple homes featuring similar attributes, then for-profit developers will be increasingly likely to build such complexes. This has implications for the green premium, as the marginal effect relative to other green homes becomes smaller.

The findings in this paper also have some implications for policy makers. Information on the energy efficiency of homes in the U.S. residential market is currently provided just for exemplary dwellings.[20] The mandatory disclosure of such information for all homes could further consumers' understanding of the energy efficiency of their (prospective) residence, thereby reducing the information asymmetry that is presumably an important explanation for the energy-efficiency gap.

An effective and cheap market signal may trigger investments in the efficiency of the building stock, with positive externality effects as a result.

Of course, we cannot disentangle the energy savings required to obtain a label from the unobserved effects of the label itself, which could serve as a signaling measure of environmental ideology and other non-financial benefits from occupying a green home. Future research should incorporate the *realized* energy consumption in green homes and conventional homes to further disentangle these effects. Reselling of green-labeled homes will also offer an opportunity to further study the value persistence of certified homes, unraveling the effect of developer quality on the green premium documented in this paper.

It also important to note that this paper focuses just on the market for owner-occupied single-family dwellings. While this represents an important fraction of the housing market, the market for rental housing has been growing considerably over the course of the housing crisis, and represents the majority of the housing stock in large U.S. metropolitan areas such as New York and San Francisco. Addressing the signaling effect of green labels for tenants in multi-family buildings should thus be part of a future research agenda.

[20] At the time of writing, the City and County of San Francisco's Office of the Assessor-Recorder is beginning to record and publish the presence or absence of green labels in the county property database. Their stated objective is to increase the incentive to make green upgrades in new and existing properties by using transparency to increase market actors' ability to act upon label information.

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TABLE 1. Comparison of Green-Labeled Buildings and Nearby Control Buildings
(standard deviations in parentheses)

	RATED BUILDINGS	CONTROL BUILDINGS
Sample Size	4,321	1,600,558
Sales Price	445.29	400.51
(thousands of dollars)	(416.58)	(380.47)
Assessed Value	425.95	355.21
(thousands of dollars)	(376.86)	(347.34)
Dwelling Size	2.06	1.80
(thousands of sq. ft.)	(0.69)	(0.86)
Lot Size	8.40	16.94
(thousands of sq. ft.)	(14.01)	(41.23)
Age	1.68	32.23
(years)	(9.49)	(24.39)
VINTAGE:		
Vintage < 6 years	0.70	0.18
(percent)	(0.46)	(0.38)
Vintage > 5 years < 11	0.00	0.08
(percent)	(0.02)	(0.28)
Vintage >10 years < 21	0.00	0.11
(percent)	(0.00)	(0.31)
Vintage > 20 years < 31	0.00	0.14
(percent)	(0.02)	(0.35)
Vintage > 30 years < 41	0.00	0.12
(percent)	(0.02)	(0.33)
Vintage > 40 years < 51	0.00	0.09
(percent)	(0.02)	(0.29)
Vintage > 50 years	0.01	0.20
(percent)	(0.08)	(0.40)
Renovated Building	0.04	0.12
(percent)	(0.19)	(0.33)
Garage	0.15	0.61
(number)	(0.55)	(0.94)
Number of Bedrooms	2.64	2.96
(percent)	(1.63)	(1.18)
Number of Bathrooms	2.03	2.11
(percent)	(1.26)	(0.94)
GREEN LABEL		
Energy Star	0.68	-
(percent)	(0.47)	-
GreenPoint Rated	0.47	-
(percent)	(0.50)	-
LEED for Homes	0.03	0.49
(percent)	(0.16)	(0.50)
Multiple Certifications	0.17	0.39
(percent)	(0.38)	(0.49)
Distressed Sale	0.08	0.11
(1 = yes)	(0.26)	(0.31)
Cooling Equipment	0.45	0.02
(1 = yes)	(0.50)	(0.15)
Swimming Pool	0.01	0.42
(1 = yes)	(0.09)	(0.41)
View	0.00	6.37
(1 = yes)	(0.02)	(4.34)
Prius Registration Share	0.45	14.94
(percent x100)	(0.38)	(1.37)
Cooling Degree Days Per Year	6.86	
(thousands)	(3.86)	
Electricity Price	15.06	
(cents/kWh)	(0.84)	

	RATED BUILDINGS	CONTROL BUILDINGS
TRANSACTION YEAR		
2007	0.01	0.13
(percent)	(0.09)	(0.34)
2008	0.04	0.19
(percent)	(0.20)	(0.39)
2009	0.15	0.23
(percent)	(0.36)	(0.42)
2010	0.55	0.21
(percent)	(0.50)	(0.41)
2011	0.23	0.21
(percent)	(0.42)	(0.41)
2012	0.01	0.02
(percent)	(0.08)	(0.14)

TABLE 2. Regression Results

Dwelling Characteristics, Amenities, and Sales Prices

(California, 2007 – 2012)

	(1)	(2)	(3)	(4)
Green Rating (1 = yes)				0.118*** [0.023]
Dwelling Size (thousands of sq. ft.)	0.309*** [0.008]	0.289*** [0.008]	0.273*** [0.007]	0.273*** [0.007]
Number of Bathrooms	0.095*** [0.005]	0.070*** [0.005]	0.066*** [0.005]	0.066*** [0.005]
Number of Bedrooms	0.015*** [0.003]	0.019*** [0.003]	0.022*** [0.003]	0.022*** [0.003]
Number of Garages	0.059*** [0.005]	0.062*** [0.005]	0.058*** [0.005]	0.058*** [0.005]
AGE#				
New Construction (1 = yes)		0.248*** [0.017]	0.190*** [0.016]	0.186*** [0.016]
1 – 2 years (1 = yes)		0.259*** [0.015]	0.209*** [0.015]	0.206*** [0.015]
2 – 3 years (1 = yes)		0.239*** [0.015]	0.223*** [0.015]	0.221*** [0.015]
3 – 4 years (1 = yes)		0.207*** [0.014]	0.219*** [0.014]	0.219*** [0.014]
4 – 5 years (1 = yes)		0.195*** [0.014]	0.213*** [0.014]	0.213*** [0.014]
5 – 6 years (1 = yes)		0.186*** [0.014]	0.203*** [0.014]	0.203*** [0.014]
6 – 10 years (1 = yes)		0.191*** [0.014]	0.193*** [0.014]	0.193*** [0.014]
10 – 20 years (1 = yes)		0.158*** [0.012]	0.149*** [0.012]	0.149*** [0.012]
20 – 30 years (1 = yes)		0.072*** [0.011]	0.064*** [0.011]	0.064*** [0.011]
30 – 40 years (1 = yes)		0.009 [0.010]	0.001 [0.010]	0.001 [0.010]
40 – 50 years (1 = yes)		0.007 [0.008]	-0.002 [0.007]	-0.002 [0.007]
Renovated (1 = yes)		0.012** [0.005]	0.011** [0.005]	0.011** [0.005]
Distressed Sale (1 = yes)			-0.161*** [0.003]	-0.161*** [0.003]
View (1 = yes)			0.063*** [0.011]	0.063*** [0.011]
Swimming Pool (1 = yes)			0.086*** [0.005]	0.086*** [0.005]
Cooling Systems (1 = yes)			0.060*** [0.008]	0.060*** [0.008]
TIME-ZIP-FIXED EFFECTS	Y	Y	Y	Y
Constant	11.743*** [0.203]	11.651*** [0.177]	11.795*** [0.161]	11.681*** [0.163]
N	1,609,879	1,609,879	1,609,879	1,609,879
R^2	0.849	0.854	0.864	0.864
Adj R^2	0.856	0.861	0.871	0.871

Notes:

Omitted variable: vintage > 50 years

Regressions include: fixed effects by quarter year, 2007I–2012I, interacted with fixed effects by zip code. (Coefficients are not reported.)

Standard errors, clustered at the zip code level, are in brackets. Significance at the 0.10, 0.05, and 0.01 levels are indicated by *, **, and ***, respectively.

TABLE 3. Regression Results
Green Labeling Schemes and Sales Prices
(Energy Star, GreenPoint Rated and LEED for Homes)

	(1)	(2)	(3)	(4)
Energy Star	0.145***			
(1 = yes)	[0.027]			
GreenPoint Rated		0.024		
(1 = yes)		[0.024]		
LEED for Homes			0.077	
(1 = yes)			[0.082]	
Green*Year 2008				-0.011
(1 = yes)				[0.057]
Green*Year 2009				0.052
(1 = yes)				[0.033]
Green*Year 2010				0.144***
(1 = yes)				[0.024]
Green*Year 2011				0.131***
(1 = yes)				[0.029]
Time-ZIP-Fixed Effects	Y	Y	Y	Y
Control Variables	Y	Y	Y	Y
Constant	11.759***	11.778***	11.795***	11.668***
	[0.162]	[0.162]	[0.161]	[0.165]
N	1,609,879	1,609,879	1,609,879	1,609,879
R^2	0.871	0.871	0.871	0.871
Adj R^2	0.864	0.864	0.864	0.864

Notes:

Regressions include: fixed effects by quarter year, 2007I–2012I, interacted with fixed effects by zip code; as well as vintage, amenities and other measures reported in Table 2 (column 4). (Coefficients are not reported.)

Standard errors, clustered at the zip code level, are in brackets. Significance at the 0.10, 0.05, and 0.01 levels are indicated by *, **, and ***, respectively.

TABLE 4. Regression Results

Robustness Check: Recently Constructed Homes #

	(1)	(2)	(3)	(4)
Green Rating	0.087***			
(1 = yes)	[0.018]			
Energy Star		0.112***		
(1 = yes)		[0.017]		
GreenPoint Rated			-0.016	
(1 = yes)			[0.026]	
LEED for Homes				0.097
(1 = yes)				[0.074]
Time-ZIP-Fixed Effects	Y	Y	Y	Y
Control Variables	Y	Y	Y	Y
Constant	12.044***	12.059***	12.119***	12.114***
	[0.245]	[0.240]	[0.222]	[0.223]
N	314,759	314,759	314,759	314,759
R^2	0.884	0.884	0.883	0.883
Adj R^2	0.899	0.899	0.899	0.899

Notes:

Sample restricted to dwellings constructed during the 2007-2012 period.

Regressions include: fixed effects by quarter year, 2007I–2012I, interacted with fixed effects by zip code; as well as vintage (ranging from 1–5 years), amenities and other measures reported in Table 2 (column 4). (Coefficients are not reported.)

Standard errors, clustered at the zip code level, are in brackets. Significance at the 0.10, 0.05, and 0.01 levels are indicated by *, **, and ***, respectively.

TABLE 5. Regression Results

Green Labels, Climatic Conditions, Electricity Costs, and Sales Prices #

	(1)##	(2)###	(2)###	(3)###
Green Rating	-0.013	0.098*	-0.057	0.082**
(1 = yes)	[0.026]	[0.054]	[0.039]	[0.033]
Green Rating*Cooling Degree Days	0.014***	0.006		
	[0.003]	[0.075]		
Green Rating*Cooling Degree Days*Electricity Price		-0.001		
		[0.005]		
Green Rating*Prius Registration			21.957***	
			[5.355]	
Green Rating*Green Density				-0.002
				[0.001]
Distance to Closest Rail Station		-0.004***	-0.004***	-0.004***
(in kilometers)		[0.001]	[0.001]	[0.001]
Distance to CBD		-0.001	-0.001	-0.001
(in kilometers)		[0.001]	[0.001]	[0.001]
Time-ZIP-fixed Effects	Y	N	N	N
Time-FIPS-Fixed Effects	N	Y	Y	Y
Control Variables	Y	Y	Y	Y
Constant	12.055***	12.494***	12.378***	12.759***
	[0.023]	[0.067]	[0.161]	[0.240]
N	323,840	238,939	242,678	286,325
R^2	0.877	0.758	0.758	0.747
Adj R^2	0.893	0.760	0.761	0.749

Notes:

Sample restricted to dwellings constructed during the 2007-2012 period.

Regression in column 1 includes fixed effects by quarter year, 2007I–2012I, interacted with fixed effects by zip code; as well as vintage, amenities and other measures reported in Table 2 (column 4). (Coefficients are not reported.)

Regressions in columns 2 - 4 include fixed effects by quarter year, 2007I–2012I interacted with fixed effects by Census tract; the following Census variables at the zip code level: percentage of the population with at least some college education, percentage blacks, and percentage Hispanics, percentage in age categories 18-64, > 64; as well as vintage, amenities and other measures reported in Table 2 (column 4).
(Coefficients are not reported.)

Standard errors, clustered at the zip code level, are in brackets. Significance at the 0.10, 0.05, and 0.01 levels are indicated by *, **, and ***, respectively.